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OVER THE COUNTER INTEREST RATE OPTIONS

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Abstract[1]

This paper provides a survey of the structure and use of the over the counter options market, focussing on interest rate options. It is based in part on interviews with eight market makers and one broker from the OTC interest rate options market in London.

Options provide information about the uncertainty and probability distribution of market participants' expectations for various asset prices. A wider range of products are traded in OTC interest rate options markets than on exchanges, including options of much longer times to expiry, many kinds of exotic options and structured products. OTC interest rate options markets may therefore contain additional information to that available from exchange-traded products about the probability distribution of interest rate expectations. The OTC market is also interesting to study since it has grown rapidly, and less information is publicly available about it than for exchange-traded options. And, a better understanding of OTC derivatives markets is likely to be useful for monitoring risks to financial stability.

[1]I would like to thank Bill Allen, Peter Andrews and Martin Brooke for their help throughout this project and for many useful suggestions, and I would like to thank staff from the trading and risk management divisions of Barclays Capital, the Chase Manhattan Bank, Credit Suisse First Boston, Goldman Sachs, J P Morgan, the Royal Bank of Scotland, Tullett & Spütz Capital Markets AG, UBS Warburg, and Westdeutsche Landesbank for interesting discussions on the interest rate options market. I would also like to thank Sue Attwood, Aris Bikos, Angus Canvin, David Collins, Ilias Lekkos, Ian Michael, Nikolaos Panigirtzoglou, Kim Pompilii, Graham Semken, Stephen Senior, Peter Sinclair, Rupert Thorne and Chris Wright for helpful comments and discussions.

1 Overview

This paper provides a survey of the structure and use of the over-the-counter (OTC) options market, focussing on interest rate options. It is based on interviews with eight market makers and one broker from the OTC interest rate options market in London[2] conducted between May and July 2000, as well as on publicly available data and literature.

Options provide information about the uncertainty and probability distribution of market participants' expectations for various asset prices. Over the past few years, there has been considerable interest by academic researchers and policy makers in extracting information of this kind [1]. In particular, the Bank of England frequently derives indicators of uncertainty relating to the outlook for interest rates, exchange rates and equity markets in order to inform monetary policy and identify risks to financial stability [2, 3].

Within the Bank of England, exchange-traded contracts have been used to extract information about the market's interest rate expectations. However, OTC interest rate options markets include a wider range of products than are traded on exchanges, including options of much longer times to expiry, many kinds of exotic options and structured products. OTC interest rate options markets may therefore contain additional information about the probability distribution of interest rate expectations. Our desire to investigate the OTC market also stemmed from its rapid development, large size, and the fact that less information is publicly available about it than for exchange-traded options. A better understanding of OTC derivatives markets is also expected to be useful for monitoring risks to financial stability.

This paper gives a general description of derivatives markets and the types of derivative instruments traded, and discusses the importance of the OTC interest rate options market relative to other derivative markets. International comparisons, information on market concentration, maturity decomposition and currency shares of OTC interest rate options are presented. The main applications of OTC options are discussed, namely risk management, speculation, and yield enhancement of investments. We present information about how OTC interest rate options are used in practice, and on whether exchange-traded and OTC interest rate options are likely to reflect the market's future interest rate expectations. To gain a better understanding of what information may be contained in option prices, we also present information about which types of models are used by market participants to price OTC interest

[2] Information from discussions with market participants is presented in italics (see also the appendix A.4).

rate options, and which factors influence speculative trading decisions.

The linkages between interest rate options and other financial markets are discussed as well as considerations which enter into decisions about the risk management of option positions.

The OTC interest rate options market has grown significantly over the past five years. Figure 1 gives a rough overview of the relative size and importance of the OTC interest rate options market when measured by notional amounts outstanding and average daily turnover. At $9.4 trillion, notional amounts of OTC interest rate options outstanding accounted for about one half of the global OTC and exchange-traded options market at end 1999, and one tenth of the total derivatives market[3]. The relative importance of OTC interest rate options is smaller when measured by turnover, however. In April 1998, average daily turnover in OTC interest rate options was only $36 billion, about 1.3% of the total daily turnover in derivatives contracts. The relatively low turnover is partly explained by OTC interest rate options having, on average, longer times to expiry than exchange-traded interest rate options and because OTC interest rate options contracts are more commonly held to maturity than exchange-traded contracts.

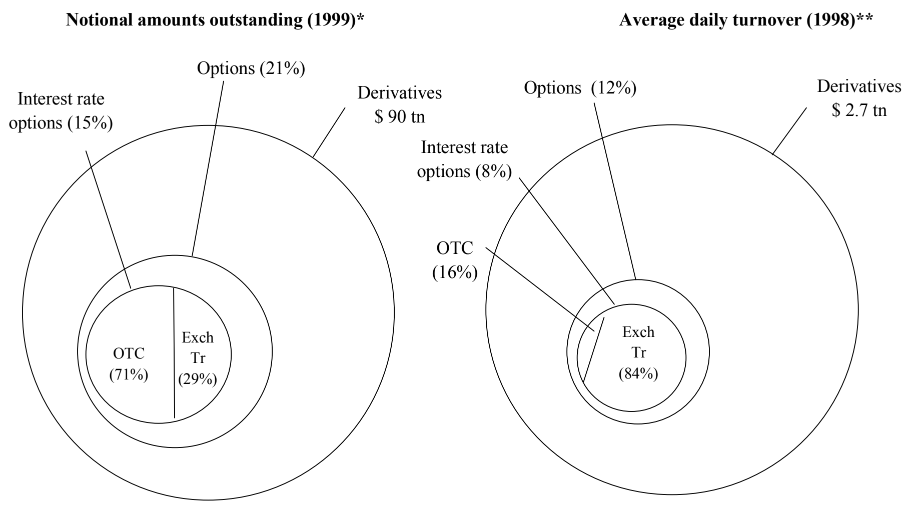
2 Background information about derivative instruments

2.1 What are derivatives ?

A derivative is a financial contract whose value is derived from the future value of one or more underlying asset(s). Originally, the underlying assets were commodities, such as cotton and rice, but now many different financial instruments may be used. Derivatives allow the contract holder to profit from price changes in the underlying contract without having to physically hold the underlying contract. Usually no principal is exchanged on derivatives and no investment income accrues on them. There are two main types of derivative instruments:

[3]Included in total notional amounts outstanding of derivatives are forward, swaps and option contracts for OTC interest rate, FX, and equity-linked contracts; and exchange-traded interest rate, currency and equity-index futures and options contracts. However, the figures do not include commodity and credit derivatives. Turnover data include the same contracts, except for equity derivatives. Data on the global options market include the options elements of the contracts mentioned above. For exchange-traded derivatives, turnover for Q2 1998 was converted to average daily turnover assuming 61 days.

Figure 1: Global OTC & exchange-traded derivatives markets



Source: FOW TRADEdata; Futures Industry Association; various futures and options exchanges, BIS [4,5,7]
*Including interest rate, foreign exchange and equity-linked derivatives, but excluding commodity derivatives; see text for details.
**Including interest rate and foreign exchange derivatives, but excluding equity-linked and commodity derivatives; see text for details.

- Outright contracts: these are instruments with a linear payoff profile; they provide symmetric payoffs to upward and downward movements in the price of the underlying contract; examples are forward contracts and swaps.

- Options: these are instruments with a nonlinear payoff profile; they provide payoffs that respond asymmetrically to movements in the price of the underlying contract.

Many derivatives are either purely outright contracts or purely options contracts, but there are also a large number of more complex derivatives which are constructed from a combination of these two building blocks. Derivatives can be traded on organised exchanges or in over-the-counter (OTC) markets. OTC derivatives are direct contracts between counterparties such as banks, often via brokers, without an exchange acting as an intermediary.

2.1.1 Outright contracts

The simplest example of an outright contract is a forward contract. Forward contracts can be written on many different kinds of underlying assets, such as commodities, foreign exchange, interest rate products, and equity indices. A forward contract on a commodity such as gold is an agreement to buy a certain amount of gold at a specified price and at a specified time in the future. A forward contract traded on an exchange is called a future.

Another type of outright contract is a contract for the exchange of payments calculated under different bases – for example, using fixed and floating interest rates to calculate interest payments on the amount of a loan, as in the case of an interest rate swap.

2.1.2 Options

A call option on an asset gives the buyer the right, but not the obligation, to buy an asset at a predetermined 'strike' price when the option expires, in return for paying a premium up front. If the price of the underlying contract at the time of the option's expiry is above the strike price, the buyer will exercise the option and buy the asset at the lower strike price, profiting from the price increase. But if the price of the underlying contract falls below the strike price, the option will not be exercised, and the loss is limited to the premium paid. Similarly, a put option on an asset gives the buyer the right but not the obligation to sell the asset at the strike price at the time of expiry of the option. The buyer of a put option profits if the price of the underlying asset falls below the strike price.

There are different types of options according to the provisions for possible exercise dates. 'European' style options can only be exercised on one date, namely at the time of expiry of the option. 'American' style options can be exercised on any date up to the time of expiry. And, 'Bermudan' style options, which are less common, can be exercised on several predetermined dates.

Options can be sold at a variety of strike prices. A call option is said to be at-the-money (ATM) if the strike price equals the forward price of the underlying contract; it is said to be in-the-money (ITM) if the strike price is smaller, and out-of-the-money (OTM) if the strike price is larger than the forward price of the underlying contract. A call option which is at-the-money has a 50% chance of being exercised at expiry, if one assumes that the price of the underlying contract is as likely to move up as down. A call option with a strike price much smaller than the forward price of the underlying contract is said to be deep in-the-money.

As we shall see in Section 2.6, OTC options can be roughly divided into the following types according to their complexity: plain vanilla options, exotic options, and structured products. Plain vanilla options use standardised contracts and market conventions, and are traded in generally liquid markets. Exotic options are more complex contracts (eg average interest rate options, and barrier FX options). And, structured products are made up of several components, including outright derivative contracts, options, and the underlying contracts, such as bonds. They can take the form of conventional debt instruments, with embedded swaps and options.

2.2 Types of derivatives by nature of the underlying contract

Derivatives can be classified into the following main types according to the nature of the underlying contract:

- Interest rates
- Foreign exchange (FX)
- Equity-linked
- Commodity
- Credit

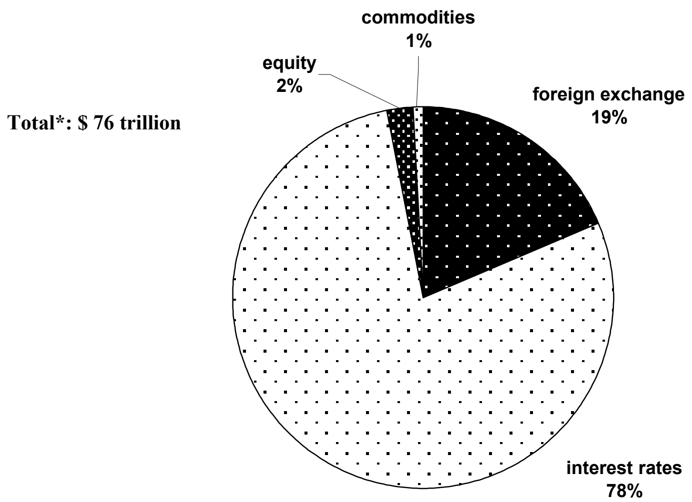
In 1999, interest rate derivatives had the largest share of notional amounts outstanding (NAO) of OTC derivatives world-wide in all currencies (see Figure 2), with foreign exchange derivatives accounting for the second largest share. Similarly, interest rate options and FX options make up the bulk of the OTC options market, with NAO shares of 71% and 17%, respectively (see Figure 3). Average daily turnover, on the other hand, was larger for foreign exchange products than for interest rate products (see Figure 4). In terms of amounts outstanding in gross market values (GMV), a concept used by the Bank for International Settlements (BIS), interest rate derivatives have a share of somewhat more than a half of the global OTC derivatives market (see Figure 5). By contrast, equity-linked options have the largest share of amounts outstanding in gross market values of the global OTC options market (see Figure 6). The surveys by the BIS of the global OTC derivatives markets, from which these data are drawn, and the concepts of notional amounts and gross market values outstanding of derivatives, are discussed in more detail in Section 2.8.

Other kinds of derivatives include insurance derivatives, weather derivatives and liquidity options [8].

2.2.1 Foreign exchange derivatives

FX derivatives include forward contracts, FX swaps, currency swaps, and plain vanilla options, as well as many kinds of exotic options. FX derivatives are mainly traded in the OTC market, rather than on exchanges. Commonly used types of exotic options include barrier and

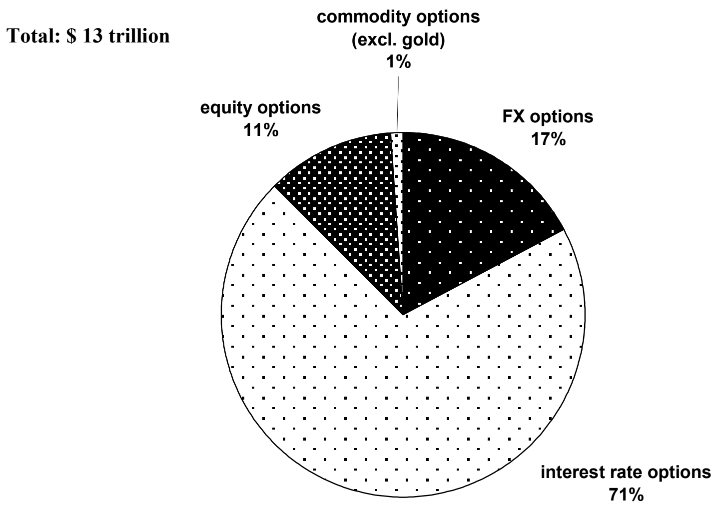
Figure 2: Global OTC derivatives markets – notional amounts outstanding*



Source: BIS, end 1999 [4]

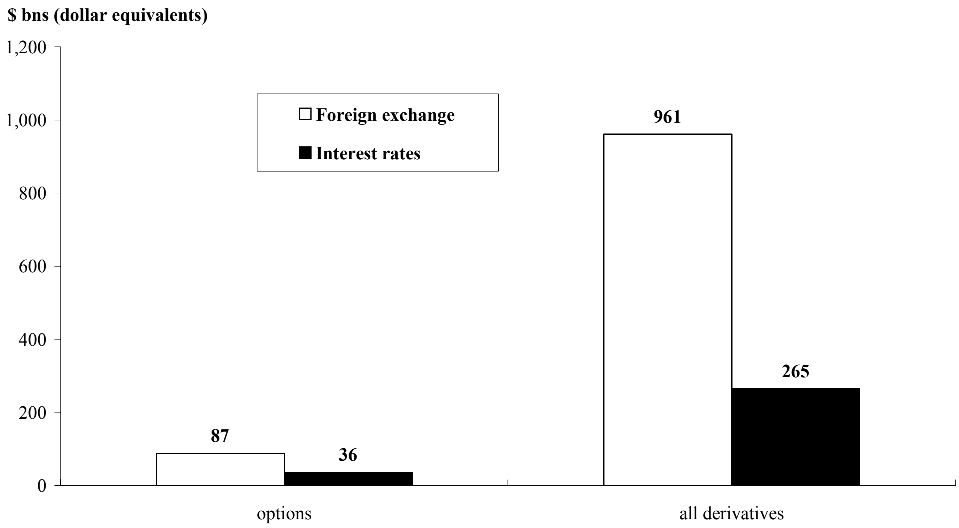
* Excluding estimated positions of non-regular reporting institutions

Figure 3: Global OTC options markets – notional amounts outstanding



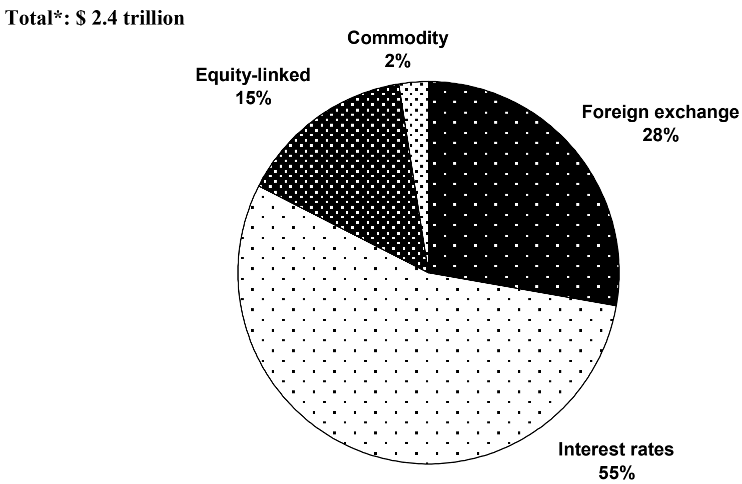
Source: BIS, end 1999 [4]

Figure 4: Average daily turnover in global OTC derivatives markets



Source: BIS triennial survey, April 1998. [5]

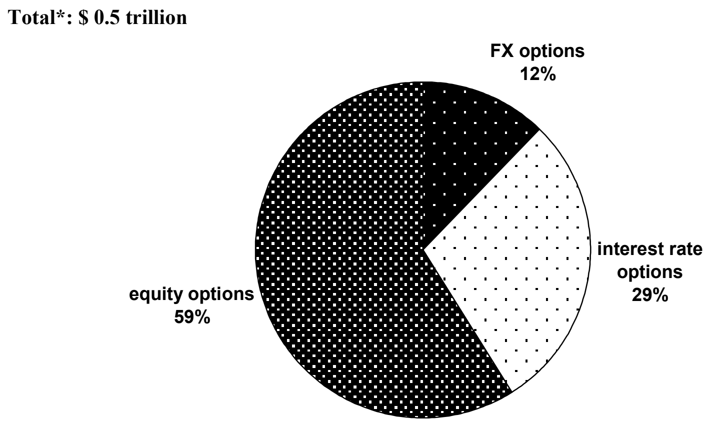
Figure 5: Global OTC derivatives markets – gross market values*



Source: BIS, end 1999 [4]

* Excluding estimated positions of non-regular reporting institutions

Figure 6: Global OTC options markets – gross market values*



Source: BIS, end 1999 [4]
*Excluding commodity options

average rate options. US dollar-based contracts are the most frequently traded in the FX derivatives market. FX options on exchange rates involving the US dollar had a share of more than a third of the notional amounts outstanding of FX options in 1999, and of turnover in FX options in 1998 [4, 5].

2.2.2 Equity derivatives

Equity derivatives are often used for retail investment products such as stock indexed deposits, in which investors are guaranteed their capital back at the end of the investment period, plus an element determined by the size of any profits generated from a rise of the stock market. OTC derivatives contracts exist on individual stocks, on baskets of stocks and on equity indices. The individual stocks in a basket can all be from a single sector, or chosen according to a customer's specifications. Derivatives on equity indices probably form the largest part of the equity derivatives market; the main indices used are the Dow Jones, S&P 500, FTSE 100 and Nikkei 225 [9].

2.2.3 Commodity derivatives

The most commonly traded commodity derivatives are linked to crude oil. Oil is traded by many companies and governments. This generates an exposure to the oil price and in many cases a desire to hedge against adverse movements in the price of oil. The most common OTC contracts are swaps and plain vanilla options. Well-traded derivatives contracts also exist for gold and aluminium [9].

2.2.4 Credit derivatives

Credit derivatives are used in credit risk management strategies. They can be a complement or a substitute for more traditional approaches, such as portfolio diversification and credit limits for counterparties. They are solely traded in the OTC market. The basic building blocks of credit derivatives are credit default swaps, credit options, and total return swaps [10].

According to a survey by the British Bankers' Association, the notional amounts outstanding worldwide in credit derivatives (excluding asset swaps) more than tripled from $180 bn (US dollar equivalents) in 1997 to $586 bn in 1999 [11]. London has a significant share of the global market. In 1999, banks were the largest buyers and sellers of credit derivatives.

The use of credit derivatives is still hindered by legal risk, however, partly due to a lack of standard documentation. In some cases there remains considerable uncertainty as to whether the contracts are legally enforceable, since the obligation to pay often depends on the precise wording of the default event in the contract and it may not be clear if an actual credit event meets the definition in the contract. Institutions surveyed by the BBA cited a lack of standard documentation, together with the regulatory environment and market liquidity, as the most important factors limiting the growth of this market [11].

2.3 Interest rate derivatives

There are three main kinds of OTC interest rate derivatives: forward rate agreements (FRAs), interest rate swaps and interest rate options. Figure 7 gives an overview of the different kinds of interest rate derivatives.

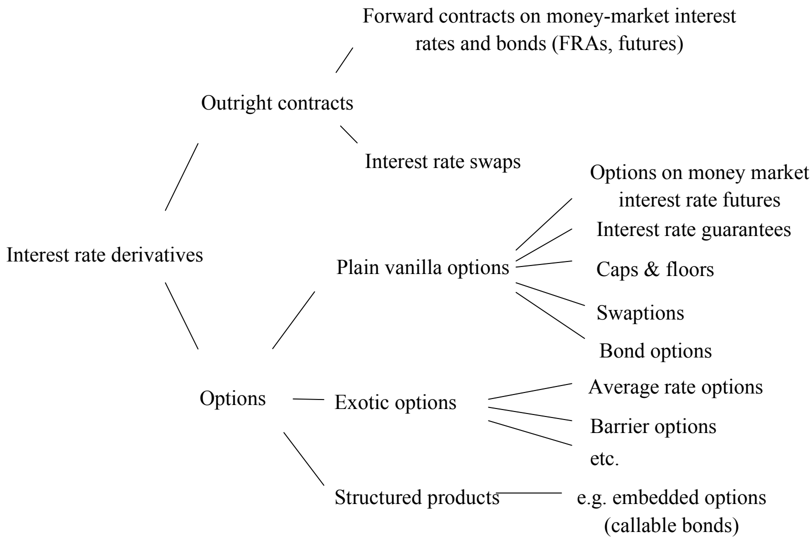
2.3.1 Futures

Forward contracts on short-term interest rates or bonds traded on exchanges as standardised products are called interest rate or bond *futures*. An example is the futures contract on 3-month sterling Libor traded on the London International Futures & Options Exchange (LIFFE), which is known as a short sterling future.

2.3.2 Forward rate agreements

A *forward rate agreement* is a contract for the exchange of fixed versus floating interest payments calculated from a notional principal amount

Figure 7: Interest rate derivatives



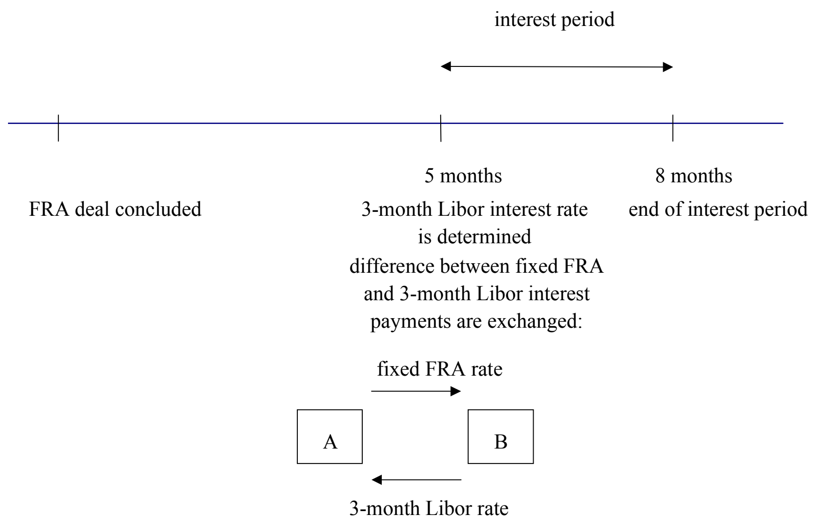
(NPA), which is not exchanged between the counterparties.

Figure 8 illustrates the composition of a FRA contract based on 3-month Libor as the floating interest rate. Two counterparties A and B agree on a certain interest period in the future, for example 3 months in 5 months' time. At the start of this period (i.e. in 5 months) A will pay B interest on the NPA accruing at an agreed fixed interest rate over the 3-month period, while B will pay A interest accruing at the floating rate prevailing over that period, which is not known in advance. Only the difference between the two interest payments is exchanged. FRAs are widely used by banks to hedge the interest rate risk arising from a mismatch in the interest rate profile of their assets and liabilities [9]. FRAs are only traded OTC, and form the building blocks for many other OTC interest rate derivatives.

2.3.3 Interest rate swaps

Interest rate swaps are the most widely used kind of interest rate derivative contract traded OTC. An interest rate swap is an agreement by two parties to exchange fixed versus floating interest payments on a certain notional principal amount at the start of each of a number of successive periods. The floating rate of interest is not known in advance, but reset each period, and the notional principal amount is not exchanged between the parties. An interest rate swap is like a strip of FRAs, each

Figure 8: Forward rate agreement



one beginning once the previous one has matured. Interest rate swaps are also only traded OTC.

2.3.4 Options on money market interest rate futures

Options on money market interest rate futures are traded on exchanges, such as the options on short sterling futures traded on LIFFE. They give the holder of the option the right to buy (or sell) an interest rate future contract at a pre-determined price at expiration of the option. The front four option contracts (those nearest to expiry) are the ones most actively traded on LIFFE, for options on short sterling, Euribor and Eurodollar futures. Option contracts on money market interest rate futures with greater times to expiry are generally much less liquid.

2.3.5 Interest rate guarantees, caps and floors

An option on a FRA is called an Interest Rate Guarantee (IRG) or interest rate caplet. A European call option on a FRA, or "Borrower's IRG", gives a floating-rate borrower the right to lock in a known maximum future borrowing rate. A put option on a FRA, or "Lender's IRG", allows a lender to lock in a known minimum lending rate.

A strip of caplets, one maturing after the other, is called an interest rate cap; these caps are an important component of the OTC interest rate options market. An interest rate cap allows the buyer to establish a maximum interest rate (the strike rate) for floating rate borrowing over a certain period, for example at the 3-month Libor rate over a period of 3 years. If at the rollover of the loan, 3-month Libor is above the strike rate, the borrower is compensated for the difference between these two rates. A cap is not a single option, but rather a strip of individual European call options on 3 month forward Libor rates, with each option expiring 3 months after the previous one. Each caplet within the cap is exercised only if the floating interest rate rises above the strike rate in that period [12].

An interest rate floor is similar to a cap, but it sets a minimum level to be paid on floating rate borrowing. It is a series of European put options on FRAs. A collar is a combination of a cap and a floor, namely the purchase of a cap and the sale of a floor. It provides both a ceiling and a floor to floating interest payments. There are also more complex products, including participations and options on caps and floors [13].

Prices for caps are quoted at certain strike levels, rather than with respect to a single forward rate. Since caps are strips of options on more than one forward Libor rate, the level of an ATM strike is not well-defined.

2.3.6 Swaptions

Swaptions are options on forward-starting interest rate swaps. A swaption gives the buyer the right, but not the obligation, to enter into an interest rate swap at a specific date in the future, at a particular fixed rate (the "strike rate"), and for a specified term. The option is called a "receiver's swaption" if the buyer has the right to receive fixed interest in the swap, and is called a "payer's swaption" if the buyer has the right to pay fixed and receive floating interest in the swap. Swaptions can be settled either in cash or physically by delivery of the underlying swap contract. Receiver's swaptions can be used to hedge against lower interest rates, and payer's swaptions to hedge against higher interest rates [14].

A particular swaption contract is specified by the time to expiry of the option, at which point a swap is entered into or the option is cash settled, and by the maturity (or "tenor") of the forward swap rate. For example, a "5 year into 10 year swaption" gives the buyer the right to enter into a 10-year swap in 5 years' time. Durations to expiry of the option range from about 1 month to 30 years, and the maturities of the swap contracts range from about 1 to 30 years. In practice, they are mainly cash-settled and European style. The market standard is to use the terminology of payer's and receiver's swaptions rather than the usual options terminology of calls and puts.

A difference between swaptions and caps is that, even though the floating interest payments of the swap are determined each period, the swaption is exercised as a whole, and not at the start of each reset period as in the case of caps.

Market makers report that there is much variation between the trading volumes for different swaption contracts. In particular, there are a number of more liquid benchmark contracts, against which other swaption contracts are priced. The number of these benchmark contracts identified by different market makers varies somewhat, and they include the following ATM swaption contracts: 3-month and 1-year options on 2-, 5- and 10-year swaps; 2-year options on 2-year swaps, 5-year options on 5-year swaps, 10-year options on 10-year swaps, and 15-year options on 15-year swaps. Other swaption contracts within the swaptions grid are much less liquid, and are said to be priced off the benchmark contracts by interpolation. Swaptions are mainly traded as ATM straddles (straddles are described in Section 2.7.2).

2.3.7 Bond options

There are also forward contracts and options on government bonds, traded both OTC and on exchanges. Bond options in the OTC market exist on government bonds, as well as on corporate bonds and eurobonds. Both plain vanilla OTC bond options, and some types of exotic options (for instance, spread and quanto options) described in Section 2.6.2 are commonly used [9].

Option market makers report that the OTC and exchange-traded gilt options markets have greatly decreased in size since 1995, and are very small now. The German Bund options market is the most liquid market among the OTC government bond options markets, followed by the market for options on US government bonds. The sterling corporate bond options market is said to be very small in size.

2.3.8 Market shares of different OTC interest rate derivatives

At the end of 1999, the total notional amount outstanding world-wide, in all currencies, of OTC interest rate derivatives was $ 60 trillion (US dollar equivalents); while the total amount outstanding in gross market values was much smaller at $ 1.3 trillion. In April 1998, average daily turnover in OTC interest rate derivatives was $ 265 billion (dollar equivalents), in all currencies[4] (equivalent data was not collected in 1999). The shares by type of derivative are given in Table 1.

[4] This average daily turnover is adjusted for both local and cross-border double counting.

Table 1: Shares of OTC interest rate derivatives

	Amounts outstanding, end 1999		Average daily turnover, April 1998
	Notional amounts	Gross market values	
options	16%	11%	14%
swaps	73%	88%	58%
FRAs	11%	1%	28%

Source: BIS [4, 5]

2.4 Differences between OTC and exchange-traded derivatives

The main characteristics of exchange-traded and OTC derivatives are summarised in Table 2. Recently, the differences between exchange-traded and OTC derivatives have decreased slightly, as some OTC contracts and their documentation have become more standardised, and some exchanges have started to provide central clearing services for OTC derivatives [15]. In the UK, swaps and FRAs (but not OTC interest rate options) can be settled via SwapClear, which was established by the London Clearing House (LCH) in 1999; this combines some of the advantages of exchange traded with OTC products. In this case, the LCH is counterparty to all market participants, replacing the bilateral contracts between them. Obligations from swaps and FRA contracts with the LCH can be netted, and the LCH provides daily margining, as well as collecting initial margin in the form of collateral or cash.

2.4.1 OTC market participants

The OTC derivatives market is almost exclusively a wholesale market. End-users of OTC derivatives are for the most part institutional investors, corporate treasurers (especially of large or multinational companies), governments, and other professionals. Providers of OTC products are mainly banks and securities houses, with the following characteristics: they are usually key members of the major exchanges, well capitalised, trading in all the world's major financial centres, with high credit ratings, and active in the market of the underlying assets [16]. Brokers also play an important role in OTC derivatives markets, acting as intermediaries between the major liquidity providers. Among the OTC derivatives, corporates mainly use FRAs and FX options [9].

Table 2: Exchange-traded and OTC derivatives

	Exchange traded	**OTC**
Trading	Central market place, traded under defined rules and regulations; access only through exchange members; some institutions are direct members of the exchanges; access for non-members via brokers.	Direct contracts between counterparties, often via brokers; no intermediation via an exchange. Both principal market with bid-offer spreads and broker market.
Transparency	Transparent market. Exchanges provide continually updated information about prices and volumes of contracts traded.	Much more opaque market - very little publicly available information about the prices of recently agreed contracts. However, indicitative prices are posted on brokers' screens.
Credit risk	Exchange Clearing House acts as counterparty, therefore minimal credit risk; initial margin deposits and daily marking to market; ease of netting of different positions.	Counterparty credit risk; margins, regular revaluation and posting of collateral can be agreed, but not obligatory; no netting of positions with different counterparties, but netting of positions with the same counterparty can be agreed.
Contract types	Standardisation of contracts and expiry dates; small number of contract types; contracts are of small and fixed size; maturities, and times to expiry of options are smaller on average than for OTC markets.	Products are flexible and can be tailored to users' specifications; no standardisation of expiry dates; proliferation of contract types. Nevertheless, there are plain vanilla contracts, which are more standardised.
Liquidity	Liquidity created by standardisation of contracts, a wide range of market participants, and a concentration of contracts at short maturities.	*For interest rate options contracts, larger sizes of trades than in exchange-traded markets are possible on average, although contracts are usually not as liquid; OTC contracts tend to be held to maturity to a greater extent than exchange-traded contracts.*
Market participants	Wide range of market participants.	Almost exclusively a wholesale market; not many types of market participant; end-users are mainly institutional investors, corporate treasurers and governments.

Source: [16, 17], and discussions with market participants.

2.5 Options

The purchase of a contract is said to create a "long" position, and the sale of a contract is said to create a "short" position. Having a long position in an option contract is also referred to as being "long volatility", and similarly for a short position. As noted previously, a call option on an asset gives the buyer the right, but not the obligation, to buy an asset underlying the option at the time of expiration of the option at a predetermined 'strike' price X, in return for paying a premium up front. If the price of the underlying contract at the time of expiration of the option, S_T, is above the strike price the buyer will exercise the option and buy the asset at the lower strike price, profiting from the price increase. But if the price of the underlying contract falls below the strike price, the option will simply not be exercised, and the loss is limited to the premium paid. The payoff of a long call option position is therefore equal to the maximum of (S_T -X) and zero, minus the option premium, p.

The buyer of a put option profits from exercising the option if the price of the underlying asset falls below the strike price. The payoff at expiry from a long put option position is therefore given by the maximum of (X-S_T) and zero, minus the option premium.

2.5.1 Payoff profiles

The payoff profiles at the time of expiry, T, of a long and a short outright position (e.g. a forward contract) as a function of the price of the underlying contract at expiry, S_T, are shown in Figure 9. Outright contracts have payoffs which are linear in the price of the underlying contract.

Figure 10 shows the payoff profiles at expiry of long and short call option positions. With options, the payoffs are nonlinear in the price of the underlying contract. Figure 11 shows the payoff profiles for long and short put options positions.

Each payoff profile exhibits a certain combination of risk and return. The long outright position shown in Figure 9 has unlimited upside and downside risks, and allows the holder to benefit fully from a price rise, while being fully exposed to downside risk if the price falls. In contrast, the downside risk for a long call option position is limited to the option premium. A short call option position has a maximum possible return equal to the premium of the option, and unlimited downside risk. By combining long and short outright contracts with call and put options, investors can create a risk/return profile suitable for their specific needs and risk appetite.

Figure 9: Payoff profiles of outright contracts

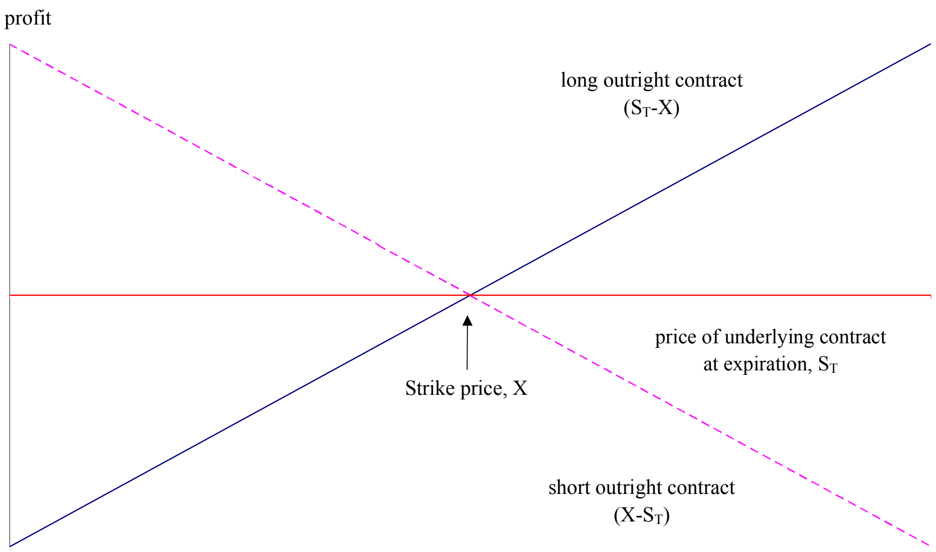


Figure 10: Payoff profiles of call option contracts

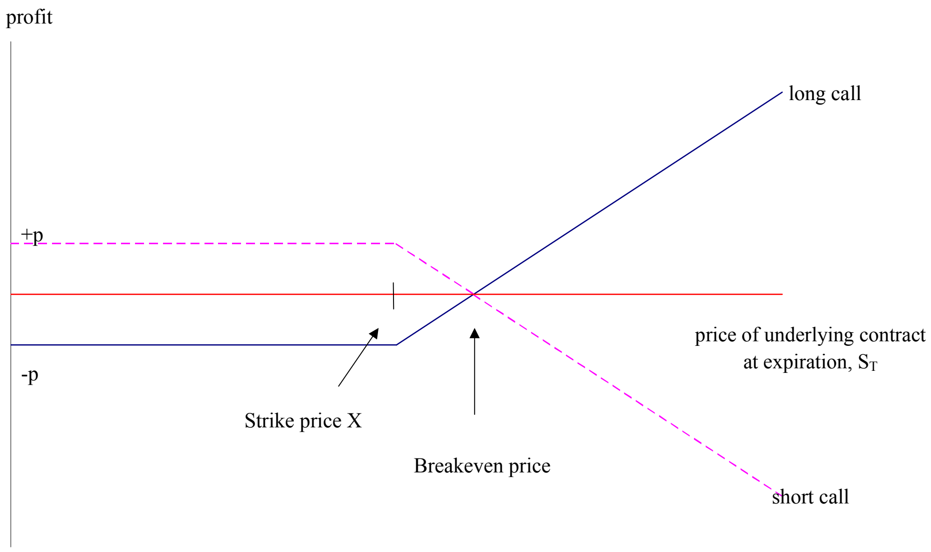
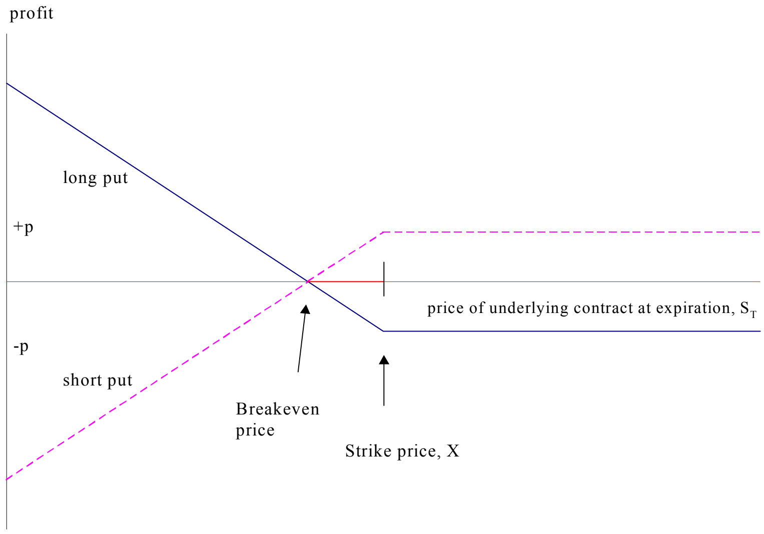


Figure 11: Payoff profiles of put option contracts



2.5.2 The value of interest rate options and volatility

Due to the asymmetric nature of the payoff profile, the price of an option is sensitive to the dispersion of expected future prices of the underlying contract. Today's price of a European option reflects today's uncertainty about prices at the time of expiry of the option. The price of an option is an increasing function of the volatility of the price of the underlying contract expected over the life of the option. Consequently, an option is more expensive the greater the width of the distribution of future prices expected by the market, i.e. the greater the uncertainty, since it is then more likely that the price of the underlying contract will move farther above or below the strike rate at the expiration of the option, leading to a greater payoff, while losses are still limited to the premium. Similarly, an option is cheaper when the distribution is narrower. Option prices therefore provide valuable information about the distribution of market expectations of future prices of the underlying contract. If the underlying contract is an interest rate future or a swap, options therefore provide information on the distribution of interest rates expected by the market in the future. By contrast, prices for futures contracts do not depend on price volatility (to a first approximation, and assuming neutrality to risk).

The Black model [18] is widely used by market participants for pricing

European-style interest rate options, since it is relatively simple mathematically and able to accurately match market prices for most plain vanilla contracts [12]. Given the market prices of options, and using the Black model's solution for option prices as a function of volatility, the volatility implicit in these prices can be inferred and is known as 'implied volatility'. This is the market's expectation of the standard deviation of the distribution of future daily interest rate changes. The Black model is used for quoting option prices in terms of implied volatilities by brokers and traders (for example in the case of swaptions and foreign exchange options). It also acts as a benchmark for calibrating other, more complicated, option pricing models, such as term structure models [12, 19]. Implied volatilities, the Black model and other option pricing models are discussed in more detail in the appendix.

2.6 Types of OTC options by complexity

OTC options can be roughly divided into the following types according to their complexity:

- Plain vanilla options
- Exotic options
- Structured products

2.6.1 Plain vanilla options

Plain vanilla options are instruments traded in generally liquid markets, using more or less standardised contracts and market conventions [20]. They include simple call and put options, for example on bonds, swaps, equity indices or an exchange rate. They also include interest rate caps and floors, and swaptions.

2.6.2 Exotic options

There are a wide variety of *exotic options* in existence, but only some of them are commonly used.

Average rate (or 'Asian') options on an interest rate or foreign exchange rate, are options on an average of the rate holding over the life of the option. They are cheaper than plain vanilla options on the underlying rate, since the volatility of the average of a rate is smaller than the volatility of the rate itself, and the price of an option increases with expected volatility of the underlying contract [21].

Barrier FX options comprise so-called knock-out options and knock-in options. Knock-out options expire early if the spot exchange rate moves outside a predetermined range. Knock-in options are valueless until the underlying spot exchange rate moves into a predetermined range, at which point they become standard European options [9]. Barrier options are well-suited for speculating on key exchange rate levels (often referred to as chart points), and for hedging against a certain range of exchange rates, for example if the user doesn't want to hedge against exchange rates being outside that range. They are cheaper to use than European options for these purposes, since their payoff is never greater than that of European options, but can be smaller [21]. Barrier options also exist on interest rates.

Other kinds of exotic options are spread options, quanto options and basket options. Spread options allow the investor to take a view on the spread between yields at different maturities or in different currencies, or on the difference in price between two different commodities. Interest rate spread options are options on relative yields at different maturities; they can be used for hedging a maturity mismatch between assets and liabilities [22].

Quanto bond options provide payouts in a currency different from the currency of the underlying bond. This allows an investor to take a view on bond yields in a foreign currency without being exposed to foreign exchange risk. For example an investor in the UK, who believes that German Bund prices are going to rise, but who does not want to be exposed to euro-sterling exchange rate risk, can buy a Bund call option quantoed into sterling. Using a quanto option fixes the payouts in sterling terms [9].

Equity basket options provide a hedge for an investor exposed to a basket of different stocks. Their advantage is that it is cheaper to buy a single basket option than it is to buy a basket of options on each of the individual stocks. This is because the price volatility of a basket of stocks is smaller than the volatility of the individual stocks, if the correlation of the individual stocks is less than one.

Most of the exotic interest rate options trades carried out by market makers are direct responses to customer demand; there is very little interbank trade in these products. Market makers note that activity in different kinds of exotic interest rate options varies over time, in part depending on the shape of the yield curve and the position in the interest rate cycle. In 1999, popular exotic interest rate products were said to include Bermudan swaptions, constant maturity swaps (CMS)[5]*, quanto products, and volatility bonds. Volatility bonds are highly leveraged products which, for example, pay coupons of 10 times the difference between the 10-year swap rate at the beginning and at the end of*

[5] A constant maturity swap is like a plain vanilla swap, except that the payments of the floating leg are not based on Libor, but on a market swap rate. Its price depends on swaption implied volatilities [23].

a coupon period. In the UK, the guaranteed annuities problem experienced by insurance companies[6] *was said to have given rise to higher than usual customer demand for Bermudan swaptions in sterling. Nevertheless, activity in Bermudan swaptions is larger in euros, where more callable bonds are issued.* Bermudan-style options can be exercised on several pre-determined dates. They are therefore well-suited for hedging callable bonds with multiple exercise dates, and for hedging cash flows due on several known future dates, as in the case of payments by insurance companies to policyholders receiving guaranteed annuities at retirement. *CMS caps*[7] *are said to be a kind of benchmark exotic option contract in both the sterling and euro markets. Other exotic interest rate options traded include average rate caps, knock-out swaps, digital interest rate options*[8]*, and equity-linked interest rate products. In the sterling market, there is little demand for exotic option contracts linked to gilts.*

2.6.3 Structured products

Structured products are made up of several components, including outright derivative contracts, options, and the underlying contracts, such as bonds. They can take the form of conventional debt instruments, which contain embedded swaps and options. The payment flows can be linked to one or more underlying asset, including interest rates, foreign exchange rates, equities and commodities. Some structured products are very illiquid, since no coherent secondary market exists for them [26].

For the issuer, structured products can provide cheaper funding. For the investor, they can provide risk/return characteristics tailored to their individual needs, including yield enhancement, capital guarantees, leverage, and access to market risks which are otherwise more expensive or forbidden (e.g. a prohibition from selling options). Investors include fund managers, pension funds, hedge funds, and retail investors, who can obtain them via commercial banks and building societies [26].

[6] In the 1960-80s, life insurance companies sold guaranteed annuity products that guaranteed a minimum annuity rate at retirement. Guaranteed annuity products are in effect options, since they allow policy holders to choose the higher of the annuity rate available in the market and the guaranteed rate, when they retire. These guaranteed annuity options were written at a time when interest rates in the UK were quite high, and were generally not hedged by the insurance companies. As gilt yields have fallen below the levels of the guaranteed annuity rates, these options have become valuable for policyholders to exercise. Consequently, insurance companies have had to hedge the liabilities arising from these products [24, 25].

[7] A CMS cap is a strip of options on single-period CMS, one maturing after the other, in the same way that a cap is a strip of options on FRAs [23].

[8] A digital interest rate option has a discontinuous payoff profile. An example is a cash-or-nothing call option, whose payoff is zero below the strike of the option, and a pre-determined fixed amount above the strike [12].

Examples of structured products include:

- Callable and puttable bonds. These are bonds with embedded call or put options. Callable bonds give the issuer the right to redeem the bond at a pre-determined price and date before the maturity of the bond. A puttable bond gives the investor the right to sell back the bond to the issuer at a specified price and date before maturity of the bond [14].

- Mortgage-backed securities (MBS). In the US, these are a major class of securities with embedded interest rate options. MBS are a pool of home mortgages, almost all of which contain prepayment provisions. These prepayment provisions are options granted by the lender to the borrower, who may wish to exercise them when interest rates, and thus mortgage refinancing rates, fall below the previously agreed mortgage rate.

- Structured medium-term-notes (MTNs). These are unsecured debt securities with maturities of up to 50 years, where the issuer enters into a derivatives transaction at the time of issuance. Structured MTNs can contain embedded options, including swaptions [25]. The issuance of MTNs with embedded options has been partly in response to investor-driven demand[9] [27].

- Equity-linked bonds. Examples include fixed income bonds that are combined with a call or put option, or an exotic option, on an equity index. Such instruments can provide capital guarantees together with partial exposure to movements in the stock market [28]. If exotic options are used, these products can be highly leveraged. Convertible bonds give the holder the right to exchange the (usually fixed rate) bond for a pre-determined number of ordinary shares or other debt instruments of the issuer at a pre-specified price and date. The redemption of the bond is linked to a stock price or index, and it may also contain various other long-dated embedded options [12, 14]. Bonds with warrants give the holder the

[9]The process can take place as follows. An investment bank identifies investors' specific requirements, and structures a security to provide the required payoffs. The bank then finds an issuer willing to issue the underlying security. At the time of issuance, the investment bank enters into a swap with the issuer, where the issuer pays the Libor interest rate minus a spread, and the bank pays the complex payoff of the MTN to the issuer. As a result, the issuer is left with attractive sub-Libor funding, the investor receives the specific payoff and risk exposure required, and the investment bank pays the payoff of the note [27]. MTNs can be placed with investors as syndicated issues, which are not offered publicly [25].

right to buy a pre-determined number of shares at a pre-determined price and time in the future.

- Guaranteed funds. These investment funds are usually sold to retail investors, and typically invest a majority of their portfolio in cash or bonds, and the remainder in near- or at-the-money call stock index options, providing a minimum guaranteed return and an exposure to a rise in the stock market [29].

2.7 Applications of options

Options on any of the various underlying asset categories can have the following kinds of applications: risk management, speculation, yield enhancement of investments, and obtaining access to other markets.

2.7.1 Risk management

Corporates, fund managers and banks use options for hedging existing or anticipated risk exposures. Hedging involves buying protection against unfavourable price movements in the underlying contract. Options are ideally suited for hedging contingent claims, since they constitute contingent assets themselves, unlike outright contracts. Options are also used to manage existing risk exposure. In this process, some return from favourable price movements is given up in order to limit the loss from unfavourable price movements.

Examples of risk management applications are:

- Portfolio insurance. Fund managers can protect against the downside risk on an outright position by buying put options on the underlying asset. This hedges the downside risk but still allows the fund manager to profit from favourable price movements in the underlying asset. This common hedging strategy is called a 'protective put'. The payoff profile of a protective put is shown in Figure 12.

- Corporates that want greater planning certainty and want to increase the likelihood of remaining within budget can buy interest rate caps to limit their floating interest payments to a certain maximum level. If the company is mainly concerned with remaining within budget, and less about profits, this planning certainty can be achieved more cheaply by buying an interest rate collar, which puts a floor under the floating interest payments as well as providing a ceiling. An interest rate collar can be cheaper than a cap on its own since it limits the profits from favourable interest rate movements, and thus provides cheaper insurance [12] (see Figures

13 and 14). Average rate options can also be used as an alternative to caps. Like collars, they are cheaper than caps (see Section 2.6.2).

- By buying interest rate caps with a strike rate related to the fixed mortgages rate offered to customers, building societies can cap the interest cost of their floating rate liabilities at a maximum rate related to the fixed rate which they receive from their mortgage customers.

- Issuers of, and investors in, bonds with embedded call or put options can hedge against the change in cash flows arising from exercise of the embedded options by using swaptions.

- Life insurance companies can hedge their guaranteed annuity products offered to customers by buying swaptions (receiving fixed interest) with strike rates equal to the minimum guaranteed rate.

- A company which expects to receive revenue in another currency, but is not sure about the timing of the receipts, can hedge the foreign exchange risk by buying an average-rate foreign exchange option. Its payoff is related to the difference between the strike rate and an average of a market rate on a certain number of predetermined dates[10].

Fund managers also use derivatives, including options, to modify their asset positions to satisfy risk management requirements given a performance benchmark or liability profile [30]. For example, equity portfolio managers who have attained their performance benchmark before the end of the benchmark period, may buy put options on the equity index to insure themselves against a fall in the equity market.

Derivatives, including options, allow companies and banks to manage the risk profile and cash flow structures of its assets and liabilities [30]. In particular, corporate treasurers can use derivatives to match liabilities (for example their maturity profile) against their assets (e.g. the revenue from selling their products), and fund managers can use derivatives to match assets against their given liabilities (e.g. pensions).

Interest rate options provide an alternative to interest rate swaps for hedging interest rate risk. In contrast to swaps, their price depends not only on the level of current and expected future interest rates, but also on the volatility of those interest rates.

[10]An alternative hedge for the company would be to establish a short outright position in the currency concerned, and use the receipts to close out the short position, when they arrive. Using an average rate FX option avoids having to establish a short position.

Figure 12: Payoff profile of a protective put

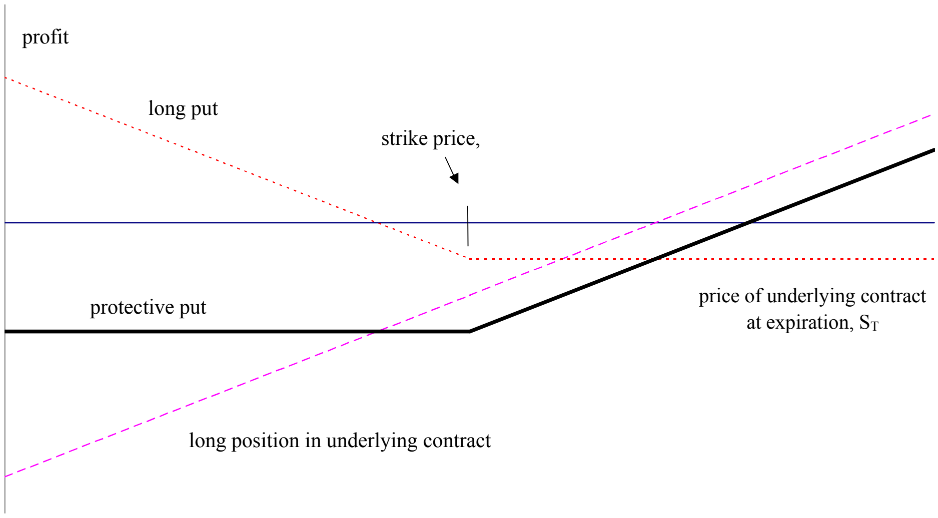


Figure 13: Capped interest rate

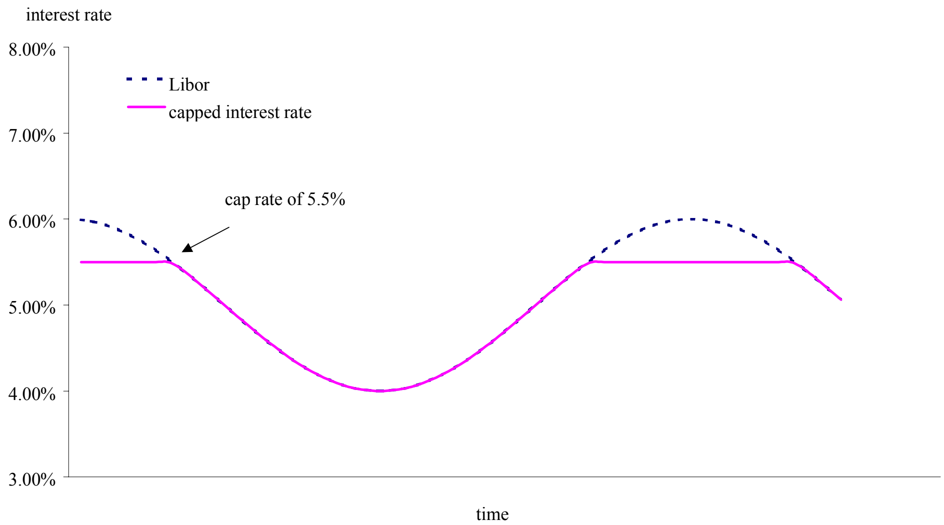
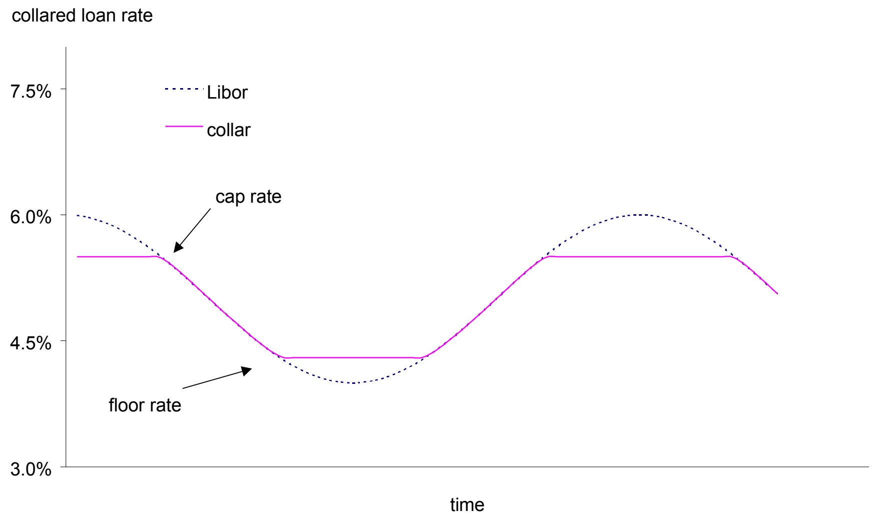


Figure 14: Collared loan rate



2.7.2 Speculation

Options can be used to speculate on the direction and volatility of price movements of the underlying contract. Hedge funds and the proprietary desks of investment banks frequently engage in such activity. If speculators buy call options, they will profit if the price of the underlying contract rises above the strike price. Options can also be used to speculate on the future price volatility of the underlying contract. By buying and selling certain combinations of call and put options and outright contracts, trades can be put on whose payoffs are (over a short period of time) sensitive to changes in the price volatility of the underlying contract, but not to the direction of the price movements. Such trades are not possible without using options. Important examples are straddle trades - long straddles consist of a long call and a long put position with the same strike price and expiration date, giving rise to the payoff profile shown in Figure 15. The holder of the straddle profits if price movements are large, no matter what direction.

2.7.3 Yield enhancement of investments

A fund manager with a portfolio of bonds can create a position known as a 'covered call' by selling a call option on a bond (see Figure 16). The fund manager will choose a strike price for the call option which he or she thinks the price of the bond will be unlikely to move above. If the bond

Figure 15: Payoff of a straddle

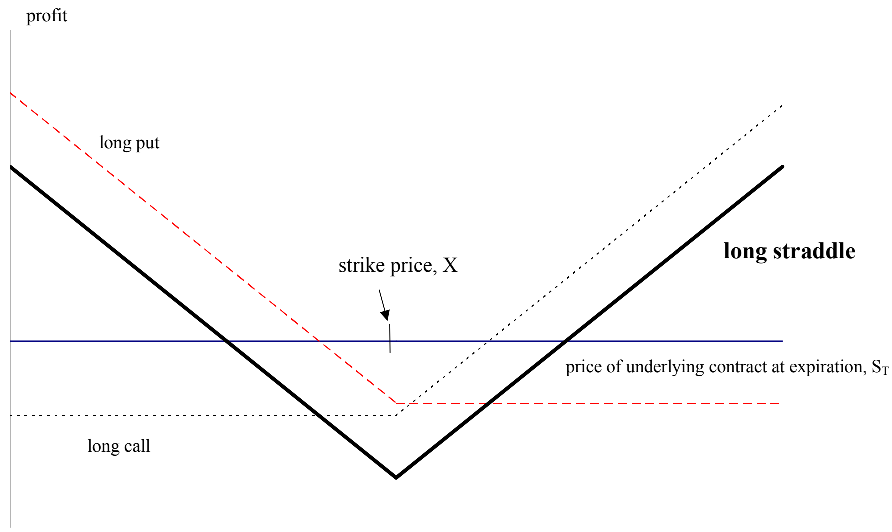
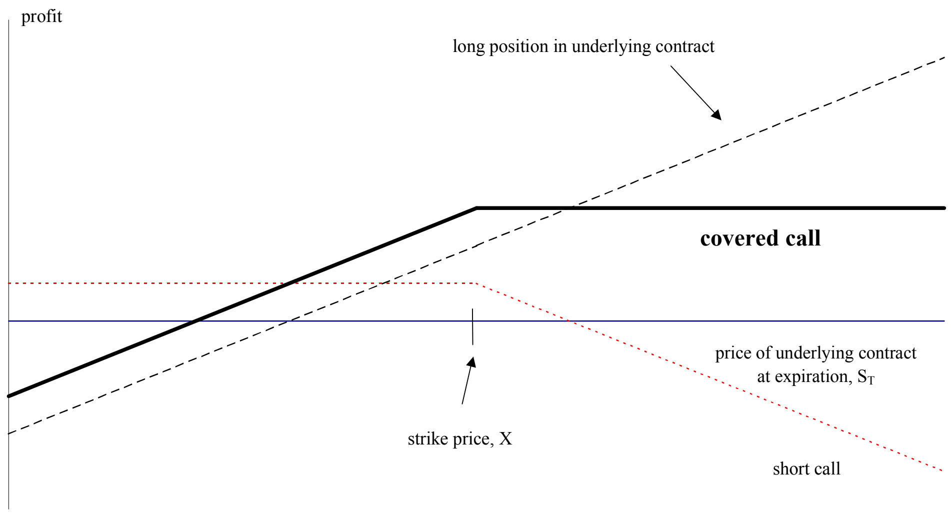


Figure 16: Payoff of a covered call



price remains below the strike price, the option will not be exercised and the fund manager earns the option premium, thereby enhancing the yield of the bond portfolio.

Callable bonds provide yield enhancement for investors. They give the issuer of the bond the right to redeem the bond before its maturity date. The issuer pays a higher yield to the investor for this optionality element, and the investor receives a higher yield over a potentially shorter time horizon, giving up yield if the bond should be called.

Bonds with embedded put options provide a lower cost of funds for issuers, since the investor pays a premium for the optionality of selling back the bond to the issuer. In addition, issuers can sell swaptions to further lower their funding cost, and callable and puttable fixed-rate debt issues can be swapped by the issuer to obtain floating-rate funding at interest rates below Libor [31]. Swaptions can then be used by the issuer in order to be able to offset the swap if the bond is put or called.

2.7.4 Obtaining (cheaper) access to markets and exploiting comparative advantages

Like interest rate swaps, swaptions can be used to borrow in a market where the counterparty has a comparative advantage, say in floating interest borrowing, and then to swap into another market, i.e. fixed rate borrowing, to obtain fixed rate funding at a cheaper rate than when borrowing directly in the fixed interest rate market. This establishes an arbitrage link between the fixed and floating interest markets and allows market participants to take advantage of any cost differences between markets.

Some institutions face regulatory restrictions on their exposure to certain markets, for example to the equity market. By buying structured products like convertible bonds or bonds with warrants, these institutions can transform interest rate exposure into equity exposure, without the equity exposure showing up on their balance sheets.

Even if a portfolio manager is allowed access to another market, it can sometimes be cheaper and faster to obtain exposure to the other market via derivatives, rather than by selling the underlying contracts in the old market and buying underlying contracts in the new market [15].

Some institutions may not be able to sell options in the OTC market due to their own insufficient credit quality. By embedding the sale of an option in a bond as a structured product, they can resolve the credit risk problem, and are able to receive the option premium for yield enhancement.

Market makers generally think that obtaining access to other markets *and exploiting comparative advantages are not important motivations in the use of OTC interest rate options.*

2.8 Valuation of derivatives

Derivatives can be valued in the following ways [32]:

- The **notional value** of a derivatives contract is the value of the notional principal amount on the contract underlying the derivative. In the case of an interest rate swap, it is the notional principal amount of the loan on which interest payments are exchanged. The notional value does not depend on the maturity of the contract or on any changes in market rates. It can be used as a measure of market activity and of exposure to future changes in market conditions (market price risk). It should be noted that this concept will greatly exaggerate the total size of gross cash flows being exchanged by counterparties in derivatives trades, since principals are usually not exchanged. Notional values are used as a base to calculate the exchange of payments, which are typically only a small fraction of the notional value.

- The **market (or 'fair') value** is the cost of replacing a derivatives contract at market prices. It represents the perceived benefit or cost of holding the contract. In the case of an interest rate swap, it is the net present value of expected future interest payments. The market value is usually zero at the start of the contract, and can then become either positive or negative. It is typically only a small fraction of the notional value and represents the cumulative gains and losses which have already taken place. Counterparty credit risk arises in respect of net present value unless the exposure is collateralised or the difference is settled, for example via margin calls. Market values tend to be larger for contracts of longer maturities.

The BIS, in conjunction with national central banks, conducts triennial surveys of turnover in notional amounts, and of notional amounts and gross market values outstanding in the OTC derivatives markets [5], the last ones taking place in 1995 and 1998 (contracts are said to be outstanding, or open, until they are closed out by delivering the underlying asset or commodity, or until they are settled in cash). In the 1995 survey, both turnover and outstandings data were reported on a locational basis, i.e. at the location of the office where the deal was done. In 1998, turnover data were again reported on a locational basis, but outstandings were reported on a world-wide consolidated basis, i.e.

all deals with other domestic or foreign offices of the same institution were netted out; the basis for reporting was the global book of the head office and all branches of a given institution. The number of reporting institutions and participating countries also differs in the 1995 and 1998 surveys. If the sample had been constant, the change from locational to world-wide consolidated reporting would have been expected to lead to an underestimate of the growth of the market.

In order to provide more timely data on the rapidly developing OTC derivatives markets, and a more consistent reporting basis, the BIS introduced regular semi-annual OTC derivatives surveys in June 1998 of notional amounts outstanding and gross market value [4], but not of turnover. These surveys use a smaller sample of institutions. Data from the BIS' regular semi-annual surveys are reported on a world-wide consolidated basis.

The International Swaps and Derivatives Association (ISDA) conducted annual surveys among its members of notional amounts outstanding and turnover in OTC derivatives markets between 1987 and 1997 [13]. These surveys were discontinued, due in part to the new semi-annual data being collected by the BIS.

Below is a more detailed description of some of the data collected by the BIS :

- **Turnover in notional amounts** provides a measure of market activity, and may provide an indication of market liquidity. It is defined as the gross notional principal amount of all deals contracted (but not closed), during a given period. The gross amount of each transaction is recorded, ignoring any netting arrangements or offsets. The premia charged on options are not included in these figures, but the notional principal amounts of their underlying contracts are [5].

- **Outstandings in notional amounts** are the notional values of all deals made and not yet settled. They are therefore a measure of market size, and are a rough proxy for the potential transfer of market price risk in derivatives markets [5]. In the semi-annual surveys, there is no netting of contracts which are bought and sold to one counterparty, even if their cash flows are subject to bilateral netting arrangements, and there is no netting of options bought against options sold [20].

- **Outstandings in gross market values** are a measure of gross exposure to counterparty credit risk [5]. In the semi-annual surveys, they are defined as the sum of the absolute market values of all derivatives contracts outstanding, with either positive or negative market values, evaluated at market prices prevailing at the reporting date. There is no netting of contracts with positive and negative market values with one counterparty, or within a risk category. As prices of the underlying contracts change, the accumulation of gains and losses on the derivatives contracts give rise to market values. Therefore, gross market values tend to reflect market volatility. For options, the market value is defined as the quoted market price, if available. If quoted prices are not available, the market value is determined from secondary market prices for options with the same strikes and remaining maturities, or by using option pricing models [20].

All positions are reported in US dollar equivalents, using the exchange rates on the reporting date (or the internal exchange rates used in the institutions for book-keeping purposes, if they are close to market rates). Transactions between reporting institutions are reported by each institution. To adjust for double-counting, notional amounts outstanding and gross market values with other reporting dealers are halved [20].

In this paper, we focus on data on notional amounts outstanding, since this has the most timely and consistent historical time series available, and is most easily comparable for the OTC and exchange-traded derivatives markets. Gross market values are not collected for exchange-traded derivatives. Turnover data for global OTC derivatives markets have only been collected every three years by the BIS, the most recent information relates to 1998. Furthermore turnover figures from the BIS surveys are only available for foreign exchange and interest rate derivatives; no information is available for equity-linked and commodity derivatives. As noted above, notional values exaggerate the size of gross flows exchanged between counterparties in a derivatives contract. Consequently, turnover and outstandings in notional amounts exaggerate the size of the global derivatives market.

A measure which is commonly used by market participants to measure the market risk exposure of portfolios of financial assets, including derivatives, is value-at-risk (VaR) [33]. VaR measures the potential loss from a derivatives contract, based on an assumption about possible future price movements of the underlying contract. In contrast, gross market value (GMV) measures the cumulative gains and losses of derivatives contracts which have already taken place. Whereas the gross market value of an interest rate swap is zero initially, its VaR is non-zero. In contrast to GMV, VaR takes into account the offsetting of risks of different financial contracts in a portfolio. By not netting different positions against each other, GMV gives an indication of credit and liquidity risk. No information on the VaR exposure of global derivative positions is publicly available.

In the semi-annual BIS surveys, dealers report contracts according to the counterparty with whom they have done the transaction, i.e. with [20]:

- *Other regular reporting dealers.* These are institutions which contribute to the regular semi-annual BIS derivatives survey; they are mainly commercial and investment banks and securities houses that act as market-makers or intermediaries, and other active dealers.

- *Other financial institutions.* These are financial institutions which do not contribute to the regular BIS derivatives surveys; they include banks, funds, and non-bank financial institutions (eg mutuals, pension funds, hedge funds, currency and money market funds, building societies, leasing companies, insurance companies, and central banks).

- *Non-financial customers.* These include all other counterparties, mainly corporates and governments.

One derivative contract can contain exposure to different kinds of market risk. In the semi-annual BIS surveys, derivatives are assigned to risk categories according to the following criteria [20]:

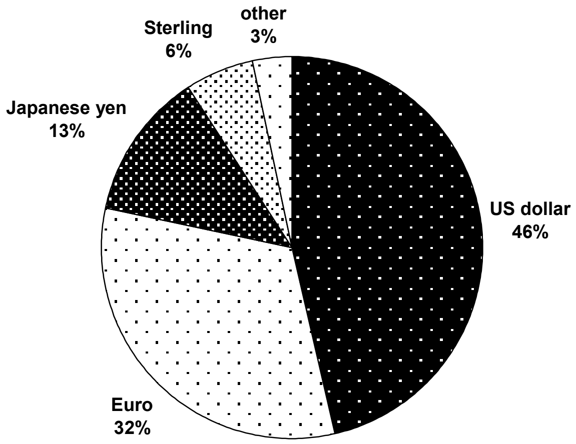
- *Commodities:* Any derivative with exposure to a commodity or commodity index, even if it also contains exposure to foreign exchange, interest rate or equity risk.

- *Equities:* Any derivative with exposure to equities or an equity index and no exposure to commodities, even if it also contains exposure to foreign exchange or interest rates.

- *Foreign exchange:* Any derivative not included under commodities or equities with exposure to more than one currency, in either interest or exchange rates.

- *Single-currency interest rate contracts:* Derivatives with exposure to only one currency's interest rate. Within the section of single-currency interest rate contracts, the OTC options category takes precedence; this means that any interest rate derivative with an embedded option is classified as an OTC option.

Figure 17: Global OTC interest rate options market – notional amounts outstanding



Source: BIS end 1999 [4]

3 Market structure and applications of interest rate options

3.1 OTC interest rate options markets

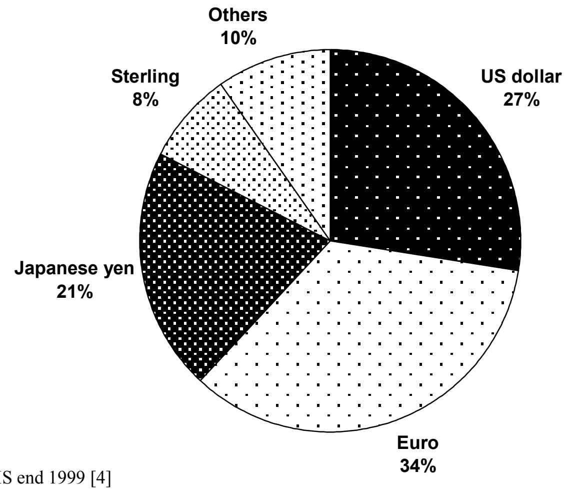
3.1.1 International comparison

At the end of 1999, the notional amount outstanding (worldwide) of OTC interest rate options totalled \$ 9.4 trillion. Within this total, US dollar-denominated contracts accounted for almost half (see Figure 17). Euro contracts had the second largest share, followed by yen and sterling contracts. However, for the global OTC market of interest rate derivatives (i.e. including FRAs and swaps, as well as options), euro contracts had the dominant share (34% out of a total of \$ 60.1 trillion), followed by dollar contracts, yen contracts, and sterling contracts (see Figure 18).

Turnover in interest rate options is not as heavily concentrated in the dollar. In April 1998, the share of total turnover accounted for by dollar-denominated contracts was 33% (see Figure 19).

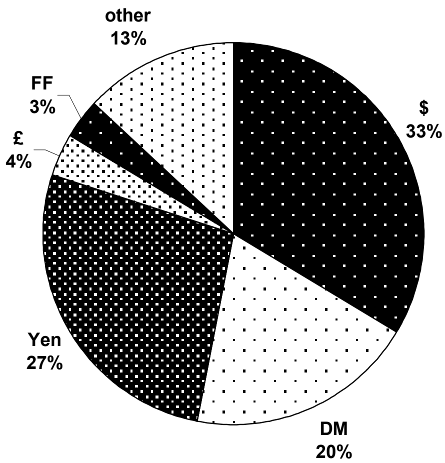
For comparison, currency shares of notional amounts outstanding in foreign exchange options and the global foreign exchange OTC derivatives market at end 1999 are shown in Figures 20 and 21. Among FX options, the dollar had the largest share of 44%, followed by yen, the

Figure 18: Global OTC interest rate derivatives market – notional amounts outstanding



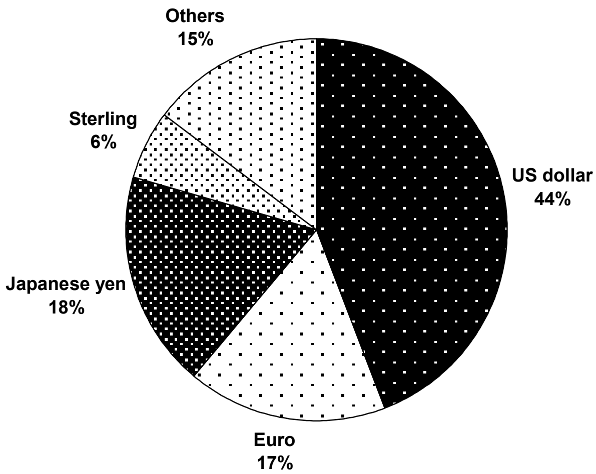
Source: BIS end 1999 [4]

Figure 19: Average daily turnover in global OTC interest rate options markets



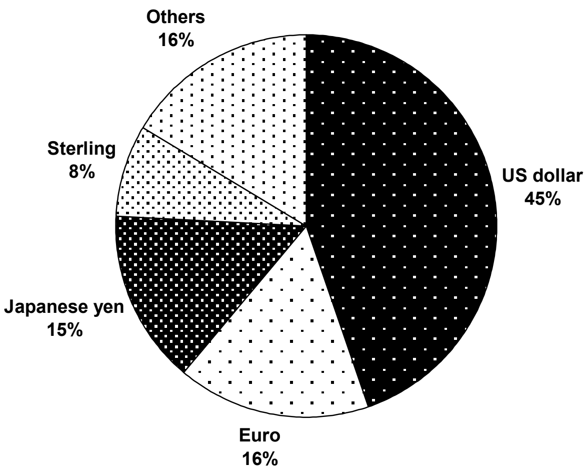
Source: BIS triennial survey, April 1998 [5]

Figure 20: Global OTC foreign exchange options markets – notional amounts outstanding



Source: BIS end 1999 [4]

Figure 21: Global OTC foreign exchange derivatives markets – notional amounts outstanding



Source: BIS end 1999 [4]

euro, and sterling.

Market participants note that, broadly speaking, the same globally active banks are the major participants in all the different currency OTC interest rate options markets. Trading in different currency-denominated OTC interest rate options tends to be more concentrated in the respective currency's time zone than trading in the underlying contracts. For instance, dollar and yen OTC interest rate options contracts are mainly traded in New York and Tokyo, respectively. OTC interest rate options in sterling and euro are mainly traded in London.

Market participants note that the demand for and supply of longer-dated interest rate options is much more balanced in the dollar market, than in the euro or sterling markets. For instance, issuers of corporate callable bonds in the US typically sell options, offsetting the demand for options for risk management purposes. Moreover, demand for swaptions arises from hedging by mortgage lenders of fixed-rate mortgages without prepayment penalties, and from mortgage-backed securities with early redemption clauses (see Section 2.6.3)*; both effectively contain embedded options which need to be hedged. In the US, the range of end-users is generally wider than in the euro and sterling markets. This enables market makers to match customer flows most of the time. Consequently, market makers in OTC interest rate options in dollars are able to act largely as risk intermediaries, and re-market risk for different customers. By contrast, option market makers dealing in long-dated sterling and euro OTC interest rate options tend to have much more of a 'risk-warehousing' function.*

The long-dated euro-denominated swaptions market is driven more by themes and by particular risk positions generated by the issuance of new structured notes. Supply of long-dated swaptions arises from issuers hedging their callable bond issues, and from insurance companies and pension funds selling swaptions for yield enhancement. However, there is generally little end-user demand for these long-dated swaptions, since mortgages are either fixed-rate without embedded options, or floating rate.

The sterling OTC interest rate options market is less liquid than the euro and dollar markets. In sterling, there is no significant demand for or supply of longer-dated swaptions. Building societies don't generally sell long-maturity mortgages with embedded options, there is less callable corporate bond issuance, and insurance companies and pension funds don't generally sell long-dated swaptions for yield enhancement. Therefore, when the customer demand for swaptions increased in 1999 (related to the hedging of guaranteed annuity products by insurance companies), the market found it difficult to absorb.

Similarly, the exotic options business is not as developed in sterling as in the euro and dollar markets. Furthermore, the dollar OTC interest rate options market is said to be much more arbitraged along the whole yield curve than the sterling market (i.e. speculative views on different parts of the yield curve are taken to a greater extent), and more than the euro market.

3.1.2 Market concentration and use of brokers

In April 1998, the share of OTC interest rate options turnover in the UK in all currencies, measured in notional values, of the largest ten banks was 71%, and 90% of turnover was accounted for by 23 banks. Of the 197 reporting institutions in the UK, 128 reported zero turnover [6].

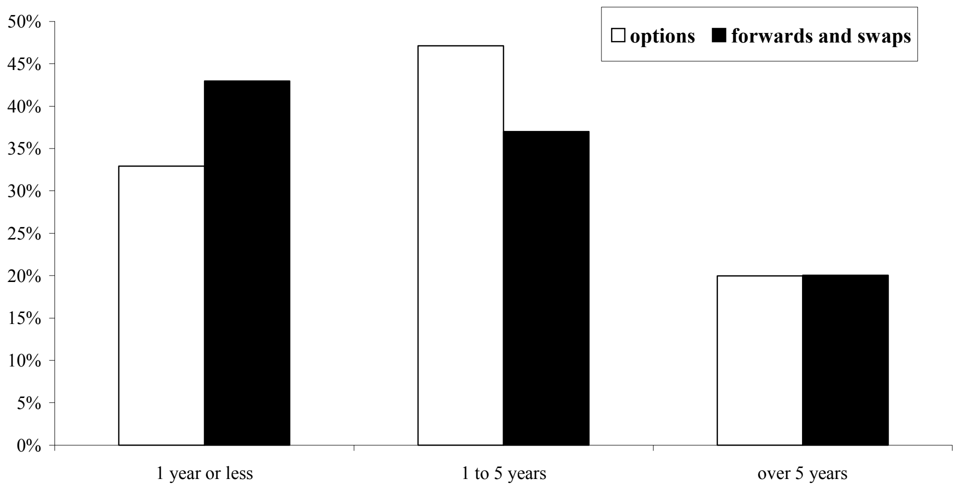
Options market participants note that there are only a small number of players in the sterling OTC interest rate options market. The number of players is thought to have fallen in the last few years partly due to mergers of investment banks, to a reduction in risk capital assigned to fixed income markets, and to a decrease in liquidity in the gilt market. Some market makers have cited the illiquidity and small number of players in the sterling interest rate options market as a reason for conducting a large fraction of their interbank trades via brokers, rather than direct. This helps to preserve anonymity until deals are concluded, and aids price discovery. On the other hand, other market makers have noted that the small number of players in sterling led them to deal to a greater extent direct with other banks in the interbank market, since they knew the other active traders. Rough estimates by some market makers of the fraction of their interbank deals in OTC interest rate options conducted via brokers ranged from somewhat less than 50% to 90%.

3.1.3 Maturity decomposition

A breakdown of interest rate derivatives by remaining maturity of the contracts is shown in Figure 22. For options, this is the remaining time to expiration of the option. Remaining maturities of interest rate options outstanding in all currencies taken together were largest in the range of 1 to 5 years at end 1999, which accounted for 47%. Forwards (i.e. FRAs) and swaps had a smaller share than options at these maturities, but a larger one at shorter maturities. Only 20% of OTC interest rate derivatives contracts have maturities exceeding 5 years.

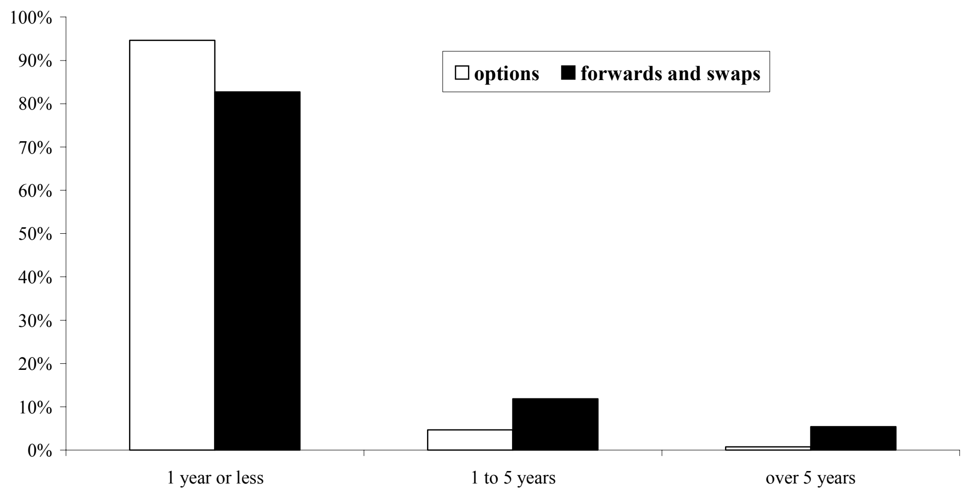
For comparison, Figure 23 shows the breakdown by maturity bands for foreign exchange derivatives. These have much shorter maturities on average than interest rate derivatives; 95% of options, and 83% of forwards and swaps had a maturity of one year or less at end 1999. Only 6% of FX options outstanding had a maturity of greater than one year. Moreover, FX options had on average slightly shorter maturities

Figure 22: Share of notional amounts outstanding for global OTC interest rate derivatives markets, by maturity band



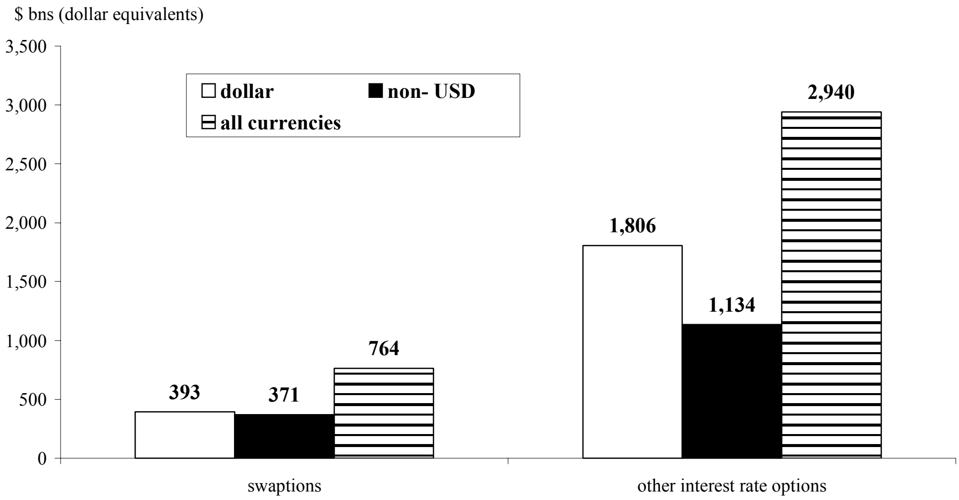
Source: BIS end 1999 [4]

Figure 23: Share of notional amounts outstanding for global OTC FX derivatives markets, by maturity band



Source: BIS end 1999 [4]

Figure 24: Notional amounts outstanding of interest rate options



Source: ISDA market survey end 1995 [13,17]

than FX forwards or swaps, whereas OTC interest rate options had on average slightly longer maturities than interest rate forwards and swaps.

Reporting dealers in the BIS' semi-annual OTC derivatives survey at end 1999 sold more OTC interest rate options to non-financial customers, including corporates, than they bought from them, by a factor of 1.7. *These data are in accordance with information from some market makers, who have said that corporates mainly buy OTC interest rate options from them, generally for hedging purposes.*

3.1.4 Relative importance of different OTC interest rate options

The ISDA market surveys provided a further breakdown of notional amounts outstanding by type of interest rate option. In this survey, caps, floors, swaptions, and specialised combinations (namely collars, participations, and options on caps and floors) were included, but structured products were not included. Figure 24 shows notional amounts outstanding for swaptions and other types of interest rate options at end 1995. In 1995, swaptions accounted for about 20% of amounts outstanding of interest rate options in all currencies [13, 17].

Market makers note that caps, floors and swaptions are the main kinds of plain vanilla OTC interest rate options traded in sterling, euro and dollar. The relative importance of caps & floors on the one hand,

and of swaptions on the other hand, depends on customer flows, which in turn depend in part on the position in the interest rate cycle, and on the shape of the yield curve. Generally, 3- to 5-year caps are actively traded, as a natural extension of exchange-traded options on money market interest rate futures. Caps are mainly traded outright, rather than as straddles; interest rate guarantees are not very actively traded.

3.1.5 Counterparty breakdown

Outstandings of derivative transactions by reporting dealers for the semi-annual surveys are derived for the three kinds of counterparties described in Section 2.8, namely other reporting dealers, other financial institutions, and non-financial customers. Options transactions are reported from the perspective of the reporting dealer, i.e. options are sold to or bought from a counterparty, and these are *not* adjusted for inter-dealer double counting. More than a half of the sales and purchases of interest rate options are with other reporting dealers, roughly a third are with other financial institutions, and only about 10% are with non-financial customers (see Figure 25).

For comparison, a similar breakdown is shown in the same chart for interest rate swaps for all currencies (these data are adjusted for inter-dealer double counting). The pattern for sterling interest rate options and swaps is roughly similar to that for all currencies taken together.

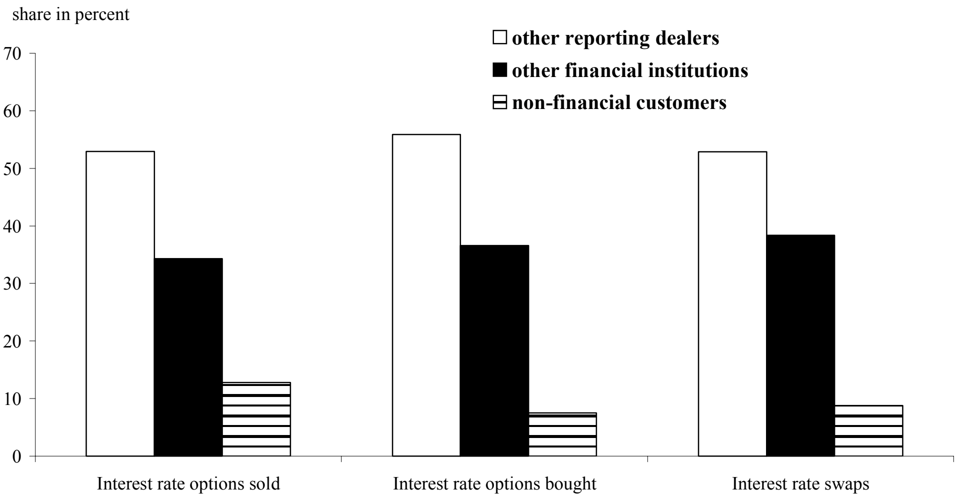
3.1.6 Turnover by country

Figure 26 shows the shares in average daily turnover[11] of OTC interest rate options by the country where the trade was transacted. Japan had the largest share (28%); the UK had the second largest share (26%), followed by the US with a share of 24%. In the US, the majority of turnover between reporting dealers, with financial institutions and non-financial customers was local. By contrast, in the UK, the majority of turnover for each type of counterparty was cross-border. For Japan, the majority of turnover between reporting dealers and with financial institutions was cross-border, while the majority of turnover with non-financial customers was local.

The turnover data by country are not adjusted for cross-border inter-dealer doublecounting, however. Therefore the shares of countries with a large proportion of cross-border trades (e.g. for Japan, where 75% of OTC interest rate options turnover was cross-border) are artificially larger than the shares of countries with a smaller proportion of cross-border trades (e.g. the US, where 24% was cross-border).

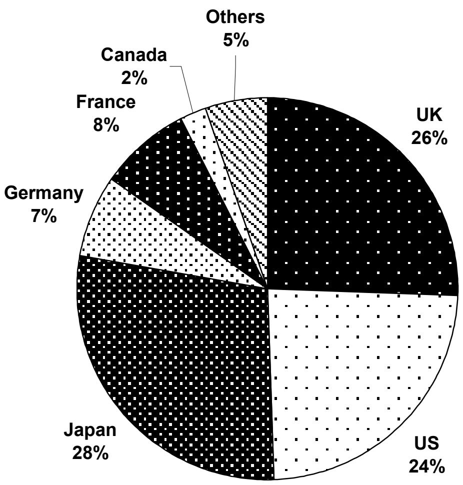
[11]Adjusted for local, but not for cross-border, inter-dealer double counting.

Figure 25: Counterparty breakdown for NAO of global OTC interest rate option and swap markets



Source: BIS end 1999 [4]

Figure 26: Turnover in global OTC interest rate options markets



Source: BIS triennial survey, April 1998 [5]

3.2 OTC and exchange-traded options

In December 1998, notional amounts outstanding of OTC interest rate options were 1.7 times larger than for exchange-traded interest rate options. However, average daily turnover of OTC interest rate options in April 1998 was only 19% of the average daily turnover of exchange-traded interest rate options in Q2 1998. *Market makers confirm this pattern and highlight that the maturity of interest rate options contracts traded in the OTC markets is on average longer than the maturity of contracts traded on the exchanges. In addition, OTC interest rate options tend to be held to maturity to a greater extent than exchange-traded interest rate options, which are often sold before their expiry.* For currency options, both notional amounts outstanding and turnover are much larger in the OTC markets than on the exchanges.

Table 3: OTC and exchange-traded options [a]

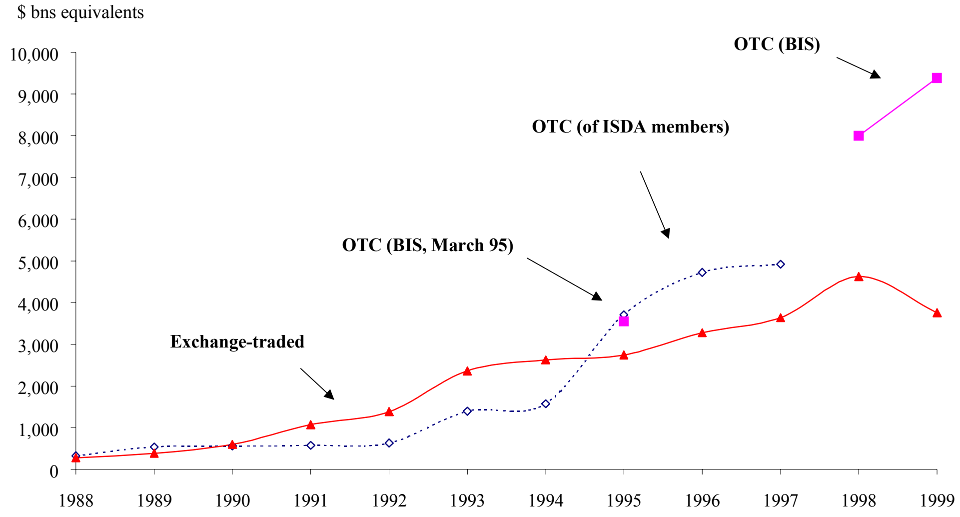
$ bns equivalents		
OTC	Notional amounts outstanding, end 1998	Average daily turnover, April 1998
Interest rate options	7,997	36
Foreign exchange options	3,695	87
Equity-linked options	1,342	not available
Exchange-traded	Notional amounts outstanding, December 1998	Average daily turnover, Q2 1998
Interest rate options	4,624	192
Currency options	49	2
Equity index options	917	43

Source: FOW TRADEdata; Futures Industry Association; various futures and options exchanges, BIS [4, 5, 7]

[a]Average daily turnover for exchange-traded options is converted from total turnover data for Q2 98, assuming 61 working days in that quarter.

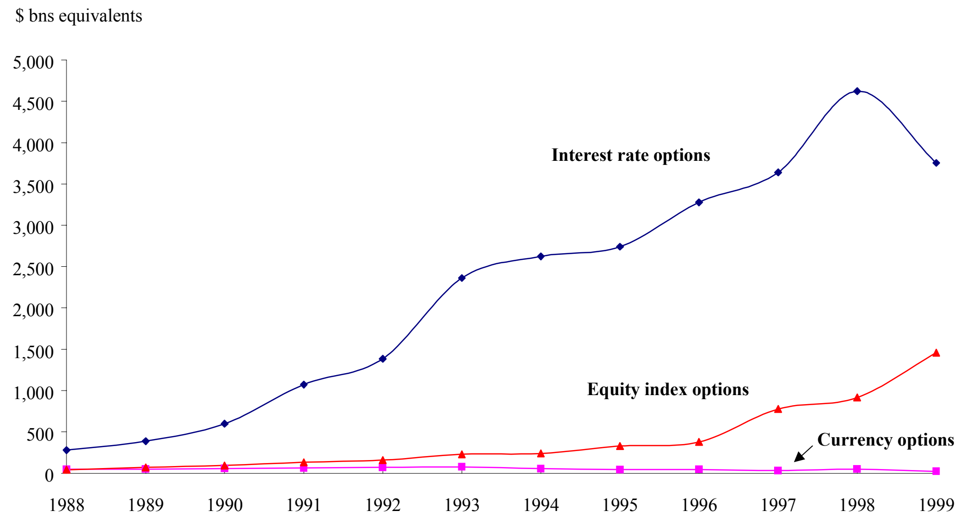
Figure 27 shows a comparison over time of notional amounts of interest rate options outstanding for the OTC markets as reported by ISDA members, and for exchange traded contracts world-wide. Also shown, for comparison, are the result for notional amounts outstanding of interest rate options at year ends from the global OTC derivatives market survey conducted by the BIS.

Figure 27: Notional amounts outstanding of global interest rate options at year-end



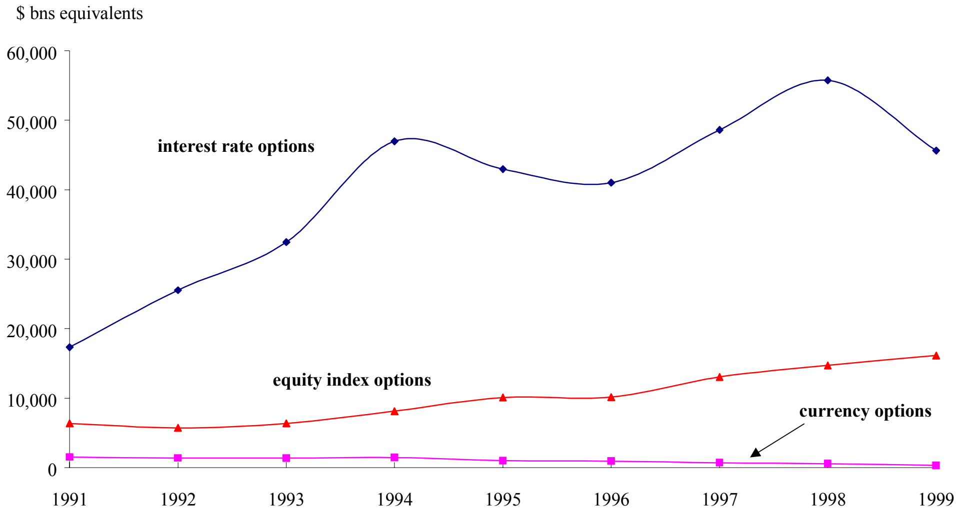
Source: FOW TRADEdata; Futures Industry Association; various futures and options exchanges;BIS [4,5,7], ISDA [13], IMF [34]

Figure 28: Notional amounts outstanding of global exchange-traded options markets



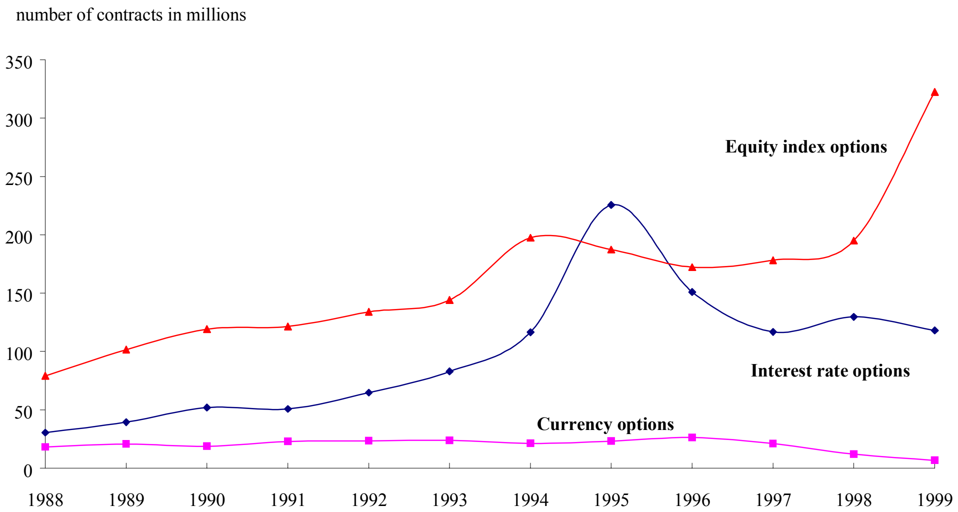
Source: FOW TRADEdata; Futures Industry Association; various futures and options exchanges; BIS [7]

Figure 29: Annual turnover of global exchange-traded options markets, notional principal values



Source: FOW TRADEdata; Futures Industry Association; various futures and options exchanges; BIS [7]

Figure 30: Annual turnover in options traded on organised exchanges worldwide, number of contracts



Source: FOW TRADEdata; Futures Industry Association; various futures and options exchanges; BIS [7]

3.3 Exchange-traded options

Interest rate options have by far the largest notional amounts outstanding of all exchange-traded options, with a value of $ 3.8 trillion in US dollar equivalents outstanding world-wide in December 1999 [7]. Equity index options had the second largest share, at $ 1.5 trillion, while currency options only totalled $ 22 billion. Notional amounts outstanding and annual turnover in notional values[12] of exchange-traded options are shown in Figures 28 and 29. NAO of exchange-traded interest rate options fell by 19% between end 1998 and end 1999. This is in contrast to NAO of OTC interest rate options, which grew by 17% between end 1998 and end 1999. Growth in the exchange-traded options market has shifted to equity index options, whose NAO grew strongly by almost 60%.

When looking at annual turnover measured in number of contracts traded, rather than notional values (see Figure 30), more contracts were traded in equity index options than in interest rate options in 1999, namely 323 million compared with 118 million. Lower turnover in terms of notional principal values, but higher turnover in terms of number of contracts traded, can be reconciled if exchange-traded equity index options have smaller notional principal values of the underlying contracts on average.

3.4 Applications of interest rate options

This section presents a summary of how interest rate options are used in practice, based on our discussions with market participants. Typical applications of options for risk management, speculation and yield enhancement are described in more detail in Section 2.7 above. *Option market makers see the main applications of OTC interest rate options as risk management, yield enhancement and speculation; gaining access to other markets and exploiting comparative advantage are not viewed as important considerations.*

3.4.1 Speculation

Market makers have said that there are very few opportunities for risk-free arbitrage trades in the OTC interest rate options market. Arbitrage trades typically link the more liquid benchmark swaption contracts with the less liquid swaption contracts, for example. Speculation using OTC interest rate options has declined in relative importance in recent years, partly reflecting past losses. The decrease in arbitrage activity was also said to be due to consolidation in the banking industry, which has left

[12] This is full-year annual turnover, and not average daily turnover, as reported in the BIS OTC derivatives market surveys.

fewer globally active banks. Over the past few years, the risk which intermediaries are prepared to take by putting on positions on the shape of the sterling yield curve was also said to have decreased since the yield curve has become more volatile and its movements have become less predictable.

Interest rate options with a shorter time to expiry, especially three months, are said to be used to a greater extent for speculation than longer-dated options. The exchange-traded short-term interest rate options market is generally felt to be more liquid than the OTC market, and is consequently used more for speculation. Short-dated exchange-traded options on money market interest rate futures, especially the front 3 to 4 contracts, are used to the greatest extent for speculation in sterling, euro and the dollar. They are used to speculate on volatility, as well as directional price movements. Strategies to speculate on payoffs at expiry include combination plays such as spread trades, which involve for example a long option position at one strike or maturity, combined with a short option position at a neighbouring strike or maturity. It was noted that such strategies are employed mainly in the exchange-traded market, but are rarely seen in the OTC market.

Among OTC contracts, short-dated swaptions are used to the greatest extent for speculation. In particular, ATM swaption straddles with 3 months' time to expiry are used to speculate on changes in the volatility of interest rates. Caps are used much less for speculation. This is partly since caps allow less flexibility in expressing views on interest rate expectations, since a cap is a strip of options, rather than a single option like a swaption. Also, caps are mainly entered into for longer periods and tend to have smaller gamma than swaptions.

Caps can be priced off exchange-traded short sterling contracts, and some traders try to arbitrage volatilities of options on short sterling futures against cap volatilties (more so in the past than now). But supply/demand arising from the use of caps for hedging is also often important in determining the volatilities of caps. At medium maturities, there is some arbitrage between cap and swaption volatilities by market makers. Price movements of medium-dated options depend on flows in the shorter- and longer-dated options markets; knowledge of customer flows is therefore also necessary to be successful in this market.

3.4.2 Risk management and yield enhancement

Market makers' customers, who use OTC interest rate options mainly for risk management, typically buy out-of-the-money options for this purpose. However, the liquidity of OTM options is generally poor in the interbank market; there is only a small amount of interbank trading in OTM swaptions, but there is somewhat more trading in OTM caps.

An integral part of the business of an active options dealer is therefore to underwrite the risk of ATM versus OTM option positions. Market makers mostly hedge their OTM options customer trades with near- or at-the-money options, due to the latter's greater liquidity.

The long-dated OTC interest rate options market is mainly used for risk management and yield enhancement, and is driven by customer flows; in the euro and dollar markets, these customer flows are mainly linked to structured products, such as callable bond issues (see Section 2.6.3 and 3.1.1). Structured products are also significant for the long-dated sterling swaptions market, but hedges for insurance companies' guaranteed annuities (which can also be a kind of structured product) were said to have been more important in sterling in 1999. Corporates sometimes sell sterling swaptions in order to lower their fixed-rate borrowing costs at long maturities.

Short-dated OTC interest rate options are used for hedging as well as speculation. Caps are mainly used for hedging, especially by corporates, who use them to hedge their floating-rate liabilities, and by mortgage banks, who use them to hedge their capped rate mortgages. Short-dated options, including swaptions, are also used by end-users for yield enhancement, and they are used by market makers to hedge the gamma exposure of interest rate option positions (see Section 6.1.3).

Options on short sterling futures of somewhat longer expiry, such as contracts expiring in one to two years' time, are used by banks to hedge their positions in caps and floors. For these contracts, hedging activity tends to be more significant than speculation. Consequently, at the longer maturities, the proprietary positions of market makers are based more on information derived from customer flows, rather than directly on expected future interest rate movements.

Market participants note that, in the UK, options are mainly used for liability management, rather than by investors for asset management. In both cases (i.e. liability and asset management), plain vanilla options are more frequently used than structured products. This is thought, by some, to reflect less sophisticated and more risk averse attitudes in the use of fixed income products among UK retails investors, than for example among their European counterparts. Also, UK retail investors use structured equity products more heavily than structured fixed income products for asset management. In the euro area, there is greater use of structured fixed income products for asset management, e.g. structured bonds. It was mentioned that corporates in the UK prefer to use the OTC interest rate options market to hedge, since the positions they want to hedge typically involve different dates from the fixed option expiry dates available for exchange-traded contracts, and are often of longer maturity *than could be matched in the exchange-traded market.*

Some market makers said that they mainly hedge their customer trades. In illiquid markets such as the sterling long-dated options market, it is unattractive to take speculative positions, since large bid-offer spreads make it hard to close out positions. One way to take a speculative position is not to hedge a customer trade. In illiquid markets with large bid-offer spreads, this is often a cheaper strategy than putting on new positions. Market makers' speculative longer-dated options positions are largely informed by knowledge of their own customer flows (see also Section 5.2).

4 Global OTC derivatives markets

4.1 Growth in interest rate derivatives markets

The OTC interest rate derivatives markets have grown substantially over the past few years.

4.1.1 ISDA market surveys

Data collected by the International Swaps and Derivatives Association in market surveys of its members suggest that notional amounts outstanding at year-end of interest rate options in all currencies more than tripled from $1.6 trillion (tn) in 1994 to $4.9 tn in 1997 (in US dollar equivalents), see Table 4. Over the same period, notional amounts outstanding of interest rate swaps grew by a factor of 2.5 to $22.3 trillion. The options data include caps, floors, swaptions, collars, participations, options on caps/floors, but exclude embedded options and other structured products. Annual turnover in notional values in OTC interest rate options reported by ISDA members grew by a factor of 2.6 between 1994 and 1997, to $4.0 trillion (in US dollar equivalents). Over the same period, annual turnover in interest rate swaps grew even faster; it almost tripled to $17.1 trillion.

Table 4: Notional amounts outstanding and full-year annual turnover [a] of OTC interest rate derivatives.

$ trillion equivalents	1994	1995	1996	1997
NAO				
Swaps	8.8	12.8	19.3	22.3
Options	1.6	3.7	4.7	4.9
Annual turnover				
Swaps	6.2	8.7	13.7	17.1
Options	1.5	2.0	3.3	4.0

Source: ISDA market surveys [13]

[a]Reported is full-year annual turnover, and not average daily turnover as reported for the BIS OTC derivatives surveys. A comparison of data from the ISDA and BIS surveys is presented below.

Amounts outstanding and annual turnover of interest rate options are separately reported for dollars, but not for other currencies. Dollar contracts made up around half of the notional amounts outstanding and turnover; their share decreased somewhat between 1994 and 1997. For turnover, the share of US dollar-denominated contracts is larger than information derived from the BIS survey of 1998 (see Figures 17 and 19). This difference may be due to the different samples, methods of reporting, and the different dates of the two surveys.

Some of the growth in turnover and amounts outstanding found by the ISDA market survey is probably due to an increase in the number of reporting members. In 1995, the survey included 71 members, and in 1997 it included 83. ISDA members reported on a voluntary basis, and the houses reporting changed from year to year. Hence a growing number of reporters may, but does not necessarily, mean that the survey has captured a larger market share. Turnover and amounts outstanding between two reporting ISDA members are halved to adjust for double-counting.

4.1.2 BIS triennial surveys

As discussed in Section 2.8, turnover data of the 1995 and 1998 triennial surveys were reported on a locational basis in both years, but the number of reporting institutions was larger in 1998. We can compare turnover of FRAs, interest rate swaps and interest rate options in the two years. Average daily turnover[13] in interest rate options in all currencies almost doubled, from $21 bn in April 95 to $36 bn in April 98 (see Table 5). Average daily turnover in interest rate swaps more than doubled, to $155 bn. By contrast, average daily turnover in FRAs grew only slightly. The

[13]Adjusted for both local and cross-border inter-dealer double counting.

average daily turnover for all interest rate derivatives in April 1998 was \$265 bn. The BIS estimated that due to the change in sample size, the growth in turnover between 1995 and 1998 is distorted by about 2%. Growth in average daily turnover of OTC interest rate derivatives and options from April 1995 to April 1998 was larger than the growth of turnover of exchange-traded interest rate futures and options from 1995 to 1998.

The reporting of amounts outstanding changed from a locational to a world-wide consolidated basis between 1995 and 1998, and the sample size and participating countries increased, the latter from 26 to 43. Also, amounts outstanding are reported at the end of different months in the two years. Therefore, there are some difficulties in cleanly interpreting the apparent market growth in amounts outstanding between the two survey dates. At end-June 1998, notional amounts outstanding in all currencies stood at \$48.1 trillion in the global OTC interest rate derivatives markets (see Table 5); this is much larger than their outstandings in gross market values of \$1.4 trillion. The large difference between outstandings in notional amounts and gross market values mainly reflects the fact that NAO overstate the size of gross flows exchanged in interest rate derivatives contracts between counterparties (see Section 2.8).

Table 5: Growth in global derivatives and debt markets[14]

$ bn equivalents	NAO		GMV		Ave. daily turnover	
OTC	Mar 95	June 98	Mar 95	June 98	Apr 95	Apr 98
Interest rate derivatives	26,645	48,124 (81%)[15]	647	1,354	151	265 (75%)
FRAs	4,597	6,602 (44%)	18	39	66	74 (12%)
Interest rate swaps	18,283	32,942 (80%)	562	1,186	63	155 (146%)
Interest rate options	3,548	8,528 (140%)	60	126	21	36 (71%)
FX options	2,379	5,040 (112%)	71	141	41	87 (112%)
Equity-linked options	527	1,161 (120%)	43	180	-	-
	NAO				Ave. daily turnover[16]	
Exchange traded	End 95	End 98			1995	1998
Interest rate derivatives[17]	8,605	12,305 (43%)			1,234	1,396 (13%)
Interest rate options	2,742	4,603 (68%)			173	221 (28%)
Debt securities						
Domestic[18]	24,110	28,982 (20%)				
International[19]	2,803	4,294 (53%)				

[14]Source: FOW TRADEdata; Futures Industry Association; various futures and options exchanges, BIS [4, 5, 7]

[15]Percentage increases between 1995 and 1998 are given in brackets. For notional amounts outstanding, these are given as an indication only, due to the change in reporting basis between the two surveys.

[16]Converted from full-year annual turnover, assuming 251 business days in each year.

[17]Includes futures and options.

[18]Domestic currency debt securities issued by residents in their own national market, whether purchased by residents or non-residents. Included are bonds, medium-term notes, commercial paper, treasury bills, and other short-term notes.

[19]International bonds, Euro-notes and Euro-commercial paper are included here. International bonds include Euro-bonds (foreign currency issues by residents and non-residents in a given country) and foreign bonds (domestic currency issues by non-residents).

Due to the change to world-wide consolidated reporting for notional amounts outstanding, the growth in NAO of OTC derivatives is less than it would have been if the data had been collected on a locational basis in 1998, other things being equal, because cross-border trades between different offices of the same company are netted out in consolidated reporting, but not in locational reporting. In terms of notional amounts outstanding, growth in the global OTC interest rate derivatives and options markets was larger than the growth in the exchange-traded interest rate derivatives and options markets, and than growth in domestic and international debt securities. Gross market values of OTC equity-linked options grew significantly between 1995 and 1998. This may partly be due to higher volatility of equities in 1998.

Comparison between the different surveys We can compare the ISDA and BIS triennial surveys in 1995, a year in which they overlap. Notional amounts outstanding of interest rate options were similar, $3.7 tn at year end for the ISDA survey, and $3.5 tn at end-March 1995 for the BIS survey (see Figure 27). We can also compare the triennial and semi-annual surveys for amounts outstanding of interest rate options at end-June 1998: they were $8.5 tn for the triennial, and $7.9 tn for the semi-annual survey, and so quite similar.

However, the turnover estimates are very different. ISDA reports annual turnover, while the BIS reports average daily turnover in April 1995. From the ISDA annual turnover for interest rate options of $2 tn in 1995, we can calculate an average daily turnover of $7.8 bn (assuming 251 working days). This is 2.7 times smaller than the average daily turnover of $21 bn reported by the BIS. The time period is different in the two cases (the whole year versus April), and there may have been significant exchange rate movements, which would affect conversions to dollar equivalents. A discrepancy in the data of the two surveys is also expected to arise from the different samples of institutions surveyed, and other differences in survey methodology.

For interest rate swaps, the two surveys compared as follows in 1995: $12.8 tn (ISDA, end-December) versus $18.3 tn (BIS, end-March) for notional amounts outstanding; and for average daily turnover $34.1 bn (ISDA, converted from annual turnover) versus $63 bn (BIS, April).

4.1.3 Possible reasons for the growth of the OTC derivatives markets

The strong growth in the OTC derivatives markets may have been due to the following reasons. Deregulation has favoured the use of derivatives [30]. In the UK, regulatory, legal and tax restrictions on the use of derivatives have been eased, especially for institutional investors, for example in the Finance Act of 1990. Fund managers have increased their use of derivatives, including options, for risk management purposes and yield enhancement, as portfolios have become more internationalised, and as quantitative techniques to value complex structured products, make investment decisions and calculate risk exposure have been developed [30].

The growth of international capital markets and disintermediation of the banking sector by international corporates has led to greater use of 'structured finance', which generally involves the use of derivatives [30]. Also, issuers have taken advantage of credit arbitrage, for example by issuing fixed-rate debt, if they have a comparative advantage in that market, and obtaining their desired floating-rate funding by entering into an interest rate swap. This can provide them with cheaper funding than directly issuing floating-rate debt. This has led to demand for interest rate swaps, which constitute a large part of the OTC interest rate derivatives market.

There has also been a trend towards investor-driven debt issues, where a bank structures payoffs of a medium-term-note according to the specific requirements of investors, finds an issuer to issue the underlying security, and enters into a derivatives transaction with the issuer (see Section 2.6.3). Since OTC derivatives can have long maturities and can be tailor-made, they are better suited for these transactions than exchange-traded ones.

If derivatives are treated as off-balance-sheet transactions, which traditionally they have been, they are attractive to use when capital requirements apply disproportionately heavily to on-balance sheet risks, especially when capital is scarce. The introduction of capital adequacy guidelines in 1988 may have increased the awareness of the scarcity of capital[20].

[20] At present, generally accepted accounting rules in the UK stipulate that derivatives used for trading purposes should be marked-to-market, while derivatives used for hedging purposes should follow the accounting treatment of the underlying instrument, which can be either marked-to-market or accounted for on accruals. In mark-to-market accounting, changes in market value – the present discounted value of future cash flows – are reported at the time when they occur. In accrual accounting, the value shown is the value the contract was bought at, and income recognition is spread over the period of the contract. In the example of an interest rate swap, income would be recorded as if it were a loan and a matching deposit, by accruing interest on each leg on a straight line basis over the relevant accounting period, at the rates applying to the swap during that period.

4.2 Composition of OTC derivatives markets

In terms of notional amounts outstanding, interest rate derivatives are the largest segment of the global OTC derivatives market, with a share of more than 75% at end 1999, followed by foreign exchange derivatives with a share of about 20%. Equity-linked and commodity derivatives have relatively minor shares of 2% and 1%, respectively (see Figure 2). In terms of gross market values, equity-linked derivatives had a more significant share of 15%, and interest rate derivatives were not as dominant, with a share of 55% (see Figure 5).

Table 6: Amounts outstanding of OTC derivatives by nature of underlying contract (end 1999)

$bn equivalents	Notional amounts	Gross market values
Foreign exchange	14,344	662
interest rates	60,091	1,304
equities	1,809	359
commodities	548	59

Source: BIS [4]

By contrast, average daily turnover in foreign exchange derivatives was about 3.5 times larger than that of interest rate derivatives in April 1998. Largely, this reflects the shorter maturities of foreign exchange derivatives contracts (see Section 3.1.3). Figure 4 shows average daily turnover for interest rate and FX derivatives (and options separately). Turnover data was not collected for equity-linked and commodity derivatives.

4.2.1 Relative importance of OTC options by nature of underlying contracts

The relevant data for amounts outstanding in notional amounts and gross market values of OTC options are given in Table 7.

Table 7: Amounts outstanding of OTC options (end 1999)

$bn equivalents	Notional amounts	Gross market values
FX options	2,307	60
interest rate options	9,380	141
equity options	1,527	288
commodity options (excl. gold)	143	n/a

Source: BIS [4]

OTC options, and OTC derivatives, have quite similar shares by underlying contracts of notional amounts outstanding. The main difference is that equity-linked contracts have a larger share for options (see Figure 3). Average daily turnover in April 1998 in foreign exchange options was larger than that of interest rate options, as in the case of all kinds of derivatives, but by a smaller factor (see Figure 4).

Equity-linked options accounted for almost 60% of gross market values of OTC options (excluding commodity options); this is a much larger share than for all kinds of derivatives (see Figure 6). Equity-linked options accounted for a very large share - 84% - of the total notional amounts of equity-linked derivatives outstanding at end-1999 (see Tables 6 & 7). This is much more than for interest rate derivatives and foreign exchange derivatives, where options accounted for only 16% of the respective totals.

4.2.2 Relative importance of OTC interest rate derivatives by instrument

More detailed breakdowns of notional amounts outstanding and turnover of OTC interest rate derivatives by instrument, for various currencies, are shown in Tables 8 and 9.

Table 8: NAO of OTC interest rate derivatives, end 1999 ($bn equivalents) [a]

	all currencies	$	Euro	Yen	£	Other
options	9,380	4,340	3,000	1,186	548	305
swaps	43,936	10,712	15,358	10,460	3,538	3,868
FRAs	6,775	1,458	2,334	744	502	1,737

Shares of instruments	all currencies	$	Euro	Yen	£	Other
options	16%	26%	14%	10%	12%	5%
swaps	73%	65%	74%	84%	77%	65%
FRAs	11%	9%	11%	6%	11%	29%

Source: BIS [4]

[a] The shares in each column sum to 100% (sometimes not exactly due to rounding).

Table 9: Average daily turnover of OTC interest rate derivatives, April 1998 ($ bn dollar equivalents) [a]

	all currencies	$	DM	Yen	£	FF	Other
options	36.4	12.2	7.1	9.7	1.4	1.2	4.7
swaps	154	35.8	46.6	14.1	7.7	21.6	28.8
FRAs	74.4	22.8	9.2	3.5	7.6	1.7	29.7
Shares of instruments	all currencies	$	DM	Yen	£	FF	Other
options	14%	17%	11%	36%	8%	5%	7%
swaps	58%	51%	74%	52%	46%	88%	45%
FRAs	28%	32%	15%	13%	46%	7%	47%

Source: BIS [5]

[a] The shares in each column sum to 100% (sometimes not exactly due to rounding).

For sterling OTC interest rate derivatives outstanding, the shares of the different types of instruments were quite close to the average for all currencies. In terms of average daily turnover in April 1998, however, the share of FRAs among interest rate derivatives turnover for sterling was 46%, much larger than the share of 28% for all currencies taken together. For currencies other than the major currencies, the share of FRAs of turnover was also very large at almost 50%. In sterling, the share of swaps was equal to that of FRAs, and 12 percentage points smaller than the average for swaps for all currencies. The share of options for sterling was also smaller at 8% compared with the average for all currencies of 14%. The relatively large share in turnover of FRAs among sterling interest rate derivatives of 46% compared with 15% for amounts outstanding may indicate that FRAs are traded at shorter maturities on average, or that they are held to maturity to a lesser extent, in sterling than in other currencies. Or, it might indicate that the short end of the sterling yield curve is traded more intensively relative to the longer end, and that FRAs, which have a shorter maturity on average than swaps, are a suitable vehicle for that.

5 Option pricing models and implied interest rate expectations

5.1 Use of option pricing models

This section discusses the kinds of option pricing models used by market participants, the factors that influence market makers' speculative trading decisions, and the suitability of interest rate options for extracting information about the market's future interest rate expectations. Some of the concepts used in this section are discussed in the appendix: Option pricing models, implied volatilities and the volatility smile and skew are discussed in more detail in Section A.1, and implied probability distributions in Section A.2.

For pricing plain vanilla interest rate options, market participants generally use option pricing models including the Black model, modifications of the Black model, which allow for a volatility smile and skew, one- and multi-factor term structure models, and binomial or trinomial tree models. The Black model is said to be the market standard for quoting option prices between market participants. In addition to the option pricing models approved for trading and risk management, option traders may look at other models, in order to gain additional insights.

Option market makers note that all option pricing models have imperfections, particularly for OTM options. The main problem with the Black model is the existence of the volatility smile and skew, which is not allowed for in the model. It was noted that when option positions are marked-to-market, and the unwinding of positions and their regular dynamic hedging or static hedging have to be considered, a limited number of models are suitable, namely no-arbitrage models. When option positions are accounted for on accruals, and not hedged, many different kinds of models, which do not need to be risk-neutral, can be used.

Some market makers prefer to use simpler option pricing models, with few unobservable parameters, since they are more intuitive to understand, and their deficiences are better understood. More complicated models may be more accurate, but they are usually less tractable and more difficult to calibrate to market prices of options; moreover, their behaviour can be more difficult to understand, especially when market conditions change. An important part of the business of trading options is the development of proprietary methods of implementing (for example by development of a numerical code, such as a Monte Carlo simulation) and calibrating option pricing models, for different segments of the options markets, and the development of proprietary methods of analysing (normalised) implied volatilities within the Black model. The choice of *option pricing model also involves a tradeoff between speed and accuracy.*

The development of proprietary option pricing models is particularly important for exotic options. Traders tend to use several different option pricing models to price exotic options, in order to provide additional insights; to obtain a range of possible prices for the illiquid exotic products, for which often no reliable outside price quotes are available; to cross-check prices against each other and explore the flaws of various models; and to find out information about which models competitors may be using. For pricing Bermudan swaptions, the Black-Derman-Toy model [35], and the Brace-Gatarek-Musiela model [36] were mentioned as becoming the market standard, partly since they are rather intuitive to interpret.

5.2 Factors influencing market makers' speculative trading decisions

Market makers' speculative trading decisions for OTC interest rate options are typically influenced by factors including the following:

- *The relative value of implied volatilities and normalised implied volatilities between different interest rate option contracts. For example for plain vanilla swaptions of different times to expiry and tenors of the underlying swap rates.*
- *The relative values of implied versus historical volatilities for different OTC interest rate option contracts.*
- *Knowledge of their customers' demand for and supply of options, especially for longer-dated OTC interest rate option contracts.*
- *Technical chart-based analysis (see eg [37]).*
- *Macroeconomic analysis, including the outlook for expected future interest rates and implied volatilities, and inflation expectations, and implications for future customer demand for options.*
- *Hedging costs of option positions.*
- *Identification of incorrectly priced exotic option contracts, using proprietary option pricing models, and arbitrage against plain vanilla options.*

Some market makers said that they take positions on the volatility smile and skew (see Section A.1.3).

5.3 Inferring the market's interest rate expectations from sterling interest rate options

Option prices can be used to infer ATM implied volatilities, implied probability distributions, and the volatility smile and skew (see for example references [2, 37, 38], Sections A.1 and A.2).

However, market makers highlight that great care has to be taken in interpreting ATM and OTM implied volatilities, and implied probability distributions, as reflecting the market's interest rate expectations, since they are also affected by other factors. These factors are said to often dominate the influence of interest rate expectations, in which case option contracts are unlikely to accurately reflect the markets' future interest rate expectations. Such factors include imbalances between demand and supply caused by strong customer demand for option contracts for hedging, or strong customer supply of option contracts for yield enhancement. Which products are popular varies over time, depending in part on the shape of the yield curve and the position in the interest rate cycle. These factors tend to have a particularly strong effect on prices of more illiquid option contracts, and consequently on the implied volatilities, implied probability distributions, and volatility smile and skew derived from them. In particular, prices of longer-dated OTC options are affected to a much greater extent by customer flows related to hedging and yield enhancement, rather than by pure expectations about future interest rates.

There are said to be dislocations in the OTC interest rate options market between short- and long-dated options. The former are used to a greater extent for speculation, while the longer-dated options market is mainly driven by customer flows. Practitioners also report that regulatory restrictions, such as the minimum funding requirement in the UK, or changes in accounting standards, for example from accrual accounting to marking-to-market, can affect the supply of and demand for OTC interest rate options, and thus their prices.

Customer flows are generally thought to be mainly driven by factors other than pure expectations about future interest rates, but interest rate expectations are thought to influence them in part. Such expectations are likely, for example, to influence customers' decisions as to which particular risk exposures to hedge and which to leave unhedged, and which kinds of interest rate contracts, including options, to choose as hedges.

Some limitations of interpreting the information extracted from option prices are discussed in reference [39][21].

[21] One caveat mentioned there is the impossibility to distinguish between the contribution to the implied probabilities (derived from options prices on the assumption

5.3.1 Relative usefulness of different option contracts

Short-dated interest rate options are thought to reflect the markets' interest rate expectations better than long-dated options, since they are more liquid, and are more used for speculation. Short-dated options also match speculators' time horizons more closely. Among short-dated options, exchange-traded contracts are thought to reflect the market's interest rate expectations better than OTC contracts, again because they are more liquid and used to a greater extent for speculation, and also since exchange-traded marketst are more transparent than OTC markets, enabling better price discovery.

Among the short-dated interest rate options traded on LIFFE, the front four exchange-traded option contracts on short sterling futures are thought to reflect the market's interest rate expectations better than longer-dated ones, and much better than options on the long gilt future. Among short-dated OTC interest rate options, market participants feel that 3-month options on 2-, 5- and 10-year swaps reflect the markets' future interest rate expectations better than other swaption contracts, caps, or OTC gilt options.

OTC and exchange-traded gilt options are thought not to provide an accurate reflection of the market's interest rate expectations, since these markets are now very illiquid. Long-dated swaptions are also unlikely to provide an accurate reflection of the markets' interest rate expectations, since their prices are mainly affected by customer flows unrelated to speculation, and since contracts are quite illiquid. Moreover, it was mentioned that it is very difficult to arbitrage long-dated swaptions by delta hedging. Similarly, exotic options are thought not to give an accurate reflection of the markets' interest rate expectations, again since the exotics market is very illiquid, and not used much for speculation.

5.3.2 Implied volatilities

Some market makers feel that implied volatilities are an indicator of fear in the market about where interest rates might be in future, rather than just reflecting risk-neutral uncertainty about future expected interest rates.

Option contracts which are used by customers mainly for hedging, rather than speculation, such as caps, can have prices and implied volatilities which are larger than their fair values based solely on future interest rate expectations. Customers are prepared to pay a premium for obtain-

of risk-neutral pricing) of the statistical probabilities of an event actually occurring, and the contribution from the different relative marginal utilities of different outcomes for market participants; the latter may be affected in part by risk-appetite asymmetries.

ing insurance by holding these options, and market makers demand a premium for providing such insurance. For example, in autumn 1998, a lot of sterling caps were sold to mortgage banks, who used them to hedge their capped-rate mortgages, for which there was strong customer demand, at a time when official interest rates were expected to rise. This strong demand for caps led to an increase in cap volatilities to levels which did not accurately reflect market uncertainty about future interest rates.

Option contracts which are used by customers mainly for yield enhancement, rather than speculation, can have prices and implied volatilities which are smaller than their fair values based solely on future interest rate expectations, since customers are keen to sell these options in order to obtain the option premium. For example, long-dated swaptions in euro are often sold for yield enhancement purposes (usually as part of structured products); this tends to decrease their volatilities below their fair values.

5.3.3 Implied probability distributions, volatility smile & skew

Implied probability distributions are derived from ATM and OTM option prices, based on the assumption of risk-neutral pricing. *However, the prices of OTM interest rate options are generally thought to differ from their fair value based solely on interest rate expectations.Therefore, implied probability distributions are thought unlikely to provide an accurate indication of the market's interest rate expectations.*

The following factors were mentioned as affecting the prices of OTM options, and contributing to the volatility smile (see Section A.1.3). In the interbank market, OTM option contracts are generally much less liquid than ATM options, but there is strong customer demand for OTM options for hedging purposes. Deep OTM interest rate options are more expensive due to their illiquidity, and most speculators are said to consider them too expensive. Market makers hedge their OTM option customer trades with ATM options in the interbank market, since these are more liquid, leaving them with strike risk. Also, OTM option positions are more costly and difficult to unwind than ATM options, due to their greater illiquidity and larger bid-offer spreads. And, OTM options positions carry more model risk for market makers (see also Section 6.4), since the behaviour of the volatility smile and skew are not well understood.

It was also mentioned that for small option premia, as for deep OTM options (or very short-dated options), a small change in option premium can lead to a large change in implied volatility. This implies that as OTM option premia change slightly due to changes in demand/supply *which are not directly related to changes in expected future interest rates, the volatility smile and skew can change quite a lot; and small liquidity premia contained in option premia can look larger in terms of implied volatilities. Moreover, implied probability densities extracted from exchange-traded option prices are thought to be problematic to use, partly since OTM contracts are not very liquid, and if they have not been recently traded, the close-of-business prices assigned by the exchange may not be representative.*

Some market makers feel that some of the changes in the volatility smile and skew of short-dated options (including options on short sterling futures and caps) are due to expected future interest rate movements. Changes in the shape of the volatility smile and skews of short-dated options (over longer periods, rather than daily) may therefore provide information about changes in the market's interest rate expectations. However, they are not necessarily an indicator of the central expectations of future interest rates. Rather, they may give an indication of perceived risks to the interest rate outlook. Other market makers think that the volatility smile and skew of short-dated interest rate options are largely driven by flows, for example due to hedging activity, and that these flows are not strongly related to interest rate expectations. They also feel that the cap and swaptions markets do not allow an extraction of meaningful risk reversals (see Section A.2).

There is no market for risk reversals for interest rate options, in contrast to foreign exchange options. The volatility skew is better understood and more actively traded in the FX options market than in the interest rate options market. This was said to be largely because the FX options market is more developed and liquid than the interest rate options market, and partly because it involves less complex dynamics.

6 Risk management of options positions

6.1 Hedging

The risk management of options positions may establish an interrelationship between the options markets and the markets of the underlying assets, as well as with other options and derivatives markets. On the one hand, these interrelationships may make markets more efficient by establishing arbitrage links between different but similar markets. On the other hand, however, these interrelationships may have some unfavourable consequences. For instance, in illiquid markets, the hedging of options positions may for example increase the price volatility of the markets of the underlying assets.

6.1.1 Delta hedging of options

An option can be hedged initially against directional price movements of the underlying asset, by buying or selling an appropriate fraction (called delta) of the underlying contracts. But other types of assets, including derivatives, can also be used, if they have risk characteristics that are similar to the original underlying asset. For example, gilts as well as swaps and corporate bonds may be used to hedge options on swaps.

This process is called delta-hedging. *Delta* is the rate at which an option's value changes as the price of the underlying contract changes. As the price of the underlying contract increases by some amount, the value of a call option increases by delta times that amount. Delta is therefore the fraction of underlying contracts the seller of a call option has to buy for each short option position held, in order to hedge exposure from directional price movements in the underlying contract from that position. Delta ranges from zero to 1.

A deep in-the-money (ITM) call option is very likely to be exercised by the buyer, since there is only a small probability that the price S of the underlying contract will move above the strike price at expiration of the option. The seller of the option will therefore almost certainly have to deliver the underlying contract at expiration. The seller therefore hedges by buying almost as many underlying contracts as call options sold, i.e. delta is close to 1. The return profile of this short option position is almost identical to a short position in the underlying contract, which can be hedged by going long the underlying contract.

A call option which is deep out-of-the-money, i.e where the strike price is much larger than the price S of the underlying contract, is extremely unlikely to be exercised in future since it is very unlikely that S will move above the strike price at expiration, and only then would exercise be profitable. The seller of this call option therefore has almost no exposure to changes in the price of the underlying contract, delta is close to zero, and the trader needs to buy only a tiny fraction of underlying contracts to hedge each call option.

A call option which is at-the-money has a 50% chance of being exercised at expiry, since the price of the underlying contract is as likely to move up as down, and its delta is close to 0.5. Hence, delta is approximately equal to the probability that the call option will finish in-the-money at expiration. As the price of the underlying contract changes, this probability and delta change, requiring traders to re-hedge their option positions by buying or selling more underlying contracts.

6.1.2 Rebalancing the delta-hedge

As the price S of the underlying contract increases, a call option moves deeper into-the-money and becomes more likely to be exercised, and its delta increases. The sellers of the options therefore have to buy additional underlying contracts if they want to hedge their exposure to movements in the price of the underlying contract. If the price of the underlying contract decreases, the sellers have to sell some underlying contracts to re-establish the delta-hedge. This process is called rebalancing the delta hedge. For short call option positions, the seller of the option is forced to 'buy high and sell low', and consequently makes a loss from rehedging. This rehedging process may increase the price volatility of the underlying asset, especially if the size of the option position is significant compared with the size of the underlying market, and assuming that the holders of the options do not do any delta hedging of their own. This also applies to short put option positions. It is assumed that, in this example, the buyer of the option does not wish to hedge, perhaps because the option itself has been bought as a hedge against pre-existing risk exposure.

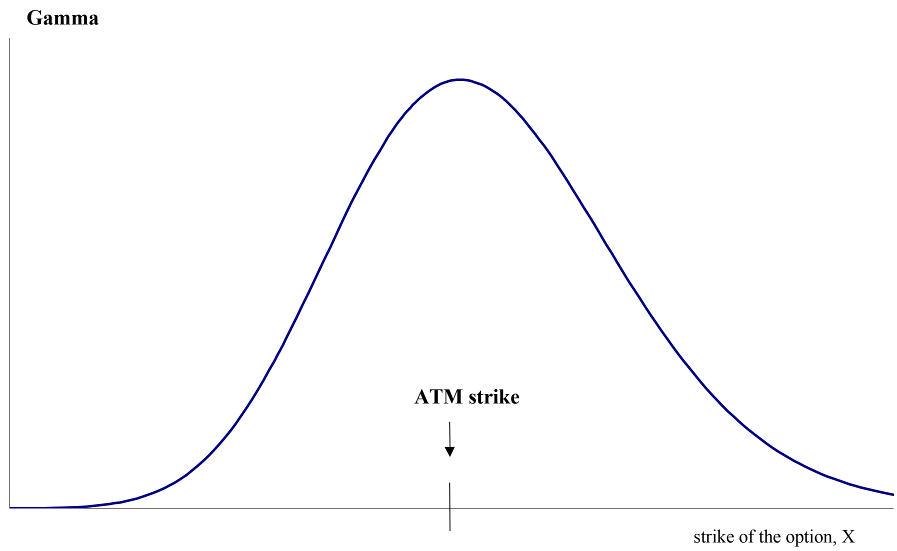
The rate at which delta changes when the price of the underlying contract changes is called *gamma*. As the price of the underlying contract changes by a certain amount, delta changes by gamma times that amount. Gamma is largest for options which are at-the-money, and decreases steadily to zero for options which are very deep in-the-money (where delta is close to 1 and approximately constant) or out-of-the-money (where delta is close to zero and approximately constant). This is shown in Figure 31. Therefore, for rehedging purposes, the largest number of contracts (for a given movement in price of the underlying asset) has to be bought or sold for ATM options; fewer contracts have to be bought or sold for options which are deep ITM or OTM. This is one illustration of the fact that options exhibit option-specific characteristics most strongly when they are ATM. Very deep ITM options are very similar to an outright position, and very deep OTM options are very similar to no position at all.

By analogous arguments, the buyer of either a call or a put option, can rebalance the delta hedge by 'buying low and selling high'. Here the process of rehedging is profitable, and it may reduce the price volatility of the underlying asset, assuming no delta hedging by the seller of the option.

6.1.3 Gamma hedging of options

Option traders can also try to make their option portfolios gamma-neutral (i.e. achieve gamma close to zero); this process is called gamma

Figure 31: Gamma of a long call or put option position



hedging. This can only be achieved by using options with a gamma of opposite sign to the gamma of the original position, since outright contracts have zero gamma. This reduces the risk exposure of an options portfolio, and reduces transaction costs, which arise from rehedging the delta using the underlying contracts. Gamma is typically positive for long option positions, and negative for short option positions. The process of gamma hedging may therefore establish an interrelationship between different kinds of interest rate options. In order to make option positions gamma-neutral, a trader may have to buy options with different times to expiry, or options with similar characteristics in a different market segment. If liquidity in that other options market is low, and if the trader's option position is large, the demand due to having to rebalance the gamma-hedge may influence the price of options in the other market segment.

Vega is the sensitivity of an option's value to changes in the implied volatility of the option. It is typically positive for long option positions, and negative for short option positions. Option positions can also be hedged against vega risk.

6.1.4 Hedging of exotic options

Exotic options can be hedged 'statically' by using a portfolio of plain vanilla options, as well as dynamically by buying and selling appropriate amounts of the underlying contracts (see for example [40]). Static hedges may lead to an interrelationship between exotic and plain vanilla options markets. *Market makers generally try to hedge exotic option positions (arising from customer deals) using plain vanilla interest rate options, which can be of different times to expiry than the exotic options. In this way, gamma and vega risk exposure are passed from the very illiquid exotic options book to the more liquid plain vanilla options book. Static hedges involving plain vanilla options are typically preferred to dynamic hedging, particularly in illiquid markets, since they avoid transaction costs from rehedging. Remaining risk exposure, which cannot be hedged in this way, are kept on the exotic options book by holding the contract to maturity. For example, such risk exposure can arise from the sensitivity of the price of a spread option to the correlation between two interest rate contracts of different maturities, or from the sensitivity of the price of a quanto option to the correlation between an interest rate and an exchange rate. It was mentioned that exotic options prices are driven by the prices of plain vanilla options, and that prices of plain vanilla options can be distorted by demand arising from exotic option hedges.*

6.2 Hedging and the role of liquidity

In options theory, which is commonly used to calculate the prices of options, rehedging is assumed to be possible continuously without incurring transaction costs. In practice, however, lack of liquidity in the market of the underlying asset may make rehedging very expensive. As the liquidity of the underlying contracts decreases, their bid-offer spreads widen, and it becomes more costly to dynamically hedge an option position by buying and selling underlying contracts. Also, when rehedging a short option position, whose size is large compared with the size of the underlying market, the price of the underlying asset may move against the trader if the underlying market is rather illiquid[22].

If the underlying asset is illiquid, the greater cost and difficulty of hedging an option position will make the option position more costly and more risky, and therefore provide a disincentive for entering into option contracts. In this way, lack of liquidity in the market of the underlying asset can lead to lack of liquidity in the market for options on that asset.

Market makers tend to confirm that the liquidity of the market of the underlying contracts has an important effect on the liquidity of the related options market. A frequently cited example of this link is the great reduction in the liquidity and size of both the exchange-traded and OTC

[22]A model which shows how delta hedging can influence and move the market in the underlying contract, is presented in a chapter on 'The feedback effect of hedging in illiquid markets' in reference [37].

gilt options markets. Market participants largely attribute this development to a reduction in the liquidity of the gilt market. Other factors, such as a move to screen-based trading of exchange-traded gilt options, were also mentioned as having contributed to the decrease in liquidity of the gilt options market. The sterling swaptions market was said to have filled some of the void created by the reduction in size of the gilt options market.

There is less agreement, however, about causal linkages from options markets to the underlying asset markets. Some market participants feel that activity in the options markets has little, if any, impact on activity in the market of the underlying asset, while other market participants believe that options markets also have an effect on the underlying market, both on activity and price volatility, partly due to the linkages generated by hedging activity. It was said that, depending on the circumstances, liquidity in the options market could either enhance or adversely affect liquidity in the underlying market. Provided liquidity in the underlying market is already large, and price movements are not too big, option positions could add to that liquidity due to the use of the underlying market for rehedging. But if there are big price realignments, or if option positions are large in relation to the size of the underlying market, liquidity in the underlying market could be adversely affected, due to demand from rehedging which could be very much one-way. It was mentioned that the effect of options on the price volatility of the underlying market is generally larger for foreign exchange options than for interest rate options.

As an example, activity in the long-dated sterling swaptions market was thought by some to have affected the long-dated sterling swaps market and to have increased the price volatility of the gilt market in 1999, when swaptions were sold by investment banks to insurance companies, as a hedge for insurance companies' guaranteed annuity products.

6.3 Market risk exposure of options and value-at-risk models

Value-at-risk (VaR) models, which are commonly used to measure market risk of underlying contracts, can also be used to estimate the market risk exposure of derivatives, including of options. There are various different VaR models, which differ mainly in choices made about the following two issues [33, 41, 42]:

- How to model potential price movements of the underlying contracts. Possibilities include assuming a joint normal distribution, and estimating the covariance matrix from historical data; using a historical run of data over a chosen time period, which does not make an explicit assumption about the distribution of price changes ('historical simulation'); simulating many different paths of price changes, using a certain stochastic process, such as a random walk, or using an estimated covariance matrix to generate paths of price changes ('Monte Carlo simulation'); or choosing certain series of price changes, for example drawn from a financial crisis in the past, or from hypothetical worst-case scenarios ('scenario analysis').

- How to model the price change of the option, given price changes in the underlying contract, since the former is a nonlinear function of the latter. Possibilities include making a local linear approximation, which involves the local risk sensitivity parameter delta (a 'delta approximation'); making a local approximation using a Taylor series expansion to second order, which involves the risk sensitivities delta and gamma (a 'delta-gamma approximation'), using a Taylor series expansion including the risk sensitivities delta, gamma and vega; or revaluing the option using the full option pricing formula at the new price of the underlying contract (a 'full valuation model'), and not relying on a local approximation involving risk sensitivity parameters. The choice can also be made to use a model combining features of full valuation and local linear approximations for valuing an options portfolio (a 'partial valuation model'). The Taylor series expansion of an option's value, involving the risk sensitivities delta, gamma and vega, is discussed in Section A.3 below.

The choice of which VaR model to use involves a tradeoff between speed and accuracy. Different market makers use a variety of different VaR models, including models based on delta approximations and on full valuation. Individual market makers also use different approaches, for example looking at both historical simulations and scenario analysis.

Market makers use their VaR models to measure market risk exposure and to set risk limits at different levels of aggregation, including at the levels of individual traders, trading desks, all the way up to aggregating at the level of the global book of the firm.

Inputs to VaR models include option prices and implied volatilities. Inputs may also include unobservable parameters such as implied correlations between prices of different underlying contracts, for example for spread options and other exotic options, and implied volatilities of OTM options. *Some market makers mentioned that they have a product control team, which verifies these inputs independently from the risk management team. Price verification may include calling several brokers* *for price quotes, and/or using special pricing services, which quote averages of submitted prices for certain options back to the market makers who contributed prices.*

6.4 Credit, liquidity and model risk

Some options market makers manage counterparty credit risk exposure at an aggregated firm-wide level. This activity is usually undertaken by a separate credit division, which decides on credit lines and collateral management. Others manage credit risk separately for options positions.

In addition to daily marking-to-market, option market makers set aside valuation reserves against further risks, including liquidity risk and model risk. Liquidity risk includes risk arising from an inability to hedge continuously at low cost and an inability to unwind an option position, without moving the price against oneself, due to illiquid markets. Liquidity risk is especially relevant for OTM options, which are traded less heavily in the interbank market than ATM options. Determinants of the size of the reserves taken against illiquidity include bid-offer spreads of options (which are sensitive to the strike price), the time to expiry of an option, and estimates of the costs of dynamically rehedging and unwinding option positions. Market makers emphasize that estimating liquidity risk is not an automatic process, but that judgement is important for this. Liquidity conditions can change so fast, that they are difficult to capture within a model, such as a liquidity-adjusted VaR model.

Model risk is particularly relevant for exotic options, whose valuations can be complex and may include assumptions about unobservable parameters, such as implied correlations in the case of spread or quanto options. Also, little price discovery takes place for exotic options, since exotics are mainly traded direct between market makers and their customers, and only rarely in the interbank market or via brokers. For plain vanilla options, valuation reserves may also be set aside if an option pricing model is used which is known to be simplified, for example if no volatility smile and skew are included.

7 Conclusions

For monetary policy purposes, and for identifying risks to financial stability, the Bank of England regularly extracts information from option prices about the market's expectations about future interest rates, exchange rates and equity prices. To date, however, relatively little use has been made of the information available from the over-the-counter interest rate options market. This paper has discussed recent developments in the sterling OTC interest rate options market to gain a better understanding of its usefulness for informing monetary policy, and its implications for financial stability. OTC interest rate options markets contain a range of financial products not traded on exchanges, such as complex structured products, and options with long periods to expiry. However, they are not as transparent as exchange-traded markets. Consequently, discussions with market participants are important to gain a better understanding of the market structure and the use of OTC interest rate options, as well as their interrelationships with other financial markets.

Given the wide range of contracts traded, OTC interest rate options markets may be useful for investigating longer-term interest rate expectations. However, market participants generally think that in the sterling OTC interest rate options market, contracts with over one year to expiry do not accurately reflect the market's future interest rate expectations, since their prices are mainly affected by other considerations. In particular, long-dated OTC interest rate options in sterling are said to be used mainly for risk management and yield enhancement, rather than interest rate speculation.

Exchange-traded interest rate options contracts on money market interest rate futures with up to a year to expiry are thought by market participants to provide a better guide to near-term market interest rate expectations than OTC interest rate options, since they are more liquid and used more for speculation. Among sterling OTC interest rate options, 3-month ATM options on 2-, 5- and 10-year swaps are thought to reflect the market's interest rate expectations to the greatest extent.

Market participants generally think that there is a strong effect of liquidity of the underlying market on the liquidity of the related options market. However, there is less agreement about the causal linkages from options markets to the underlying markets; some think that there is little, if any, effect, while others think that there can be some effect on the price volatility and liquidity of the underlying market.

A Appendix

A.1 Option pricing models and implied volatility

This section discusses implied volatility and its relationship with expected uncertainty of future interest rates, and the Black model for pricing options on forward interest rates, forward swap rates, or interest rate futures.

A.1.1 Implied volatility

The Black model described in Section A.1.2 is the market practitioners' standard for pricing plain vanilla options on forward interest rates or forward swap rates. Within the model, the standard deviation of the probability distribution of the forward interest rate expected at expiration of the option, F_T, can be related to the standard deviation of relative daily rate changes, called the volatility σ, expected over the remaining lifetime T of the option, and the current forward interest rate F. The relation is approximately given by[23]

$$\text{standard deviation of } F_T \cong \sigma F \sqrt{T} \tag{1}$$

Neither the standard deviation of expected future interest rates nor the expected volatility σ are directly observable. Given the market prices of options, and using the Black model's solution for option prices as a function of volatility, the volatility implicit in these prices can be inferred. Volatilities inferred in this way are called 'implied volatilities'. They are the standard deviation of the distribution of future relative daily rate changes implied in option prices. The implied standard deviation of future interest rates at expiration of the option is then given by equation (1). As can be seen, it is approximately proportional to the square root of the time to expiry of the option. The implied volatilities quoted in financial markets strip out this trivial dependence of uncertainty on the time to expiry of the option. Implied volatilities may also contain risk premia; for example, investors may be prepared to pay an insurance premium for hedging their interest rate exposure with options (see Section 5.3). This may distort the read on 'pure' market uncertainty about the level of future interest rates.

For a comparison of implied interest rate volatilities, it is also possible to use normalised implied volatilities. Normalised implied volatility

[23]Equation (1) follows from the full expression for the variance [43], $\mathrm{var}(\mathrm{F}_T) = \mathrm{F}^2 \exp(2\mu\mathrm{T})\ (\exp(\sigma^2\mathrm{T})\ \text{-}1)$, when making the approximation that μT and σ^2T are both much less than 1, where μ is the risk-free return. The volatility is usually quoted on an annualised basis in percentage points. Note that the Black model, on which equation (1) is based, assumes that the probability distribution of F is lognormal.

is approximately equal to the standard deviation of the distribution of expected daily changes in the *level* of interest rates measured in basis points (rather than of the fractional changes in interest rates as for implied volatility), which is approximately given by

$$\text{normalised implied volatility} \cong \sigma F \tag{2}$$

A.1.2 The Black model for pricing options on forward interest rates

The Black model [18] assumes that the forward interest rate of the underlying contract, for example a forward-starting swap rate or the 3-month Libor interest rate, follows a certain stochastic process (a random walk with drift), and it assumes risk-neutral pricing. Within the Black model, the probability distribution of forward interest rates is assumed to be lognormal. Given these assumptions, the price of a European call option can be derived as the present discounted value of the expected future payoff at expiry of the option. Due to the assumption of risk-neutrality, the risk-free rate can be used for discounting.

The Black model solution for the price (or 'premium') of a European-style call option on a forward interest rate, i.e. the option to borrow at a predetermined strike rate X in the future[24], is given by [12, 43]

$$c(X) = exp(-rT)(FN(d_1) - XN(d_2)) \tag{3}$$

where F is the current market value of the forward interest rate, X is the strike rate, T is the time to maturity of the option as a fraction of a year, r is the risk-free zero-coupon interest rate at maturity T; N is the standard cumulative normal distribution with a mean of zero and standard deviation equal to one; d_1 and d_2 are defined according to

$$d_1 = (ln(F/X) + 0.5\sigma^2 T)/(\sigma\sqrt{T}) \tag{4}$$

$$d_2 = d_1 - \sigma\sqrt{T} \tag{5}$$

and, finally, σ is the expected daily volatility of the forward interest rate over the time to expiry of the option, which is assumed to be constant over the life of the option. Given σ, the option price can be calculated. Alternatively, given option prices traded in the market, σ

[24]Interest rate futures are quoted in price terms, with the price equal to 100 minus the futures rate. A call option in terms of the interest rate corresponds to a put option in terms of the price of the future. However, if one uses the price as the underlying asset, the price is assumed to have a lognormal probability distribution, so that the interest rate will not be lognormal.

can be calculated from Equation (3), using an iterative procedure (since it isn't possible to solve Equation (3) for σ analytically), and it is then called 'implied volatility'. In practice, both treasury bill yields and Libor interest rates of the appropriate maturities are used as alternative measures of the risk-free interest rate r.

A similar expression to Equation (3) holds for the price of put options, namely

$$p(X) = exp(-rT)(XN(-d_2) - FN(-d_1)) \tag{6}$$

The Black model is widely used in the market for pricing European-style interest rate options, such as European options on interest rate futures and bonds, European swaptions, caps and floors. It is relatively simple mathematically and can match market prices accurately [12]. It is used for quoting option prices in terms of implied volatilities by brokers and traders (for example in the case of swaptions and foreign exchange options). It also acts as a benchmark for calibrating other, more complicated, option pricing models [12, 19].

To price options on bond futures, the forward bond price is assumed to be lognormally distributed. The forward bond price can be calculated from the spot bond price and the interest received over the life of the option (see reference [43] for details).

A.1.3 Volatility smile and skew

In the Black model, the implied volatility is assumed to be constant as a function of strike price. In practice, however, the implied volatility calculated from market prices of options using the Black-Scholes model usually varies by strike. Implied volatility as a function of strike price often exhibits a so-called volatility smile or volatility skew, or both [2, 37, 38]. In the presence of a volatility smile, implied volatilities of both OTM calls and puts are larger than those of ATM options, and more so the further OTM the options are. In the presence of a positive volatility skew, implied volatilities of OTM calls are larger than implied volatilities of OTM put options which are equally OTM as the calls, as measured by delta (and vice versa for a negative volatility skew). Under the assumption of risk-neutral pricing, this implies that the implied probability distribution of the interest rate of the underlying contract (see Section A.2) is different from the lognormal probability distribution assumed in the Black model.

A.1.4 The Black-Scholes model and other option pricing models

If the underlying asset is a spot interest rate S, rather than a forward interest rate, the solution is somewhat different from the expressions given in equations (3) and (6), and the model is called a Black-Scholes model. Within the Black-Scholes model, the spot interest rate is assumed to have a lognormal probability distribution. The solution for the price of a European call option on a spot interest rate contract is given by [25]

$$c(X) = SN(d_1) - exp(-rT)XN(d_2) \tag{7}$$

where S is the current market spot interest rate,

$$d_1 = (ln(S/X) + (r + 0.5\sigma^2 T)/(\sigma\sqrt{T}) \tag{8}$$

and the other variables are as defined in Section A.1.2. The solution for the premium of a European put option is given by

$$p(X) = exp(-rT)XN(-d_2) - SN(-d_1) \tag{9}$$

The Black-Scholes model can also be used for pricing European options on foreign exchange, equities and commodities [43].

The Black model does not describe how interest rates evolve over time, and cannot be used to price American -style options, structured products (e.g. callable bonds) and many kinds of exotic options. These options can be priced using numerical techniques, and term structure models, which model the evolution of the entire yield curve. In some cases, however, for example for American options, approximate solutions can be derived within the Black-Scholes model [43].

An example of a numerical model is the binomial model, which models the evolution of the price of the underlying contract as a stochastic process in discrete time intervals. The option premium is defined as the present discounted value of the expected payoff of the option, and it is calculated within the binomial model as an average over many different possible price evolutions. Taking the limit of infinitesimally small time steps, the binomial model solution converges to the Black-Scholes model solution in the case of European-style options.

One drawback of the Black-Scholes model is that the implied volatility is assumed to be constant as a function of strike price, whereas the implied volatility calculated from market prices of options using the

[25]Note that equation (7) can be obtained from equation (3) by substituting the relation F=Sexp(rT) between the forward and spot interest rates into equation (3).

Black-Scholes model usually varies by strike, and exhibits a volatility smile or volatility skew, or both (see Section A.1.3). Under the assumption of risk-neutral pricing, this implies that the implied probability distribution of the interest rate of the underlying contract is different from the lognormal probability distribution assumed in the Black model.

In the Black-Scholes model, the risk-free interest rate and the volatility of the underlying interest rate are assumed to be constant over the time to expiry of the option. For options whose time to expiry is short compared with the maturity of the underlying interest rate this is a good assumption, but for longer-dated options the assumption does not hold as well [22]. In practice, implied volatilities vary with time to expiry of an option, exhibiting a so-called term structure of volatility [43].

It is theoretically inconsistent to price options on different kinds of interest rates using the Black model for each, since it is theoretically inconsistent to assume that different kinds of interest rates, e.g. a 2-year swap rate and 3-month Libor, are all lognormally distributed[26]. One makes this assumption, for example, when pricing both caps and swaptions using the Black model for each.

Another problem with using the Black-Scholes model for options on interest rates is that interest rates are not only the underlying asset, but they are also used for discounting. As the underlying asset, the interest rate is assumed to follow a stochastic process, but as the discount factor it is assumed to be constant over the time of maturity of the option.

In order to price different kinds of interest rate options within a unified and theoretically consistent framework, one has to use more sophisticated models, including term structure models. However, it is not evident that any of these term structure models are the 'correct' model of reality. The free parameters of these models are generally calibrated to market prices for plain vanilla options obtained from the Black model. As their name suggests, term structure models describe the evolution of the term structure of interest rates; examples are the Heath-Jarrow-Morton model and the Black-Derman-Toy model [35]. These models are based on the assumption of no-arbitrage (as is the Black model). No-arbitrage means that no riskless strategy of zero setup cost should yield a positive return with certainty [19].

For options such as American-style options or many kinds of exotic

[26]If two random variables each have a lognormal probability distribution, then a linear combination, or other more general function, of the two random variables, won't have a lognormal probability distribution. Within the expectation theory of the yield curve, a 2-year swap rate can be expressed as a function of 3-month Libor interest rates. Therefore, if each 3-month Libor interest rate is lognormally distributed, the 2-year swap rate isn't.

options, which depend on the path of the price of the underlying contract, and not just on its final value at the time of expiry, term structure models may be implemented numerically using a lattice-based approach, or using Monte Carlo simulations [19].

Models are now starting to be developed to include liquidity risk in the pricing of options. Reference [44] presents a model incorporating liquidity aspects into the Black-Scholes option pricing model. In this work, liquidity for an asset is defined as the notional value of the asset that has to be traded in order to move the asset price by one unit. It is found that including the liquidity effect into the Black-Scholes model leads to bid-offer spreads between long and short call option positions, which grow linearly in the size of the position. No such spreads are present in the simple Black-Scholes model. These bid-offer spreads are largest for ATM options, and fall off to zero for very deep ITM and OTM options; their profile as a function of strike price is similar to that of gamma.

A.2 Implied probability distributions

The option price, c(X), of a European-style call option may be derived as the risk-neutral expected payoff of the option at expiration, according to [45]

$$c(X) = exp(-rT) \int_X^{\infty} g(S_T)(S_T - X) dS_T \tag{10}$$

where S_T is the terminal asset price, and $g(S_T)$ is the probability distribution of terminal asset prices expected in the market. From equation (10) one can derive an expression for the implied probability distribution by differentiating twice with respect to the strike price [46],

$$g(S_T) = exp(rT) \frac{\partial^2 c(X)}{\partial X^2} \tag{11}$$

An advantage of using relation (11) for deriving the probability distribution of future prices of the underlying asset expected in the market, given option prices observed in the market, is that one does not have to make any assumptions about price evolution between the present and the time of expiry. Moreover, one does not have to make any assumptions about the shape of the probability distribution; in particular, it need not be lognormal. By contrast, the Black-Scholes model assumes a particular process for price evolution, and it assumes that its volatility is constant, leading to a lognormal probability distribution $g(S_T)$.

To use equation (11) it is necessary, however, to interpolate option prices (or their Black-Scholes implied volatilities) between the discrete strikes at which prices are available, in order to approximate the derivative numerically.

Implied probability distributions can be used to infer the asymmetry of the markets' expectations of future interest rates about the markets' mean expectations. A measure of this asymmetry is the skewness of the implied probability distribution, which is defined as the normalised third moment of the probability distribution [2].

The skewness of the implied probability distribution is related to the volatility skew [37, 38], and the so-called risk reversal, which is calculated from the implied volatilities of OTM options. The '25-delta' risk reversal[27] is defined as the implied volatility of a call option with a delta of 0.25, minus the implied volatility of a put option with a delta of -0.25. Assuming risk-neutral pricing, a positive risk reversal of an option implies that markets assign a greater probability to a large rise in price of the underlying contract than to an equally large fall in price.

In order to price an option using Equation (10), one would have to assume a form for the whole probability distribution $g(S_T)$.

A.3 Greek option sensitivity parameters

The value of an option, $c(S)$, is a nonlinear function of the price S of the underlying contract. If the price of the underlying contract changes from its original value S_0 by a small amount ΔS, the resulting change in the value of the option, Δc, can be approximated by a Taylor series expansion in ΔS. The Taylor series expansion to second in order in ΔS involves the first and second derivatives of the value of the option with respect to S, which are equal to delta (δ) and gamma (Γ) of the option, respectively [12]:

$$\delta = \frac{\partial c(S)}{\partial S} \qquad ; \qquad \Gamma = \frac{\partial^2 c(S)}{\partial S^2} \tag{12}$$

Delta and gamma are two examples of so-called 'Greek' sensitivity parameters of options. They vary with the price S of the underlying contract. In the Taylor series expansion, they are evaluated at the original price S_0:

$$\Delta c = \delta(S_0)\Delta S + \frac{1}{2}\Gamma(S_0)(\Delta S)^2 \tag{13}$$

[27] Risk reversals also exist as option trading strategies. A risk reversal is a long position in a call option with strike above the current ATM level, combined with a short position in a put option with strike below the current ATM level. Market practitioners can use the price of such a risk reversal trade to deduce the volatility skew [37].

The Taylor series expansion is a *local* approximation, since the coefficients delta and gamma are evaluated at the original price S_0 of the underlying contract. This approximation becomes less accurate as the change in price of the underlying contract increases, and it can be quite inaccurate if the value of the option is not a smooth function of the price of the underlying contract, but displays discontinuities. The latter can for example happen in the case of digital options close to their expiry. Equation (13) represents the 'delta-gamma approximation' to a change in an option's value. In the 'delta-approximation', only the first term in equation (13) is included, which is linear in ΔS.

The value of an option also depends on other variables, including the implied volatility σ. The sensitivity of the value of an option to a change in σ is called vega:

$$\text{vega} = \frac{\partial c}{\partial \sigma} \tag{14}$$

The change in the value of an option, Δc, due to a change in implied volatility from its original value σ_0 by $\Delta\sigma$, can similarly be approximated linearly by

$$\Delta c = \text{vega}(\sigma_0)\Delta\sigma \tag{15}$$

A.4 Discussions with option market participants

This paper is based in part on discussions with participants in the OTC interest rate options market. These discussions took place between May and July 2000 with staff from the trading and risk management divisions of the following institutions in London: Barclays Capital, the Chase Manhattan Bank, Credit Suisse First Boston, Goldman Sachs, J P Morgan, the Royal Bank of Scotland, Tullett & Spütz Capital Markets AG, UBS Warburg, and Westdeutsche Landesbank.

A.5 Glossary of abbreviations

ATM - at-the-money
BBA - British Bankers' Association
BIS - Bank for International Settlements
CMS - constant-maturity-swap
FRA - forward rate agreement
FX - foreign exchange
GMV - Gross market value
IMF - International Monetary Fund
ISDA - International Swaps and Derivatives Association
ITM - in-the-money
LIFFE - London International Futures & Options Exchange
MBS - mortgage-backed security
MTN - medium-term-note
NAO - Notional amounts outstanding
OTC - over-the-counter
OTM - out-of-the-money
VaR - value-at-risk
r - risk-free interest rate
S_T - price of underlying contract at expiry of an option
T - time to expiry of an option
X - strike price of an option

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