

Do Surprising Central Bank Moves Influence Interest Rate Derivatives Prices? Empirical Evidence From the European Caps and Swaptions Market

Matthias Muck

WHU - Otto Beisheim Graduate School of Management
Dresdner Bank chair of Finance
Burgplatz 2, 56179 Vallendar, Germany
Tel.: +49 - 261 / 6509 423 Fax: +49 - 261 / 6509 409
Email: mmuck@whu.edu <http://www.whu.edu/banking>

February 2003

Abstract:

This paper examines the effects of possible surprising central bank actions on derivatives prices. It implements a LIBOR market model with jumps to capture possible large changes due to these actions. It compares the pricing performance of this model to one without jumps. The key finding of this paper is that the jump component which mimics surprising ECB behavior significantly improves the fit to a series of observed swaption quotes. The model with jumps also prices interest rates caps more consistently to the swaptions market.

Key Words:

Term Structure, Market Model, Jumps, Monte Carlo Simulation

JEL classification: **G13, G21**

Do Surprising Central Bank Moves Influence Interest Rate Derivatives Prices? Empirical Evidence From the European Caps and Swaptions Market

February 2003

Abstract:

This paper examines the effects of possible surprising central bank actions on derivatives prices. It implements a LIBOR market model with jumps to capture possible large changes due to these actions. It compares the pricing performance of this model to one without jumps. The key finding of this paper is that the jump component which mimics surprising ECB behavior significantly improves the fit to a series of observed swaption quotes. The model with jumps also prices interest rates caps more consistently to the swaptions market.

Introduction

Over the past two decades we have observed a rapid growth of the market of interest rate derivatives. The total notional amount alone of interest rate options outstanding was more than \$ 10.8 trillion which exceeds the gross domestic products of countries like Germany, France, or Great Britain by far.ⁱ Therefore, the development of reliable models to correctly price and hedge interest rate derivatives has been a major concern to both practitioners and academics.

Ho and Lee [1986] were the first to introduce a no-arbitrage model of the term structure which takes as input a given yield curve. Their approach to model observed bond prices was further generalized by Heath, Jarrow, and Morton [1992]. Baxter [1997] shows that many of the most popular models are special cases of this HJM framework (e.g. Hull and White [1990], [1994a], and [1994b], Black, Derman, and Toy [1990], Black and Karasinski [1991], etc.). Björk, Kabanov, and Runggaldier [1997] extend the HJM-approach to a jump diffusion setting. Goldstein [2000] and Santa-Clara and Sonrett [2001] consider so called “string” shocks of the yield curve, i.e. each (instantaneous) forward rate is driven by its proper risk factor.

Another recent development - the LIBOR-market model first introduced in the parallel work of Brace, Gatarek, and Musilia [1997], Jamshidian [1997], and Miltersen, Sandmann und Sondermann [1997] - has become a new paradigm for modeling term structure movements for both its conceptual elegance and its practical impact for pricing interest rate sensitive securities. Based on the general no arbitrage considerations developed by HJM [1992] the LIBOR market model considers only discretely compounded forward rates, which can be directly observed in the market place. Therefore the user of the model is not forced to estimate a continuous yield curve and derive the dynamics of the instantaneous forward rates, which are the basic block of the traditional HJM-approach. Furthermore the LIBOR-market model approach overcomes some technical problems associated with the lognormal assumption of forward rate dynamics (cf. Sandmann and Sondermann [1997] for this point). It can be shown that in the framework of the LIBOR market model a closed form solution for caplets can be derived, which is consistent with the popular Black [1976] formula.

Therefore the LIBOR-market model has been subject to extensive research: Andersen and Andreasen [2000] consider an extended market model where the forward rates follow a non-lognormal process and derive a closed form solution for a constant elasticity of variance (CEV) – process specification. Zühlsdorff [1999] further extends the volatility specification. Joshi and Rebonato [2001] introduce stochastic volatility where the volatility coefficient follows some mean reverting dynamics. Hull and White [2000], Rebonato [1999], and Longstaff, Santa-Clara, and Schwartz [2001] provide further insight into efficient numerical implementation of the model. Longstaff and Schwartz [2001] implement a modified algorithm to price American swaptions and compare the prices to results obtained by applying the model of Black, Derman, and Toy [1990]. Finally, Glasserman and Kou [2001] and Glasserman and Merener [2001] proposed a LIBOR-market model with jumps.

Given this vast number of different possibilities to describe the term structure dynamics the question naturally arises which model is most suitable for a given valuation problem at hand. A number of studies which implemented and tested derivatives pricing models: Flesaker [1993] tests the Ho and Lee [1986] model and Amin and Morton [1994] analyze several specifications for the volatility function of the forward rates in the HJM [1992] framework. However the problem with both studies is that they use (short-term) options on Eurodollar futures and therefore do not consider the dynamics of longer term yields. Bühler, Uhrig-Homburg, Walter, and Weber [1999] use historical parameter estimates to price (mostly) short term warrants on German government bonds. Finally, Longstaff, Santa-Clara and Schwartz [2001] and de Jong, Driessen, and Pelsser [2001] employ a LIBOR market model to verify the consistent pricing of caps and swaptions in the US market.

However, none of the studies mentioned has ever studied the impact on derivatives prices of another important player in the market: the central banks. Due to the regulatory setting the European Central Bank has direct control over the short end of the yield curve. The aim of this paper is therefore to investigate whether potential surprising moves of the central bank is reflected in derivatives prices. Babbs and Weber [1997] develop an equilibrium model of the term structure which takes central bank movements into account. They model the short rate dynamics as a pure jump process and show that prime rate changes might cause jumps of the term structure.

El-Jahel, Lindberg, and Perraudin [1997] draw on their results and find empirical evidence that a jump model which is nested in the specification of Babbs and Webber [1997] can better explain the distributional properties of interest rates. Das [1999] finds that the Federal Reserve has an impact on short term interest rates via “information surprises” which are captured by jumps. Piazzesi [1999] and [2000] comes to similar results. For the European market Honoré [1998] finds that the behavior of the Bundesbank can cause jumps in the dynamics of short term interest rates.. Johannes [2000] even finds a dominant role for jumps in the short-rate dynamics in the US-market. He attributes these jumps to fundamental information entering the term structure.

We will examine caps and swaptions quotes throughout this study because they offer two main advantages: First of all caps and swaptions quotes are easily available for a large number of maturities which enables us to consider the dynamics of the whole yield curve. Second, although we only observe quotes instead of transaction prices, caps and swaptions are among the most liquidly traded OTC instruments. We therefore consider the pricing overall as competitive. As derivatives pricing model we consider the LIBOR market model approach for both its conceptual elegance and its intuitive appeal. In line with the existing literature we incorporate jump risk for short term rates in order to account for central bank actions.

The outline of the study is as follows: Section 1 gives an overview over the European fixed income market and the data used. Section 2 describes the model, its implementation, and the calibration methodology. Section 3 presents the empirical results. Section 4 concludes.

1 The European Market for Fixed Income Instruments

The purpose of this section is twofold. In the first subsection we describe the data used in this study and explain how the yield curve and the prices for interest rate options are determined. In the second subsection we investigate the effects that movements of the European Central Bank (ECB) had on interest rates.

1.1 European Swaps, Caps, and Swaptions Data

Similar to Longstaff, Santa-Clara, and Schwartz [2001] we use two types of datasets. European term structure data to determine the yield curve and European OTC-derivatives data which consists of caps and swaptions quotes.

The term structure data comprises both daily EURIBOR and swap quotes comprising the period from 4 January 1999 until 31 October 2002. The EURIBOR is published each day at 11:00 am CET by the European Banking Federation. It represents an aggregated rate for Euro interbank term deposits offered by one European prime bank to another. Furthermore, we obtain the 2-year, 3-year, 4-year, 5-year, 7-year, and 10-year mid-swap quotes from Datastream, to exchange 6-Month EURIBOR versus an annual fixed payment. Each trading day Datastream publishes end-of-the-day swap quotes which they obtain from Garbain Intercapital, a major derivatives broker. Datastream also provides swap rates for the 6-year, 8-year, and 9-year period. However, we are reluctant to incorporate them in our dataset because these types of swaps are less liquidly traded. Table 1 summarizes the term structure data used.

We construct our yield curve in the following way: as short term interest rates, we are using the EURIBOR rates. Since all of the other rates are end-of-the day trading data, we assign the EURIBOR quotes to the day before they were quoted. This choice is also motivated by the fact that we want to study the impact of central bank interventions. The ECB usually publishes its monetary decisions at 1:45 pm. Therefore, we can rest assured that we do not mix up data which include and which exclude information about the monetary decisions. The longer term interest rates are calculated out of the swap rates. First we use a standard cubic spline to interpolate the swap curve for maturities that are not in our dataset. We then calculate the spot rates by applying the following bootstrapping procedure: We know that we can replicate a swap by buying a floating rate note and selling a coupon bond where the coupon is equal to the swap rate (or vice versa). At origination this portfolio must have zero value. Hence the coupon bond must have a value of 1 today. We can now solve iteratively for the appropriate discount rates. From the spot curve we can immediately

obtain the forward curve. Altogether we will use 19 forward rates and the spot rate such that we have a set of rates spanning over each 6-month period out to 10 years. Figure 1 shows that most of the time we observed an increasing forward curve in the Eurozone.

Clearly the credit quality of the yield curves that we are using in this study is strictly speaking not as good as for yields calculated out of government bonds. Furthermore Longstaff, Santa-Clara, und Schwartz [2001] mention that a small bias might be induced due to the fact that we are using rates from two different market segments: the market for short term interbank deposits and the swap markets. However, since banks tend to price and hedge derivatives based on these rates we feel that they are the most appropriate to chose.

The second dataset consists out of daily observations of mid-market quotes for at-the-money- (ATM) caps and swaptions collected from 2 January 2002 to 30 October 2002. Altogether we have 213 observations for each instrument. The quotes were obtained from Datastream. Again Garbain Intercapital is the contributor for the Datastream data.

A cap consists out of a series of caplet options. Each caplet can be seen as a call option on a discrete short term interest rate. In the Eurozone caps are usually written on the 6-month EURIBOR. Hence e.g. a 5-year cap represents a portfolio of 9 caplets. The value of the cap is therefore equal to the sum of the single values of the caplets. According to the market convention ATM - caps are quoted in terms of their flat implied volatilities where the strike is chosen to be equal to the swap rate with the respective maturity. The flat volatility can be seen as an "average volatility" which if inserted into the Black [1976]-formula returns the correct overall price for the T_C -year cap (notional €100):

$$(1.1) \quad C(T_C) = 50 \cdot \sum_{i=1}^{T_C/2+1} B_0((i+1) \cdot 0.5) \cdot [F_t(i \cdot 0.5, (i+1) \cdot 0.5) \cdot Nd(d_1) - X_C \cdot Nd(d_2)]$$

where

$$d_{1,2} = \frac{\ln[F_0(i \cdot 0.5, (i+1) \cdot 0.5) / X_C] \pm 0.25 \cdot \sigma_{\text{flat}} \cdot i}{\sigma_{\text{flat}} \cdot \sqrt{i \cdot 0.5}}$$

X_C is the strike rate of the cap. $B_t(T)$ is the price of a zero coupon bond at time t with maturity in T , $F_t(T_1, T_2)$ denotes the forward rate spanning from T_1 to T_2 at t , σ_{flat} stands for the flat volatility. Nd is the operator for the cumulative normal distribution.

Finally a swaption is an option to enter a payer or a receiver swap at a pre-defined swap rate at expiry of the option. Swaptions are quoted in terms of their implied Black [1976]- volatilities. The dataset includes only quotes for ATM-swaptions, i.e. the strike rate equals the forward swap rate. According to the market convention the underlying swaps always have fixed annual payments. The price of the swaption (notional € 100) with expiry in T_1 and maturity of the underlying swap in T_2 can be calculated according to:

$$(1.2) \quad S(T_1, T_2) = 100 \cdot \sum_{i=T_1}^{T_2} (B_0(i)) \cdot [FS_0(T_1, T_2) \cdot Nd(d_1) - X_S \cdot Nd(d_2)]$$

where

$$d_{1,2} = \frac{\ln[FS_0(T_1, T_2)/X_S] \pm 0.5 \cdot \sigma_S \cdot T_1}{\sigma_S \cdot \sqrt{T_1}}$$

X_S is the strike rate of the swaption, σ_S the Black volatility of the forward swap rate FS_t which is given by

$$FS_t(T_1, T_2) = \frac{B_t(T_1) - B_t(T_2)}{\sum_{i=T_1+1}^{T_2} B_t(i)}$$

Note that an ATM payer and receiver swaption must have identical values. This follows from the fact that a forward payer-swap can be replicated by buying an ATM-payer-swaption and selling an ATM-receiver-swaption.

Tables 2 and 3 provide summary statistics for both cap and swaption data used. We find that the implied flat cap volatilities display a humped shape which is in line with empirical observations of other authors (e.g. de Jong, Driessen, and Pelsser [2001], Rebonato [1998]).

1.2 Actions of the ECB 1999 – 2001

The principal goal of the ECB is to preserve price stability within the Eurozone. Important instruments are the (short-term) prime interest rates. Three prime interest rates must be distinguished: The main refinancing operations, the marginal lending facility and the deposit facility. The main refinancing operations are used to provide the banking system with sufficient liquidity. They are conducted in a tender operation once a week with maturity in two weeks. The tenders used to be fixed rate tenders. However, the ECB changed towards variable tenders on 8 June 2000. The marginal lending facility allows banks to get liquidity from the ECB overnight. Banks also may make overnight deposits at the ECB at the rate for the deposit facility. Figure 2 graphs the development of the three prime rates as well as the short term spot interest rates for the years 1999, 2000, and 2001.

{Figure 2}

The time span under investigation can be split up into two sub-periods: From mid-1999 until May 2001 we observe a period of increasing prime rates. The second half of 2001 is characterized by decreasing prime rates. Large reductions are observed in September and November 2001. These central bank interventions are obviously linked to the terrorist attacks on 11 September 2001. During nearly the whole observation period, the 6-Month-EURIBOR lies within the corridor established by the rates for the deposit facility and the marginal lending facility. The only exception is a small time span before the ECB increased the prime rates in November 1999 where the market anticipated the central bank's move. Furthermore we observe that the 12-Month-EURIBOR also seems to be tied to the level of the prime rates. We find that during the period of increasing prime rates the 12-Month-EURIBOR is higher than the 6-month-EURIBOR while it is generally lower during the second half of 2001.

To distinguish between ECB-movements which were expected by the market participants and therefore reflected in the interest rates and those that were not, we analyzed the press coverage of the monetary decisions in the economic press. We considered two types of surprises: The central bank moves with a larger step than expected or the ECB does not change prime rates although it was expected to do so.

Tables 4 and 5 report the daily log- changes in forward rates at the identified surprising moves as well as on all 12 prime rate changes:

{Tables 4 and 5}

As the tables 4 and 5 show the prime rates were subject to unexpected changes 5 times. Although the timing of the ECB action on 5 October 2000 was considered as “surprising” in the press coverage at that particular date an increase of the prime rate was expected in that fall. Therefore, forward rates did not react intensely on that event.

Overall it becomes apparent that especially the spot rate as well as the first forward rate are sensitive to surprising moves of the ECB. The surprising announcements of the ECB are followed by large movements in these rates. Longer term forward rates (perhaps with the only of the surprising decrease of prime rates on 8 April 1999 where some mid-term forward-rates reacted quit strongly) seem to be less affected. This observation is in-line with Honoré [1998] who finds that the Bundesbank only had an impact on short term German (spot -) interest rates during the time period from 1988 until the beginning of 1995. Hence in order to investigate the question to what extend these surprising ECB-movements affect derivatives pricing it appears to be natural to establish a model which incorporates a jump-factor in addition to the usual diffusion factors. The next section discusses the model set up and the implementation in detail.

2 The Model

This section first deals with the a LIBOR Market Model with jumps. The second subsection discusses the implementation of the model as well as the calibration methodology.

2.1 The LIBOR Market Model with Jumps

As main building blocks of the model we consider a finite set \mathbf{B} of n zero coupon bonds $\{B_{1,t}, \dots, B_{n,t}\}$ with maturity dates $\{T_1, \dots, T_n\}$. For simplicity we assume that the maturity dates are equally spaced, i.e. $T_{i+1} - T_i = \delta$, $i = 1, \dots, n-1$. Following Björk, Kabanov, and Runggaldier [1997] we assume the existence of an equivalent risk neutral (pricing-) measure Q . Under this measure, the bond price dynamics are driven by both an m -dimensional Wiener process W_t^Q and a marked point process (MPP) $\mu^Q(dt, dx)$ with intensity $v^Q(t, dx)$. The marks x are drawn from the abstract space E . More precisely, each zero coupon bond fulfills the following SDE:

$$(2.1) \quad dB_{i,t} = B_{i,t} \cdot r_t dt + B_{i,t} \cdot V_{i,t} dW_t^Q + B_{i,t-} \cdot \int_E N_i(t, x) \cdot (\mu^Q(dt, dx) - v^Q(t, dx) dt)$$

where $V_{i,t} = (V_{i,t}^{(1)}, \dots, V_{i,t}^{(m)})$ is m -dimensional and predictable and $N_i(t, x)$ is a real function which transforms the abstract mark into a jump magnitude. $N_i(t, x)$ is strictly greater than -1 . The bond price process is càdlàg and intuitively $t-$ is the point in time immediately before a jump. Henceforth, the bond price deflated with the continuously compounded money market account at time t is given by

$$(2.2) \quad dZ_{i,t} = Z_{i,t} \cdot \left[V_{i+1,t} dW_t^Q + B_{i,t-} \cdot \int_E N_i(t, x) \cdot (\mu^Q(dt, dx) - v^Q(t, dx) dt) \right]$$

where $Z_{i,t} = \frac{B_{i,t}}{\beta_t}$ and β_t is the continuously compounded money market account.

Given a suitable version of the Girsanov theorem as stated in theorem 3.12 in Björk, Kabanov, and Runggaldier [1997] and which is given in the appendix changing between measures is now very easy. We want to define a forward martingale measure P_i such that:

$$(2.3) \quad D_0 = E^Q \left[\frac{D_T}{\beta_T} \right] = E^{P_i} \left[\frac{D_T}{B_{i,T}} \right] \cdot B_{i,0}$$

where $E^Q(\bullet)$ and $E^{P_i}(\bullet)$ denote the expectations operators when the continuously compounded money market account and the zero coupon bond with maturity T_i are taken as numéraire respectively. D_t is the price of an arbitrary derivative instrument. Using the Girsanov stated in the appendix it follows from (2.2) under some technical conditions

$$(2.4) \quad \begin{aligned} dW_t^Q &= dW_t^{P_i} + V_{i,t}^T \\ v^Q(t, dx) &= (N_i(t, x) + 1) \cdot v^{P_i}(t, dx) \end{aligned}$$

Consider next the dynamics of a zero-coupon bond $B_{i,t}$ which is deflated $B_{i+1,t}$. Applying Itô's lemma with respect to (2.1), we obtain under Q

$$(2.5) \quad \begin{aligned} d\left(\frac{B_{i,t}}{B_{i+1,t}}\right) &= \frac{B_{i,t}}{B_{i+1,t}} \left(\|V_{i+1,t}\|^2 - V_{i,t} \cdot V_{i+1,t}^T \right) dt \\ &+ \frac{B_{i,t}}{B_{i+1,t}} \int_E \left((N_{i+1}(t, x) - N_i(t, x)) \cdot v^Q(t, dx) dt \right) + (V_{i,t} - V_{i+1,t}) dW_t^Q \\ &+ \frac{B_{i,t-}}{B_{i+1,t-}} \cdot \int_E \left[\frac{N_i(t, x) + 1}{N_{i+1}(t, x) + 1} - 1 \right] \mu^Q(dt, dx) \end{aligned}$$

Under the measure P_{i+1} this becomes using (2.4)

$$(2.6) \quad \begin{aligned} d\left(\frac{B_{i,t}}{B_{i+1,t}}\right) &= \frac{B_{i,t}}{B_{i+1,t}} (V_{i,t} - V_{i+1,t}) dW_t^{P_{i+1}} \\ &+ \frac{B_{i,t-}}{B_{i+1,t-}} \cdot \int_E \left[\frac{N_i(t, x) + 1}{N_{i+1}(t, x) + 1} - 1 \right] \left(\mu(dt, dx) - v^{P_{i+1}}(t, dx) dt \right) \end{aligned}$$

This result is not surprising since the process of a deflated bond-price under its own forward measure must be a martingale. The discretely compounded forward rate spanning from T_i to T_{i+1} is given by

$$(2.7) \quad F_{i,t} = \frac{1}{\delta} \left[\frac{B_{i,t}}{B_{i+1,t}} - 1 \right]$$

Using this and applying Itô's lemma on (2.6) yields

$$(2.8) \quad dF_{i,t} = \frac{B_{i,t}}{B_{i+1,t} \cdot \delta} (V_{i,t} - V_{i+1,t}) dW_t^{P_{i+1}} \\ + \frac{B_{i,t-}}{B_{i+1,t-} \cdot \delta} \cdot \int_{\mathbb{E}} \left[\frac{N_i(t,x)+1}{N_{i+1}(t,x)+1} - 1 \right] \cdot (\mu(dt,dx) - v^{P_{i+1}}(t,dx)dt)$$

Equation (2.8) is the most general relationship between jumpy bond prices and the corresponding forward rates. The specification of Glasserman and Kou [2001] is a special case of (2.8) where the ratio of jumps in the bond prices is specified according to

$$(2.9) \quad \frac{N_i(t,x)+1}{N_{i+1}(t,x)+1} = \frac{\delta F_{i,t-} \cdot (1 + H_i(t,x)) + 1}{1 + \delta F_{i,t-}}$$

where $H_i(t,x)$ is a real function which is strictly greater than -1 and which transforms the mark x into a percentage jump-magnitude of the forward rate. Secondly, it is worthwhile noting that the diffusive behavior of the forward rate can be chosen completely independent of the jump behavior. An obvious example is the specification of a CEV-dynamic as it is given in Andersen and Andreasen [2000] and to combine it with the possibility of lognormal jumps in the forward rates as long as the forward rates can never jump negative.

Throughout the rest of this paper, we will work under the spot pricing measure S , where we use the bond with the shortest time to maturity as numéraire. Applying the change of measure technique yields:

$$(9) \quad dF_{i,t} = \frac{B_{i,t}}{B_{i+1,t} \cdot \delta} \cdot \int_{\mathbb{E}} \left(\left(1 - \frac{N_i(t,x)+1}{N_{i+1}(t,x)+1} \right) \cdot \frac{N_{i+1}(t,x)+1}{N_s(t,x)+1} v^S(t,dx) dt \right) \\ + \frac{B_{i,t}}{B_{i+1,t} \cdot \delta} \cdot \left[(V_s - V_{i+1}) \cdot (V_i - V_{i+1}) dt + (V_i - V_{i+1}) dW_t^S \right] \\ + \frac{B_{i,t-}}{B_{i+1,t-} \cdot \delta} \cdot \int_{\mathbb{E}} \left[\frac{N_i(t,x)+1}{N_{i+1}(t,x)+1} - 1 \right] \mu(dt,dx)$$

where s is the index for the bond with the shortest time to maturity.

2.2 Implementation and Calibration of the Model

This section discusses the implementation as well as the calibration of the model described above.

2.2.1 Implementation of the Model

The model (2.9) in its most general form allows for a large number of fitting parameters. Thus virtually any series of observed option prices can be perfectly fitted by just adding enough degrees of freedom. Therefore our first task is to reduce dimensionality to obtain a robust – albeit economically plausible model. More specifically we will assume that the forward rates will follow a lognormal diffusion process. The surprising movements of the central bank are introduced by a jump process: Each forward rate may either jump up or jump down by a fixed percentage amount. We furthermore assume that the probability for a jump upwards is 50% under the spot measure. This assumption corresponds to the requirement that the probabilities for up- and down-jumps are equal under each pricing measure. Although this requirement seems to be quite restrictive at first glance extensive numerical experiments suggest that this probability parameter has a very small influence on the option prices obtained as long as the up- jump amplitude is of the same order as the downwards jump-amplitude. As discussed below this will be indeed the case. Thus, the model (2.9) with a suitable choice of $V_{i,t}$ and by assuming that (2.9) holds reduces to the binomial jump-diffusion model

$$(2.10) \quad dF_{i,t} = F_{i,t} \left[\sigma_{i,t} \cdot \sum_{k=s}^i \frac{\delta F_{k,t} \cdot \sigma_{i,t}^T}{1 + \delta F_{k,t}} - \sum_{x=0}^1 H_i(t, x) \prod_{k=s}^i \frac{1 + \delta F_{k,t-}}{1 + \delta F_{k,t-} (1 + H_k(t, x))} \lambda \right] dt \\ + F_{i,t} \cdot \sigma_i dW_t^S + F_{i,t-} \cdot \sum_{x=0}^1 (H_i(t, x) - 1) \mu^S(x, dt)$$

where $\sigma_{i,t} = (\sigma_{i,t}^{(1)}, \dots, \sigma_{i,t}^{(m)})$ is m -dimensional and predictable, and λ is the intensity for an up- and a down-jump. The total intensity is thus $2 \cdot \lambda$. An economic interpretation

for the abstract mark x is to view it as the “surprise – function”, i.e. if $x = 0$ then we have a down-jump and an up-jump otherwise.

The model (2.10) is a time-homogeneous specification of the forward rate dynamics. The volatility of each forward rate and the covariance to the other forward rates in the diffusion component depends only on the time to maturity. The same is true for the jump amplitude of the rate. Note that the jump component is per definition uncorrelated to the diffusive dynamics. In the case of a jump all forward rates which are sensitive to the jump component though their respective H_i -functions are affected. The overall variance-covariance structure of the forward rates follows hence from both the jump- and the diffusion-component. The specification of a deterministic jump-amplitude might be viewed as very simple and contrasts e.g. the specification of Glasserman and Kou [2001] who allow for stochastic jump sizes. However, our primary goal is mimicking the ECB actions: In the past the central bank adjusted prime rates either by 25 or by 50 basis points. This observation applies to both the European and the US market. Therefore “surprises” should be roughly about the same size. A second argument in favor of the model (2.10) is technical concern: The numerical implementation of the general model (2.9) involves the numerical solution of an integral in the drift term if forward rates are affected by a stochastic jump which may occur with the *same* probability of a jump occurring in a given time increment (as we would require in this context). This integral must be solved numerically which turns out to be computationally infeasible for the purpose of this study.

To price caps and swaptions we implement a Monte-Carlo-simulation algorithm. We use 3-month-time steps and apply a log-Euler-discretization-scheme. In an arbitrary 3-month-time interval, the forward rate with maturity T_i is simulated as:

$$(2.11) \quad F_{i,t+0.25}^- = F_{i,t} \cdot \exp \left\{ 0.25 \cdot \left[\text{drift}(F_{i,t}) - 0.5 \cdot \|\sigma_{i,t}\|^2 \right] + \sqrt{0.25} \cdot \sigma_{i,t} \cdot z_t \right\}$$

where $\text{drift}(\bullet)$ is the operator to determine the value of the drift in model (2.10) at t and $z_t^T = (z_t^{(1)}, \dots, z_t^{(m)})$ are standard normally distributed quasi-random numbers. At the end of each 3-month interval the forward rates may jump. Therefore we draw two quasi-random variables which are uniformly distributed on the interval $[0..1]$. They are

used to calculate the number of up- and down jumps U and D according to the Poisson distribution. The new forward rates at $t+0.25$ are then given by

$$(2.12) \quad F_{i,t+0.25} = F_{i,t+0.25}^- \cdot (H_i(t,0)+1)^D \cdot (H_i(t,1)+1)^U$$

Biases may result from two sources: First the (stochastic) drift terms are assumed to be constant over the 3-month interval. However, Hull and White [2000] show this bias for realistic volatility structures is very small. Second the total number of jumps happens at once. However, extensive numerical testing of the algorithm suggests that the pricing differences to an implementation which allows for stochastic jump times is indeed very small. We chose this implementation because computational speed will be a critical issue due to the fact that calibration will involve Monte-Carlo simulation and allowing for stochastic jump times will become computationally infeasible. Please refer to the appendix to assess the numerical quality of the algorithm proposed.

2.2.2 Calibration of the Model

The model (2.10) still allows for a large number of fitting parameters. We will therefore put additional structure on both the jump and the diffusion component. Similar to Longstaff, Santa-Clara, and Schwartz [2001] and Hull and White [2000] we perform a principle component analysis on the weekly log-changes of the rates spanning over the whole period from time 0 up to 10 years in the entire period from beginning of the year 1999 to the end of 2001. We exclude those weeks in which we have identified a jump due to surprising ECB actions. Altogether 199 weekly log changes are considered. More specifically we estimate the historical variance-covariance matrix and decompose it into its eigenvectors and eigenvalues. Figure 3 plots the factor weights of the first four eigenvectors. Table 6 shows the corresponding eigenvalues and the cumulative variance explained.

{Figure 3 Table 6}

Obviously 4 factors are needed to explain at least 95% of the total variation, 7 factors to explain at least 99%. This observation is in line with Lekkos [2000] who finds that at least 5 factors are needed to explain the total variance of the forward rates each

spanning over a period of 1 year in the major currencies. However according to his study the first factor in general explains less variance than reported here. The eigenvectors shown in figure 3 are similar to the ones found in other studies with the usual interpretation of level, steepness, and curvature shift of the forward curve. The fourth eigenvector resembles the one of Longstaff, Santa-Clara, and Schwartz [2001] and affects mainly the short end of the yield curve. Intuitively this can be interpreted as (small) variations in short term-yields due to liquidity management of economic agents or changing expectations about future prime rate variations.

In the course of the calibration of the model we assume that the factor loading and the ratios of the eigenvalues are constant over time. Illustratively this requirement means that the term structure of forward rates is driven by the historic factors and that the explanatory power of these factors remain constant. This implicitly presumes that the degree of correlation between forward rates is given by the historical correlation matrix. Certainly, these assumptions concerning the diffusion component of the model is more restrictive than in Longstaff, Santa-Clara, and Schwartz [2001]. However we first acknowledge that their focus is on the number of diffusive factors driving the term structure of forward rates. Therefore, they had to allow the variation of eigenvalues. Second a consequence of their fitting procedure is that the ratios of the historical eigenvalues are not at all taken into account when calculating their implicit covariance matrix. As their results show for some periods of time they obtained implicit eigenvalues which appear implausible (e.g. the fourth factor seems to have a relatively large explanatory power compared to the other factors in the beginning of 1999, a result which has never been observed historically). Hence we fear that their model might be periodically overfitted. Our calibration methodology avoids this problem.

More specifically we assume that the variance-covariance structure of the forward rates is piecewise constant over time. As explained earlier we divided each 6 month interval $[t_1, t_2]$ into two subperiods of 3-month length. The forward rate with maturity in T_i is affected by the factors calculated for a rate with a total time to maturity of $T_i - t_1$ in the first 3-month interval. In the second 3-month interval it is driven by the factors calculated for the rate with maturity $T_i - t_2$. As an example consider the period from 3 years to 3.5 years from now and the forward rate maturing in 5 years. During the pe-

riod from 3 to 3.25 years the forward rate is shocked by the diffusion factors of a forward rate maturing in 2 years. However, from 3.25 to 3.5 years it should behave more like a rate maturing in 1.5 years. Hence, we chose the corresponding factors. In contrast to Longstaff, Santa-Clara, and Schwartz [2001] we also incorporate the information from the spot market in our model because each forward rate is affected by the factors for the 0.5 year spot rate during the last 3 months of its life.

For the jump functions we assume the arithmetic averages of the simply compounded returns. We distinguished between up-jumps and down-jumps. Similar to the diffusion component, we claim that the jump-functions are piecewise constant over each 3-month subinterval. We chose the jump functions such that only short-term rates may jump (i.e. during the last 0.75 years of their life). As table 5 shows these are the rates that are affected most strongly by a surprising ECB move and thus justify the identification of a jump. This is also plausible because the central bank only has direct control over the short end of the yield curve. Furthermore, effects on longer term forward rates may be spoiled by possible twists in the forward curve which move in the opposite direction. These twists may result from the fact that longer term spot rates are less affected by ECB shocks than short term interest rates. The jump function used is given in table 7.

{table 7}

We are left with two calibration parameters: One which controls for the level of the eigenvalues and one for the intensity of jumps. We solve for these parameters by applying the model to daily observations in the swaption markets from January 2002 to November 2002 (213 observations) in the following way: For a given parameter combination we simulate 10'000 sample paths. As variance reduction method we employ antithetic variates. We solve for the prices of the swaptions by calculating their final payoffs, discounting with the discretely compounded money market account and taking the arithmetic average. We do this for both payers and receivers swaptions. Since both must have the same value we chose the final price to be the average of both. We use the final price to calculate the implied Black volatility and compare each volatility with the corresponding market quote. Finally we add up the squared residuals. The comparison in terms of the Black model is due to the fact that it gives a fairer weighting scheme because all quotes in terms of the Black volatilities

are of comparable size. This is in line e.g. with the study of de Jong, Driessen, and Pelsser [2001]. Bossaerts and Hillion [1997] were the first to argue in favor of this weighting scheme. We vary over the fitting parameters (one eigenvalue and the intensity parameter) until the minimum for the sum of squared errors is found. To achieve this task we employ the Powell direction set algorithm similar to version given in Press, Teukolsky, Vetterling, and Flannery [1992]. In the course of the optimization, the same seed of random numbers is used. Otherwise the optimization algorithm gets heavily confused due to the fact that it cannot distinguish between changes in the optimization function due to variation of the fitting parameters and numerical noise coming from different random numbers. Monte Carlo experiments suggest that the algorithm proposed is extremely robust and finds the true parameters very well. This is partially also due to the random seed employed which seems to have good distributional properties. For further details please refer to the appendix.

3 The empirical results

This section reports the empirical results. First, we address the question whether the jump factor significantly increases the explanatory power of the model. Second, we study the relative valuation of swaptions for both the pure diffusion model and the jump-diffusion model. Finally we turn to the relative valuation of caps and swaptions in both modeling approaches.

3.1 The impact of the jump factor

We implement four versions of the model described in the preceding section: These models differ only in terms of the number of risk diffusive risk factors. More specifically we consider models which are driven by 4, 5, 6, and 7 risk factors. We do so in order to investigate how robust the estimation of the jump intensity is with respect to the number of diffusive risk factors considered. As can be seen from table 6 four risk factors explain roughly 95 % of the historical variance, 7 risk factors roughly 99%. Figures 4 and 5 plot the parameter estimates for the first eigenvalue and the

intensity for the up-jumps (recall that the intensity of up-jumps is equal to the intensity of down-jumps). Figure 6 shows the estimated first eigenvalue for the pure diffusion model.

{Figures 4, 5, and 6}

We see immediately that neither the choice of the first eigenvalue nor the level of the jump intensities is seriously affected by the number of diffusive factors considered. Taking a closer look at the estimated jump intensity a couple of observations are worth mentioning: Overall the jump intensity under the spot-measure appears to be very high. Empirically we identify 5 ECB surprises in the period from 1999 – 2001. Under the spot pricing measure we estimate an intensity around 2 – 4 up-jumps p.a. in the beginning of the sample period which increases up to a record 16 up-jumps p.a. in fall 2002. However, we have to keep in mind that the intensity under the pricing measure is influenced by the market price of jump-risk. Hence it is difficult to compare the intensities under both measures. An increase in the intensity may be due to either an increasing intensity under the empirical measure or a higher market price of jump risk. Second, we use a rather hands-on approach to estimate the potential jump sizes. If market participants expect larger (smaller) jumps due to surprising ECB-actions than certainly the pricing intensity should decrease (increase). Therefore the estimated intensities should be interpreted as indication for pricing relevance of the uncertainty in short term interest rates due to surprising ECB behavior.

With this caveat in mind the results obtained can be interpreted very nicely: First of all we note that there is certainly a regime switch for the jump intensities. We identify two subperiods where the first one comprises roughly the first seven months of the sample period (“low intensity period”). The second subperiod starts on 17 July 2002 and is labeled “high intensity period”. We observe a sharp increase around 1 August when the last meeting of the central bank council before the summer brake took place. During the first half of the year most market participants felt that the ECB would lower prime rates in fall 2002. The pricing impact of uncertainty about future short term rates increased when the ECB decided to leave prime rates unchanged on that day. The intensities peaked the first time right before 11 September 2002, the anniversary of the terrorist attacks on the World Trade Center. The second peak is

more difficult to explain. It occurred in the week after the federal election in Germany on 22 September 2002.

To formally test whether the jump-diffusion model has a higher explanatory power, we conduct the same likelihood ratio test as Longstaff, Santa-Clara, and Schwartz [2001] i.e. we add up the total sum of squared pricing errors for all 35 swaptions in terms of the implied Black volatilities for both models for all 213 days. Under the null hypothesis of equality, 213 times 35 times the difference between the logarithms of the sum of squared pricing errors is asymptotically distributed as chi-square variate with 213 degrees of freedom. We repeat the procedure for the two subperiods accordingly to test whether the jump-factor significantly improves the fit in both situations, i.e. when we consider low and high jump intensities. Table 8 reports the results.

{Table 8}

It becomes clear that the jump-diffusion model which accounts for potentially surprising ECB behavior is doing a significantly better job in explaining observed swaption prices than the pure diffusion setting. As a robustness check we also consider both subperiods separately. Table 8 indicates that for both the “low intensity period” and the “high intensity period” the “ECB-jump-factor” is statistically significant. Obviously the uncertainty induced by potentially surprising actions of the ECB is reflected in derivatives prices. The estimated time series of jump intensities furthermore suggests that the influence on prices is not constant over time. This key finding is independent of the number of diffusive factors taken into account. Thus, in the following we report results for the models with 7 diffusive factors. The results for the other models considered in this subsection are similar.

3.2 The Relative Pricing of Swaptions

To assess the overall quality of fit of the two modeling approaches it is instructive to consider the root mean squared errors (RMSE). The RMSE is given by summing up the squared pricing errors in terms of the implied Black volatilities, dividing by 35

(number of swaptions) and taking the square root. Figure 7 plots the time series of RMSE for both the diffusion- and the jump-diffusion-model.

{Figure 7}

Figure 7 shows that the ability of the models to fit swaption prices changes over time. In the “low intensity period” the RMSE is less than 1% of Black volatilities for most of the time. In the “high intensity period” the models perform worse. There are two possible explanations for this observation: Either swaptions are quoted worse relatively to each other or the fundamental modeling assumptions of time homogeneity as well as the use of the historical correlation matrix are too restrictive.ⁱⁱ In absolute terms, the improvement of the model by adding the jump-component is greater in the “high intensity period”.

To further investigate the effect of the jump risk on swaption prices we consider the fit of each swaption individually. Table 9 gives the results for the jump diffusion model and table 10 for the pure jump model.

{Table 9 and 10}

The most striking difference in terms of the implied Black volatilities are for the 1x1 and the 2x1 swaption. For the 1x1 swaption the jump-diffusion model is better when comparing the medians and the means by 1.33% and 2.07% respectively. However the jump model is worse than the diffusion model in fitting the 2x1 swaption by 0.61% in the median and 0.73% in the mean. In the “low intensity period” the jump-model is doing a better job in pricing the 1x1 by 1.24% in mean (1.27% in mean) while the diffusion model is more accurate for the 2x1 swaption by 0.45% (0.43%). For the “high intensity period” the jump – diffusion model improves pricing for the 1x1 and the 1x2 swaptions (3.48% and 0.44% improvement in means respectively) while it has problems in correctly capturing the prices of the 2x3, 3x4, 4x5, and 5x6 swaptions (they are worse by 1.06%, 0.78%, 0.62%, and 0.47% in medians respectively).

Generally speaking the greatest differences between the two models are observed for swaptions with an underlying 1-year swap ($i \times 1$ swaptions, $i \in 2..5$). Clearly this is due to the fact that their value is driven by forward rates which may jump before maturity. Both models tend to undervalue the 1x1 swaption while the jump diffusion

model overprices the other $i \times 1$ swaptions, $i \in 2..5$. This result suggests that the 1×1 swaption either is quoted with Black volatilities that are relatively high in comparison to the other swaptions or that the model is missing an important feature for the short term. As a consequence the jump-model overfits the jump-intensity for these options. The problem becomes especially relevant during the 2nd subperiod when we observe extremely high jump intensities due to expensive 1×2 and 1×2 swaptions and a worse model fit.

Tables 9 and 10 indicate that there are some clear patterns of systematic valuation errors for the swaptions. Most striking is the fact that in most cases the swaptions with maturity in 1 year are undervalued by the models. Furthermore, the valuation errors display high degrees of first order-autocorrelation. To formally test whether the valuation errors are statistically significant we conducted sample mean tests. Under the null hypothesis the mean pricing error of each swaption is equal to zero. The standard deviations and the t-values were adjusted for first-order autocorrelation. As tables 9 and 10 show the null hypothesis is rejected for most of the swaptions. The only exceptions are the 4×5 and the 5×5 for the jump-diffusion model and the 3×5 , 4×6 , and the 5×5 swaptions in the diffusion model.

3.3 The Relative Pricing of Caps and Swaptions

The relative valuation of caps and swaptions provides a good way of backtesting the results obtained in the previous subsection. As mentioned earlier caps are portfolios of options written on single forward rates – the caplets. The maturity of each caplet coincides with the maturity of the respective forward rate. Thus at maturity of the caplet the forward rate has passed through the entire jump period. This contrasts swaptions which are options on baskets of forward rates of which not each one of them has necessarily jumped at maturity. Therefore the jump component should have a larger impact on cap prices. It is well known in the literature (e.g. Rebonato [1998]) that cap prices are independent of the correlation structure. They therefore allow to check whether the overall variance of the forward rates induced by both the jump and the diffusion components are in line with market expectations.

To obtain the cap prices we do the following: For each day in the sample period we use the optimal parameters calculated from the swaptions market. We simulate 10'000 paths using antithetic variates as variance reduction method for both the jump-diffusion model as well as the diffusion model. We calculate the prices of the caplets as expected payoffs discounted by the discretely compounded money market account. The total price of the cap is the sum of all the caplets. Since we are working in terms of the Black volatilities throughout this paper we finally compute the flat Black volatility for each cap and compare it to the market quote. The procedure of finding the flat volatilities is similar to the calculation of implied volatilities. Tables 11 and 12 report the results.

{tables 11 and 12}

In the entire sample period the jump-diffusion model is doing better than the diffusion models in terms of the medians and the means for the 1-year, 2-year, 3-year, 4-year, and 5-year cap. The diffusion model provides a closer fit only for the 7-year and the 10 year-cap. Taking a closer look at the two subperiods reveals a particularly interesting result: In the "low-intensity-period" the jump-diffusion model is better for all caps considered. In the "high-intensity-period" however it fits short-term caps closely while long term caps are substantially overpriced. This accords to the observation made earlier that the intensity might be overfitted.

Like it is the case for swaptions, tables 11 and 12 indicate some persistence of the pricing errors: Short-term caps tend to be undervalued while longer term-caps are overvalued. Furthermore, the valuation errors also display a high degree of first-order autocorrelation. To formally test whether the models correctly price the caplets we conduct the same sample-mean test as for the swaptions. The results are given as well in tables 11 and 12. Similar to the case of swaptions, the test rejects the null hypothesis of the sample mean being equal to zero for most of the caps. Remarkable is again the quality of fit for the short term caps for the "high intensity period".

4 Conclusion

This paper analyses the effects of potential surprising actions of the ECB on derivatives prices. We employ a LIBOR market model with potential jumps in short term forward rates and compare it to a pure diffusion model. The jump sizes, the diffusion factors and the correlation matrix are estimated historically to ensure a parsimonious modeling approach.

The key finding of this paper is that the jump component significantly improves the models ability to fit observed swaptions prices. However the estimated pricing-intensities are extremely high compared to the frequency of ECB surprises identified in the historical term structure data. We divide the sample period into two subperiods: A “low intensity period” and a “high intensity period”. The jump-diffusion model provides a better over-all fit in the “low intensity period” while the results in the “high intensity period” suggest that the intensity parameter might be overfitted. Especially the pricing of the of the 1x1 and to some extend the 1x2 swaptions are improved when the jump component is included. However, the other swaptions with an underlying 1-year swap are fitted worse. Considering the relative valuation of caps and swaptions we find that the jump-diffusion model prices these derivatives more consistently.

The robustness of the model employed certainly comes at the cost of a less than perfect fit to both swaptions and caps prices. We note that some pricing errors might be attributed due to misquotes coming e.g. from the unwillingness to take certain positions. However the worse model fit in the “high intensity period” suggests that there might be some improvement.

An extension of this paper would therefore be to develop a more flexible modeling approach which is able to fit stress periods like the “high intensity period” in a better way. This task is far from being trivial since the calibration of the simple model considered in this paper is numerically extremely expensive. Our intuition for a potential improvement is to allow for greater flexibility in the diffusion component especially for short term forward rates. A possible route might be the relief of the strict assumption of time-homogeneity in the model (e.g. through the incorporation of stochastic volatility). A second extension might be to consider a CEV – type process for the diffusion

as in Andersen and Andreasen [2000] and couple it with a jump component. Third a more elaborate determination of the historical variance – covariance matrix which takes into account potential mean reversion properties of interest rates in the spirit of Lo and Wang [1995] and Korn and Uhrig-Homburg [2002] could bring a further improvement.

Finally this paper only deals with pricing issues but has not touched upon the hedging problematic. Addressing this issue might also deliver some valuable insight about the plausibility of the high intensities implicitly estimated in the course of this study.

5 Appendix

5.1.1 Girsanov theorem

This appendix gives the suitable version of the Girsanov theorem in the presence of a MPP. For further background refer to Björk, Kabanov, and Runggaldier [1997] in the context of pricing fixed income instruments. The relevant mathematical definitions can be found in Jacod and Shiryaev [1988] and Brémaud [1981].

Define the martingale process L_t under the measure P according to

$$(A.1) \quad dL_t = L_t \Gamma_t^T dW_t^P + L_{t-} \int_E [\phi(t, x) - 1] (\mu(dt, dx) - \nu^P(t, dx) dt)$$

where $L_0 = 1$, Γ_t is an m -dimensional predictable process and $\phi(t, x)$ is a strictly positive P -measurable function and the following technical conditions hold

$$(A.2) \quad \int_0^t \|\Gamma_s\|^2 ds < \infty, \quad \text{and} \quad \int_0^t \int_E \phi(s, x) \cdot \nu^P(s, dx) ds < \infty$$

then there exists an equivalent probability measure Q such that $dQ_t = L_t dP_t$ such that

$$(A.3) \quad \begin{aligned} dW_t^P &= \Gamma_t^T dt + dW_t^Q \\ \nu^Q(t, dx) &= \phi(t, x) \cdot \nu^P(t, dx) \end{aligned}$$

Note that we can use this result of course for both switching between the empirical measure and the pricing measure as well as between pricing measures. Under the empirical measure (A.1) can be compared to the process of the stochastic discount factor (SDF) without drift. In this case Γ_t is the market price of diffusion risk and $\phi(t,x)$ is the market price of jump risk. If $\phi(t,x) = \text{const} = 1$ then the market does not price jump risk. Hence the SDF would not jump.

5.1.2 Numerical Quality of the Algorithm

The purpose of this appendix twofold. First we calculate the prices of zero bonds and swaptions to check whether the implementation is arbitrage-free. Second we check for the convergence properties given the random seed employed.

Table 13 gives the term structure of zero-bond prices for the 2 January 2002 calculated out of the optimal parameters for that day. The prices are obtained by Monte Carlo simulation and compared to their theoretical counterparts. We observe that they are equal at least up to the level of 1 basis point (0.01%).

{Table 13}

The same procedure is repeated for the prices of payer and receiver swaptions (notional = € 100). Table 14 reports the prices, their averages price and the standard errors for the average prices. We observe that the prices are in line within a basis point.

{Table 14}

To further assess the convergence properties we recalculate table 9 and 11 using the optimal model parameters to generate 200'000 antithetic sample paths where the random number seeds are randomly picked. Tables 15 and 16 show the differences. Obviously that the seed of random numbers used in the course of model calibration is actually performing because it matches the results for 200'000 sample paths very closely. The deviation in Black volatilities if the prices deviate by 3 standard errors corresponds to less than 0.08% if 200'000 antithetic sample paths are employed. We therefore judge the results obtained as reliable and the numerical quality of the algorithm as good. {Table 15 and 16}

6 References

- Amin, K. and A. Morton [1994]: “Implied Volatility Functions in Arbitrage-Free Term Structure Models“, *Journal of Financial Economics* 35, 141 – 180.
- Andersen L. and J. Andreasen [2000]: “Volatility Skews and Extensions of the LIBOR Market Model“, *Applied Mathematical Finance*, 7, 1, 1-32.
- Babbs, S. and N. Webber [1997]: “Term Structure Modelling under Alternative Official Regimes“, in: Dempster, M. and S. Pliska (eds.): *Mathematics of Derivative Securities*, Cambridge: Cambridge University Press.
- Baxter, M. [1997]: “General Interest Rate Models and the Universality of HJM“, in: Dempster, M. and S. Pliska (Hrsg.): „Mathematics of Derivative Securities“, Cambridge University Press.
- Björk, T., Y. Kabanov, and W. Runggaldier [1997]: “Bond Market Structure in the Presence of Marked Point Processes“, *Mathematical Finance*, 7, 2, 211 – 239.
- Black, F. [1976]: “The Pricing of Commodity Contracts“, *Journal of Financial Economics*, 3, 167 – 179.
- Black, F. and P. Karasinski [1991]: “Bond and Option Pricing when Shortrates are Lognormal“, *Financial Analysts Journal*, 47, 4, 52 – 59.
- Bossaerts P. and P. Hillion [1997]: “Local parametric analysis of hedging in discrete time“, *Journal of Econometrics*, 81, 1, 243 – 272.
- Brace, A., D. Gatarek, and M. Musiela [1997]: “The Market Model of Interest Rate Dynamics“, *Mathematical Finance* 7, 2, 127 – 154.
- Brémaud, P. [1981]: *Point Processes and Queues : Martingale Dynamics*, Berlin: Springer-Verlag.
- Bühler, W., M. Uhrig-Homburg, U. Walter and T. Weber [1999]: “An Empirical Comparison of Forward-Rate and Spot-Rate Models for Valuing Interest-Rate Options“, *Journal of Finance*, 1, 269 – 305.
- Das, S. [2000]: “The Surprise Element: Jumps in Interest Rates“, Working Paper, Santa Clara University.
- de Jong, F., J. Driessen, and A. Pelsser [2001]: “Libor Market Models versus Swap Market Models for Pricing Interest Rate Derivatives: An Empirical Analysis“, *European Finance Review*, 5, 201 – 237.
- El-Jahel, L., H. Lindberg, and W. Perraudin [1997]: “Interest Rate Distributions, Yield Curve Modelling and Monetary Policy“, in: Dempster, M. and S. Pliska (eds.): *Mathematics of Derivative Securities*, Cambridge: Cambridge University Press.

Flesaker, B. [1993]: "Testing the Heath-Jarrow-Morton/Ho-Lee Model of Interest-Rate Contingent Claims Pricing", *Journal of Financial and Quantitative Analysis* 28, 483 – 495.

Glasserman P. and S.G. Gou [2001a]: "The Term Structure of Simple Forward Rates with Jump Risk", Working Paper, Columbia University.

Glasserman P. and M. Merener [2001b]: "Numerical Solution of the Jump-Diffusion LIBOR Market Model, Working Paper, Columbia University.

Goldstein, R. [2000]: "The Term Structure of Interest Rates in a Random Field", *Review of Financial Studies*, 13, 365 – 384.

Heath, D., R. Jarrow, and A. Morton [1992]: "Bond Pricing and the Term Structure of Interest Rates: A New Methodology for Contingent Claims Evaluation", *Review of Financial Markets* 9, 55 – 76.

Ho, T. and S. Lee [1986]: "Term Structure Movements and Pricing Interest Rate Contingent Claims", *Journal of Finance* 41, 5, 1011 – 1029.

Honoré, P.[1998]: "Modelling Interest Rate Dynamics in a Corridor with Jump Processes", Working Paper, Aarhus School of Business.

Hull, J. and A. White [1990]: "Pricing Interest Rate Derivative Securities", *Review of Financial Studies* 3, 4, 573 – 592.

Hull, J. and A. White [1994a]. "Numerical Procedures for Implementing Term Structure Models I: Single-Factor Models", *Journal of Derivatives*, 2, Fall, 7-16.

Hull, J. und A. White [1994b]: "Numerical Procedures for Implementing Term Structure Models II: Two-Factor Models", *Journal of Derivatives* 2, Winter, 37 – 48.

Hull, J. and A. White [2000]. "Forward Rate Volatilities, Swap Rate Volatilities, and the Implementation of the LIBOR Market Model", *Journal of Fixed Income*, 10, 2, 46 – 62.

Jacod, J. and A. Shiryaev [1987]: *Limit Theorems for Stochastic Processes*, Berlin: Springer-Verlag.

Jamshidian, F. [1997]: „LIBOR and Swap Market Models and Measures“, *Journal of Finance and Stochastics*, 1, 293 – 330.

Johannes, M. [2000]: "A Nonparametric View of the Role of Jumps to Interest Rates", Working Paper, Columbia University.

Joshi, M. and R. Rebonato [2001]. "A Stochastic Volatility, Displaced-Diffusion Extension of the LIBOR Market Model", *Working Paper*, Quantitative Research Centre (QUARC), Royal Bank of Scotland.

Korn, O. and M. Uhrig-Homburg [2002]: "Do Lead-Lag Effects Affect Derivative Pricing?", Working Paper, University of Mannheim.

Lekkos, I. [2000]: "A Critique of Factor Analysis of Interest Rates ", *Journal of Derivatives*, 72 – 83.

Lo, A. and J. Wang [1995]: "Implementing Option Pricing Models when Asset Returns are Predictable", *Journal of Finance*, 50, 87 – 129.

Longstaff, F., P. Santa-Clara, and E. Schwartz [2001]. "The Relative Valuation of Caps and Swaptions: Theory and Empirical Evidence", *Journal of Finance*, 56, 6, 2067 – 2109.

Longstaff, F. und E. Schwartz [1992]: "Interest Rate Volatility and the Term Structure of Interest Rate: A Two-Factor General Equilibrium Model", *Journal of Finance* 47, 1259-1282.

Miltresen, K., K. Sandmann, and D. Sondermann [1997]: "Closed Form Solutions for Term Structure Derivatives with Log-Normal Interest Rates", *Journal of Finance* 52, 1, 409 – 430.

Piazzesi, M. [2000]: *Essays in Monetary Policy and Asset Pricing*, PhD-Thesis, Stanford University.

Piazzesi, M. [2001]: "An Econometric Model of the Yield Curve with Macroeconomic Jump Effects", Working Paper, Anderson School at UCLA.

Press, W., S. Teukolsky, W. Vetterling, and B. Flannery [1993]. *Numerical Recipes in C*, 2nd edition, Cambridge: Cambridge University Press.

Rebonato, R. [1998]: *Interest Rate Option Models*, 2nd ed., Chichester: John Wiley & Sons.

Rebonato, R. [1999]. "On the Simultaneous Calibration of Multifactor Lognormal Interest Rate Models to Black Volatilities and to the Correlation Matrix", *Journal of Computational Finance*, 2, 4, 5-27.

Sandmann, K., and D. Sondermann [1997]: "A Note on the Stability of Lognormal Interest Rates Models and the Pricing of Eurodollar Futures", *Mathematical Finance*, 7, 2, 119 – 125.

Zühlsdorff, C. [1999]: "Extended Market Models with Affine and Quadratic Volatility", Working Paper, University of Bonn.

Table 1
Descriptive Statistics of the Term Structure Data Used

The table shows summary statistics for the entire period (4 January 1999 – 30. October 2002) for the term structure data. Weekly data is used to estimate the moments.

Rate	Maturity (years)	Mean	Standard Deviation	Minimum	Median	Maximum
EURIBOR	0.5	3.82%	0.73%	2.59%	3.55%	5.20%
EURIBOR	1	3.93%	0.74%	2.68%	3.85%	5.34%
Swap	2	4.23%	0.71%	2.83%	4.33%	5.56%
Swap	3	4.44%	0.68%	2.99%	4.54%	5.64%
Swap	4	4.61%	0.64%	3.20%	4.74%	5.70%
Swap	5	4.76%	0.61%	3.40%	4.88%	5.75%
Swap	7	5.03%	0.55%	3.69%	5.14%	5.85%
Swap	10	5.28%	0.49%	4.02%	5.37%	5.99%

Figure 1
Dynamics of the Spot and Forward Rates

The figure shows the dynamics of selected rates spanning over a period of 6 months for the whole period considered (4 January 1999 – 30 October 2002).

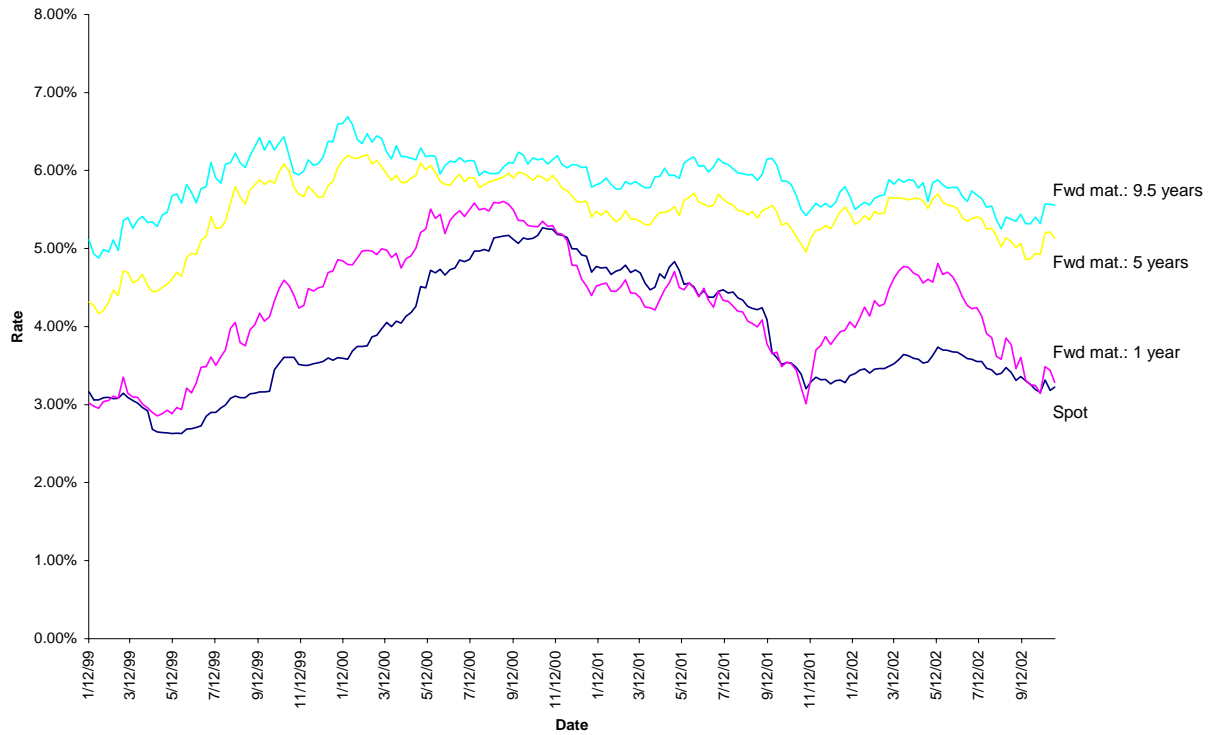


Table 2

Descriptive Statistics of the Cap Data Used

The table shows summary statistics for the entire period (4 January 1999 – 30 October 2002) for the cap data (flat volatilities). Weekly data is used to estimate the moments.

Cap	Mean	Standard Deviation	Minimum	Median	Maximum
1-year	18.35%	4.44%	10.20%	17.40%	29.80%
2-year	19.02%	3.33%	12.40%	18.30%	27.00%
3-year	19.13%	3.08%	13.60%	18.50%	27.00%
4-year	18.66%	2.83%	14.10%	18.20%	26.50%
5-year	18.25%	2.76%	14.30%	17.80%	26.50%
7-year	17.21%	2.39%	13.60%	16.80%	24.50%
10-year	15.99%	1.99%	12.70%	15.90%	22.30%

Table 3
Descriptive Statistics of the Swaption Data Used

The table shows summary statistics for the entire period (4 January 1999 – 30 October 2002) for the swaption data (Black [1976]-volatilities). Weekly data is used to estimate the moments

Swaption	Mean	Standar Deviation	Minimum	Median	Maximum
1x1	18.76%	3.33%	12.70%	17.80%	27.30%
1x2	17.49%	2.64%	12.25%	16.90%	23.90%
1x3	16.18%	2.21%	11.65%	15.75%	21.70%
1x4	15.17%	1.96%	11.15%	14.85%	19.90%
1x5	14.38%	1.77%	10.80%	14.10%	18.50%
1x6	13.82%	1.62%	10.60%	13.50%	17.60%
1x7	13.35%	1.50%	10.45%	13.10%	16.80%
1x8	12.94%	1.41%	10.25%	12.75%	16.10%
1x9	12.59%	1.34%	10.10%	12.50%	15.50%
2x1	17.90%	2.66%	13.75%	17.60%	27.25%
2x2	16.31%	1.99%	13.20%	16.05%	22.10%
2x3	15.06%	1.60%	12.50%	14.75%	19.55%
2x4	14.11%	1.38%	11.85%	13.85%	17.85%
2x5	13.39%	1.22%	11.40%	13.10%	16.60%
2x6	12.94%	1.11%	11.00%	12.80%	16.00%
2x7	12.57%	1.02%	10.65%	12.45%	15.60%
2x8	12.27%	0.98%	10.35%	12.15%	15.15%
3x1	17.01%	2.47%	13.25%	16.55%	26.55%
3x2	15.34%	1.78%	12.40%	14.95%	20.90%
3x3	14.15%	1.37%	11.75%	13.90%	18.65%
3x4	13.23%	1.09%	11.15%	13.00%	16.65%
3x5	12.57%	0.94%	10.75%	12.35%	15.60%
3x6	12.22%	0.86%	10.45%	12.05%	15.25%
3x7	11.94%	0.82%	10.20%	11.80%	14.85%
4x1	16.07%	2.37%	12.35%	15.50%	25.00%
4x2	14.42%	1.62%	11.65%	14.15%	20.05%
4x3	13.31%	1.19%	11.05%	13.05%	17.70%
4x4	12.47%	0.92%	10.60%	12.35%	15.65%
4x5	11.90%	0.79%	10.25%	11.70%	14.85%
4x6	11.65%	0.76%	10.05%	11.50%	14.60%
5x1	15.13%	2.18%	11.65%	14.75%	22.55%
5x2	13.61%	1.48%	10.90%	13.40%	18.35%
5x3	12.62%	1.09%	10.50%	12.45%	16.55%
5x4	11.90%	0.86%	10.15%	11.80%	15.10%
5x5	11.40%	0.78%	9.80%	11.20%	14.30%

Figure 2
Prime Rate Changes 1999 – 2002

The figure plots the levels of the 6-month- and 12-month EURIBOR and the prime rates for the Eurozone.

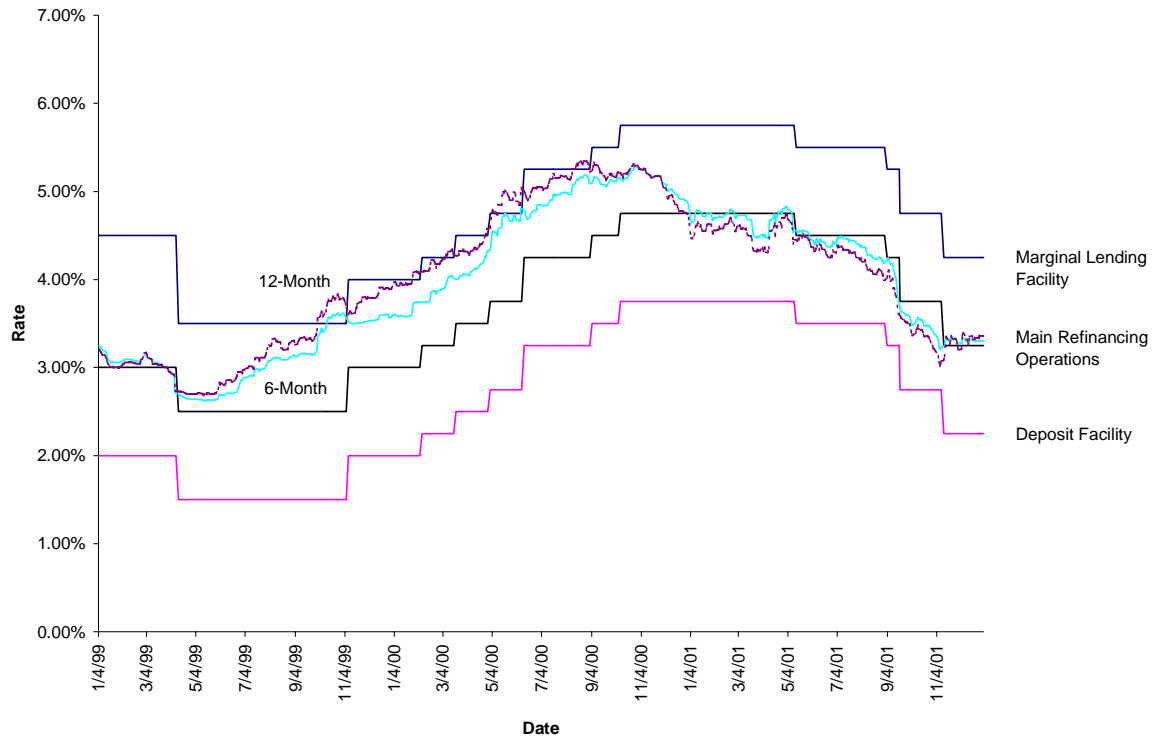


Table 4
Surprising ECB-Moves

The table lists the surprising ECB actions identified. The change refers to the rate for the main refinancing operations. 1 basis point (bp) corresponds to 0.01%

Date	Change (in bp)	ECB-Move
8-Apr-99	-50	Market participants expected smaller change (-25 bp) of prime rates.
8-Jun-00	50	Market participants expected smaller change (25 bp) of prime rates. Furthermore, ECB changed tender system.
5-Oct-00	25	Market participants did not expect change of prime rates on that particular day. However change of prime rates was "in the air"
11-Apr-01	0	Market participants anticipated lowering of prime rates. However, the ECB kept prime rates constant. This led to a change in expectations of the market participants that the ECB would keep the prime rates at their current levels.
10-May-01	-25	ECB surprisingly lowered prime rates which were believed to remain unchanged on 11-Apr-01
17-Sep-01	-50	Coordinated lowering of prime rates of ECB and Federal Reserve after the terrorist attacks on 11-Sep-01

Table 5

Log-Forward Rate Changes at ECB Interventions

The table lists the log changes of forward rates at the days when the ECB announced changes of interest rate. We furthermore add the 11 April 2001 to the list. Surprising actions as identified in table 4 are printed in bold. The values in brackets are standardized measures z of the log changes which are calculated according to $z = (\text{Log change} - \text{Estimated Mean}) / \text{Estimated Standard Deviation}$.

	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5
04/08/99	-7.31% (-10.0)	-5.43% (-4.8)	-1.78% (-1.3)	0.58% (0.3)	-1.01% (-0.8)	-3.00% (-2.5)	-3.37% (-3.0)	-3.43% (-2.9)	-3.60% (-3.5)	-3.49% (-3.5)
11/04/99	-0.51% (-0.7)	-1.22% (-1.1)	-2.18% (-1.7)	-2.37% (-1.3)	-1.20% (-0.9)	-0.33% (-0.3)	-0.74% (-0.7)	-1.38% (-1.2)	-1.81% (-1.8)	-2.03% (-2.1)
02/03/00	-0.05% (-0.1)	-0.68% (-0.6)	-0.59% (-0.5)	-0.35% (-0.2)	-0.44% (-0.4)	-0.28% (-0.3)	0.33% (0.3)	0.35% (0.3)	-0.60% (-0.6)	-1.37% (-1.4)
03/16/00	-0.65% (-0.9)	-1.15% (-1.0)	-1.24% (-1.0)	-1.06% (-0.6)	-0.86% (-0.7)	-0.96% (-0.8)	-1.47% (-1.3)	-1.66% (-1.4)	-1.24% (-1.2)	-0.79% (-0.8)
04/27/00	1.47% (2.0)	1.92% (1.7)	0.92% (0.7)	-0.12% (-0.1)	0.44% (0.3)	1.36% (1.1)	1.73% (1.5)	1.38% (1.1)	0.38% (0.3)	-0.05% (-0.1)
06/08/00	3.28% (4.5)	4.44% (3.9)	3.33% (2.5)	1.59% (0.9)	1.55% (1.1)	2.18% (1.8)	2.65% (2.3)	2.40% (2.0)	1.25% (1.2)	0.28% (0.2)
08/31/00	-0.95% (-1.3)	-0.99% (-0.9)	-0.20% (-0.2)	0.64% (0.3)	0.49% (0.3)	-0.14% (-0.1)	-0.75% (-0.7)	-0.93% (-0.8)	-0.50% (-0.5)	-0.17% (-0.2)
10/05/00	0.81% (1.1)	0.79% (0.7)	0.82% (0.6)	0.55% (0.3)	-0.22% (-0.2)	-0.49% (-0.4)	0.21% (0.1)	0.48% (0.4)	-0.23% (-0.3)	-0.78% (-0.8)
04/11/01	3.91% (5.3)	5.00% (4.4)	2.88% (2.1)	0.23% (0.1)	0.45% (0.3)	1.39% (1.1)	1.67% (1.4)	1.66% (1.4)	1.51% (1.4)	1.29% (1.2)
05/10/01	-4.14% (-5.6)	-4.02% (-3.6)	-1.43% (-1.1)	0.43% (0.2)	-1.18% (-0.9)	-2.45% (-2.0)	-1.05% (-1.0)	0.27% (0.2)	0.37% (0.3)	0.39% (0.4)
08/30/01	-0.89% (-1.2)	-2.54% (-2.3)	-1.58% (-1.2)	-0.18% (-0.1)	-0.80% (-0.6)	-1.44% (-1.2)	-1.02% (-0.9)	-0.69% (-0.6)	-0.91% (-0.9)	-0.98% (-1.0)
09/17/01	-6.93% (-9.4)	-4.15% (-3.7)	1.51% (1.1)	4.39% (2.4)	1.80% (1.3)	-0.76% (-0.7)	-0.10% (-0.1)	0.80% (0.6)	0.79% (0.7)	0.63% (0.6)
11/08/01	0.19% (0.3)	1.61% (1.4)	2.40% (1.8)	2.31% (1.3)	1.89% (1.4)	1.49% (1.2)	1.32% (1.1)	1.24% (1.0)	1.21% (1.1)	1.15% (1.1)

Table 5 (continued)

	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5
04/08/99	-3.02% (-3.5)	-2.49% (-3.0)	-2.03% (-2.3)	-1.67% (-1.8)	-1.40% (-1.7)	-1.15% (-1.4)	-0.91% (-1.1)	-0.68% (-0.8)	-0.48% (-0.5)	-0.30% (-0.3)
11/04/99	-1.98% (-2.3)	-1.84% 2.2)	-1.67% (-1.9)	-1.48% (-1.6)	-1.27% (-1.5)	-1.05% (-1.3)	-0.83% (-1.0)	-0.63% (-0.8)	-0.46% (-0.5)	-0.32% (-0.3)
02/03/00	-1.49% (-1.7)	-1.44% 1.7)	-1.38% (-1.5)	-1.31% (-1.5)	-1.25% (-1.5)	-1.19% (-1.5)	-1.13% (-1.4)	-1.08% (-1.3)	-1.05% (-1.1)	-1.04% (-1.1)
03/16/00	-0.57% (-0.7)	-0.43% 0.5)	-0.32% (-0.4)	-0.27% (-0.3)	-0.26% (-0.3)	-0.27% (-0.4)	-0.27% (-0.4)	-0.27% (-0.3)	-0.26% (-0.3)	-0.23% (-0.3)
04/27/00	0.55% (0.6)	1.26% (1.4)	1.75% (1.9)	1.89% .0)	1.66% (1.9)	1.34% (1.6)	1.04% (1.2)	0.76% (0.9)	0.53% (0.6)	0.38% (0.4)
06/08/00	-0.08% (-0.1)	-0.24% (0.3)	-0.34% (-0.4)	-0.36% (-0.4)	-0.32% (-0.4)	-0.27% (-0.4)	-0.22% (-0.3)	-0.20% (-0.3)	-0.21% (-0.2)	-0.27% (-0.3)
08/31/00	-0.20% (-0.3)	-0.30% 0.4)	-0.38% (-0.5)	-0.41% (-0.5)	-0.39% (-0.5)	-0.36% (-0.5)	-0.33% (-0.4)	-0.30% (-0.4)	-0.28% (-0.3)	-0.26% (-0.3)
10/05/00	-0.73% (-0.9)	-0.52% 0.6)	-0.30% (-0.4)	-0.09% (-0.1)	0.10% (0.1)	0.29% (0.3)	0.47% (0.5)	0.64% (0.7)	0.79% (0.8)	0.90% (0.9)
04/11/01	1.04% (1.2)	0.81% (0.9)	0.62% (0.6)	0.49% (0.5)	0.40% (0.4)	0.33% (0.4)	0.26% (0.3)	0.19% (0.2)	0.11% (0.1)	0.01% (0.0)
05/10/01	0.73% (0.8)	1.06% (1.2)	1.26% (1.4)	1.32% (1.4)	1.23% (1.4)	1.10% (1.3)	0.98% (1.2)	0.89% (1.0)	0.84% (0.9)	0.85% (0.8)
08/30/01	-0.67% (-0.8)	-0.33% 0.4)	-0.09% (-0.1)	0.03% (0.0)	0.00% (0.0)	-0.06% (-0.1)	-0.11% (-0.2)	-0.15% (-0.2)	-0.17% (-0.2)	-0.17% (-0.2)
09/17/01	0.57% (0.6)	0.55% (0.6)	0.54% (0.6)	0.57% (0.6)	0.63% (0.7)	0.70% (0.8)	0.77% (0.9)	0.84% (0.9)	0.90% (0.9)	0.96% (1.0)
11/08/01	1.06% (1.2)	0.97% (1.1)	0.88% (0.9)	0.79% (0.8)	0.72% (0.8)	0.65% (0.8)	0.58% (0.7)	0.51% (0.6)	0.44% (0.5)	0.38% (0.4)

Table 6

Historical Eigenvalues and Explanatory Power

The table gives the first eigenvalues corresponding to the factors in figure 3 ordered by size.

Factore	Eigenvalue	Explanatory Power	Explanatory Power (cumulative)
1	0.712%	74.08%	74.08%
2	0.135%	13.99%	88.08%
3	0.041%	4.24%	92.32%
4	0.034%	3.51%	95.83%
5	0.017%	1.73%	97.56%
6	0.009%	0.95%	98.51%
7	0.008%	0.84%	99.34%
8	0.006%	0.65%	100.00%

Figure 3

The First Four Historical Eigenvectors

This figure gives the eigenvectors for the first 4 eigenvalues in table 6.

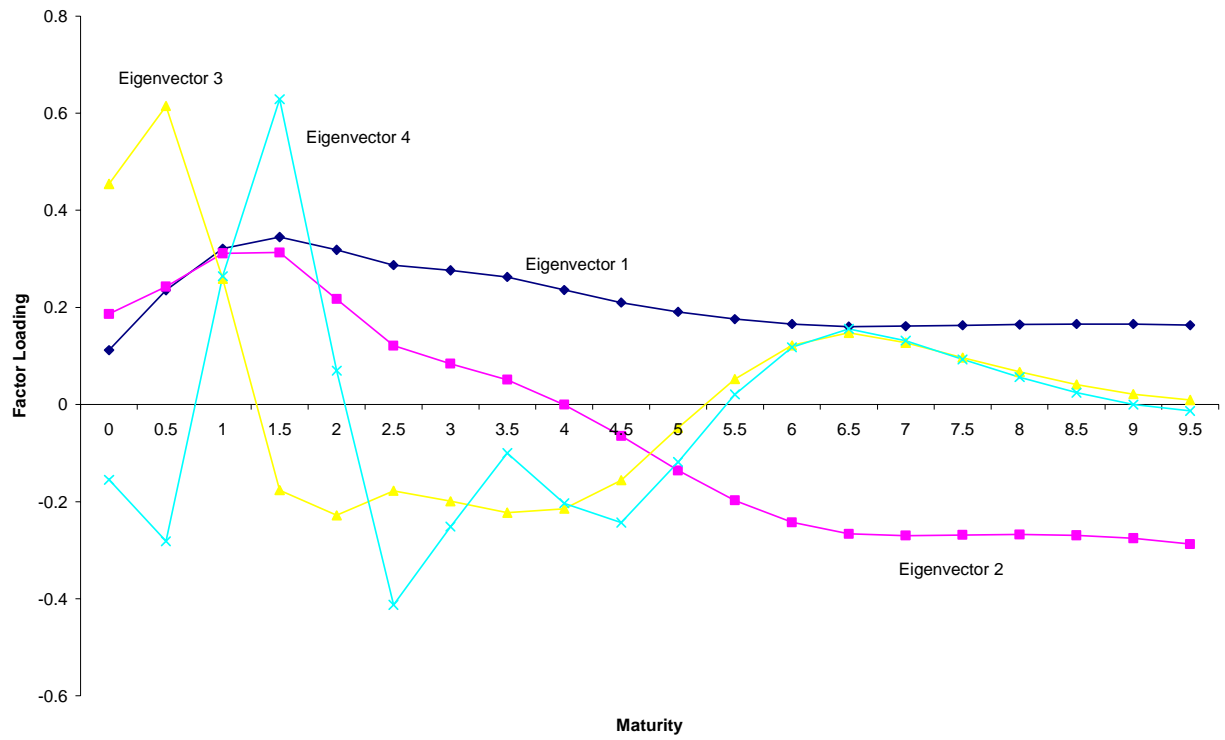


Table 7
The Jump Functions

The table gives the assumed jump amplitudes in % p.a. (% Jump). The jump function is a piecewise constant function of time to maturity of the respective forward rate.

Time to maturity		% Jump	
<i>From</i>	<i>To</i>	<i>Up</i>	<i>Down</i>
0	0.25	3.66%	-5.93%
0.25	0.75	4.83%	-4.43%

Figure 4

Estimated First Eigenvalue (Jump-Diffusion-Model)

The figure plots the first eigenvalue for the 4 jump-diffusion-models considered. The other eigenvalues are given accordingly.

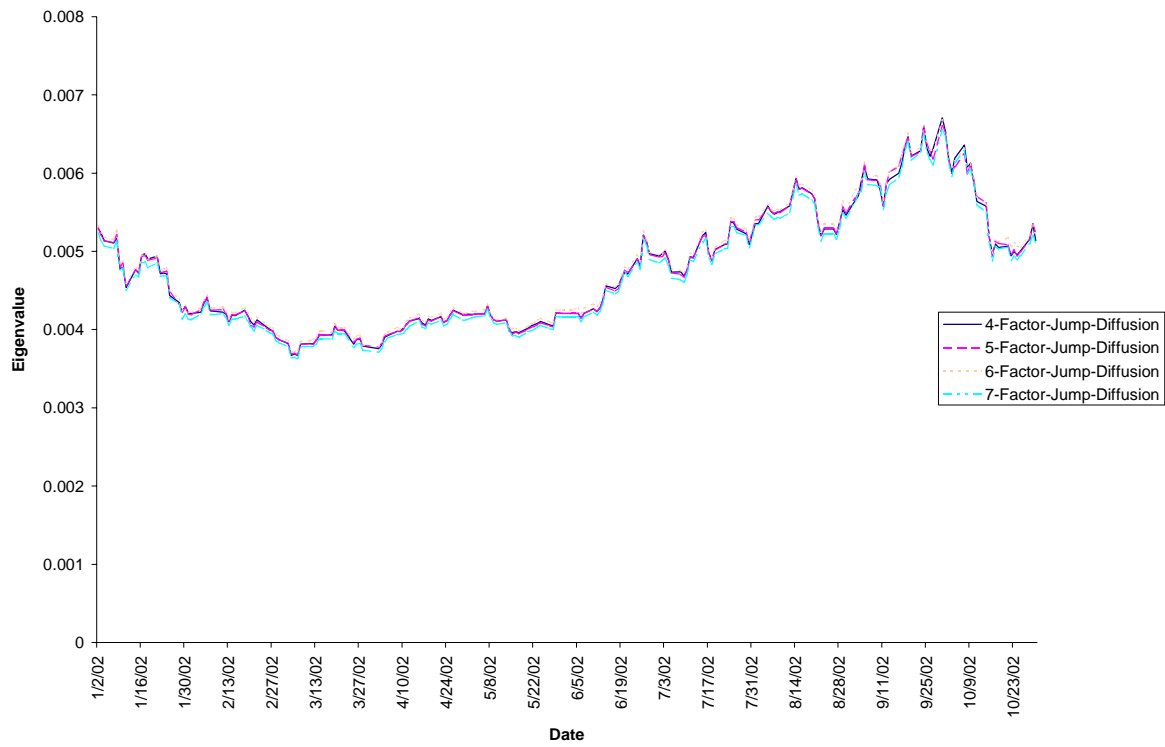


Figure 5

Estimated Up-Jump Intensities (Jump-Diffusion Model)

The figure plots the estimated intensities for up-jumps in the 4 jump-diffusion models considered. The down-jump intensities are given accordingly.

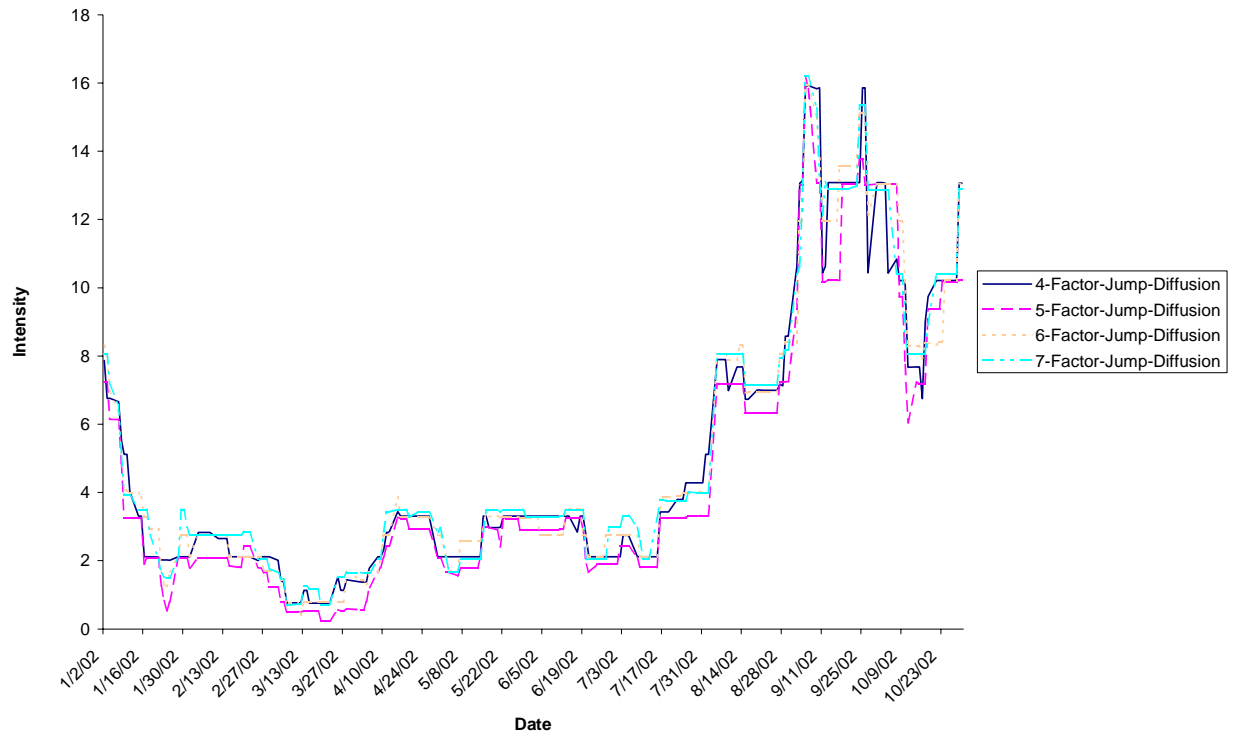


Figure 6

Estimated First Eigenvalue (Diffusion-Model)

The figure plots the first eigenvalue for the 4 diffusion-models considered. The other eigenvalues are given accordingly.



Table 8

Results of the Likelihood Ratio Tests

The table reports the test statistic, the p-value and the critical p-value at the 99% confidence level for the likelihood ratio tests. To obtain the test statistic, we add up the total sum of squared pricing errors for all 35 swaptions in terms of the implied Black volatilities for both models for all 213 days (137 days in the “low intensity period”, 76 days in the “high intensity period”). Under the null hypothesis of equality, 213 (137, 76) times 35 times the difference between the logarithms of the sum of squared pricing errors is asymptotically distributed as chi-square variate with 213 (137, 76) degrees of freedom.

A Full Sample Period

	4 Factors	5 Factors	6 Factors	7 Factors
Test-Statistic	1265.60	1173.38	1236.06	1287.64
p-Value	0.00	0.00	0.00	0.00
Critical Value	268.39			

B “Low Intensity Period”

	4 Factors	5 Factors	6 Factors	7 Factors
Test-Statistic	460.31	344.75	409.30	479.78
p-Value	0.00	0.00	0.00	0.00
Critical Value	181.84			

C “High Intensity Period”

	4 Factors	5 Factors	6 Factors	7 Factors
Test-Statistic	402.45	387.16	399.17	406.77
p-Value	0.00	0.00	0.00	0.00
Critical Value	84.73			

Figure 7

RMSE in the Jump-Diffusion and in the Diffusion Model

The figure plots the RMSE as defined in the text for both the 7-factor-diffusion and the 7-factor-jump-diffusion-model.

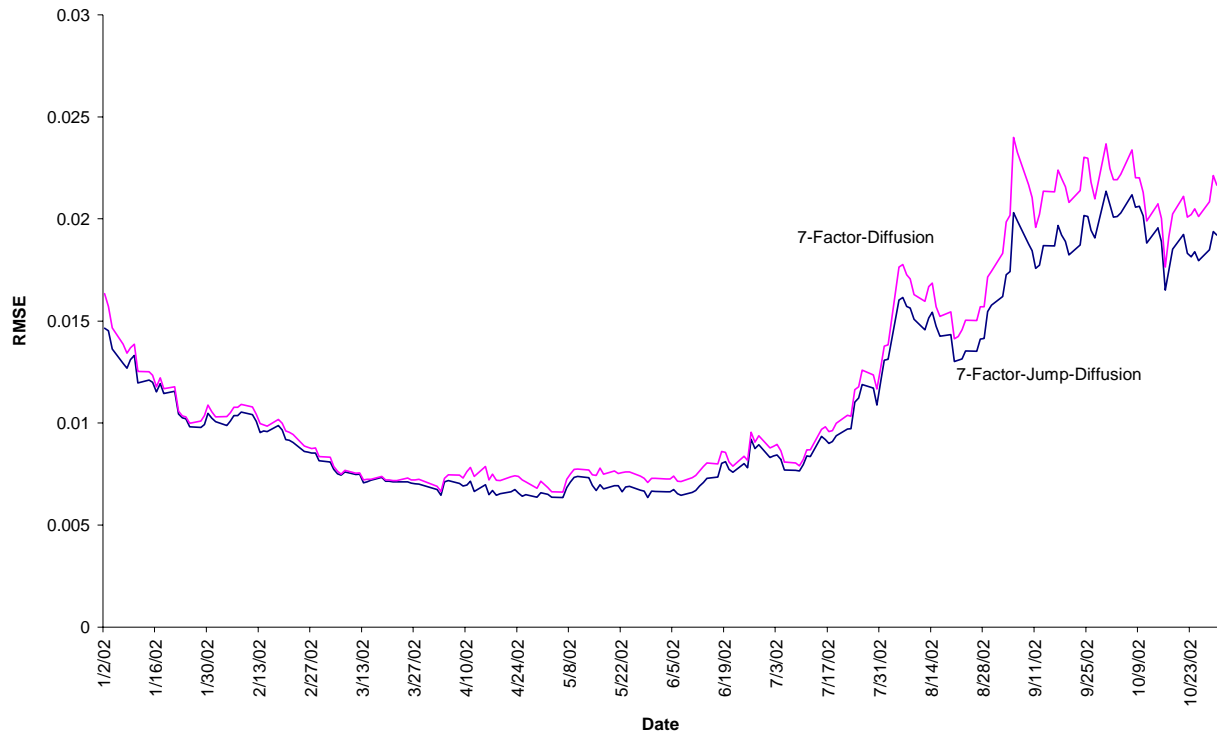


Table 9

Model Fit to Swaptions in the Jump-Diffusion-Model

The table reports the model fit (model – market) to swaptions for the whole sample period and the two subperiods assuming a jump-diffusion process. The column “Autocorr” denotes first order autocorrelation. The t-values are the test statistic for the sample mean test. The t-values and the standard deviation are adjusted for first order autocorrelation and shaded grey if the null hypothesis (mean = 0) cannot be rejected at the 95% confidence level.

Pls. Turn to next page

A Full Sample Period (213 Observations)

Swaption	Standard						Autocorr.	t-Value
	Mean	Deviation.	Minimum	Median	Maximum			
1x1	-1.63%	1.47%	-3.99%	-1.41%	-0.61%	0.895	-16.1	
1x2	-1.54%	4.32%	-3.94%	-1.06%	-0.04%	0.969	-5.2	
1x3	-1.17%	4.93%	-3.26%	-0.73%	0.11%	0.98	-3.5	
1x4	-1.02%	4.38%	-2.84%	-0.64%	-0.06%	0.981	-3.4	
1x5	-1.24%	3.88%	-2.91%	-0.95%	-0.30%	0.98	-4.7	
1x6	-1.57%	3.84%	-3.04%	-1.32%	-0.74%	0.983	-6.0	
1x7	-1.72%	3.34%	-3.04%	-1.53%	-0.94%	0.981	-7.5	
1x8	-1.70%	3.04%	-2.89%	-1.55%	-0.94%	0.981	-8.2	
1x9	-1.59%	1.48%	-2.63%	-1.47%	-0.81%	0.93	-15.7	
2x1	1.01%	0.36%	0.44%	0.98%	1.77%	0.741	40.5	
2x2	0.77%	0.60%	0.15%	0.81%	1.31%	0.908	18.7	
2x3	0.54%	0.51%	0.02%	0.57%	1.02%	0.911	15.4	
2x4	0.21%	0.35%	-0.22%	0.25%	0.54%	0.887	8.7	
2x5	-0.27%	0.34%	-0.67%	-0.24%	-0.04%	0.895	-11.7	
2x6	-0.68%	0.43%	-1.07%	-0.67%	-0.38%	0.924	-23.2	
2x7	-0.88%	0.43%	-1.25%	-0.89%	-0.58%	0.922	-30.2	
2x8	-0.95%	0.47%	-1.31%	-0.96%	-0.60%	0.93	-29.3	
3x1	1.44%	2.17%	0.58%	1.23%	2.85%	0.958	9.7	
3x2	1.19%	0.98%	0.66%	1.17%	1.84%	0.95	17.7	
3x3	0.80%	0.56%	0.42%	0.78%	1.31%	0.923	20.8	
3x4	0.34%	0.41%	0.05%	0.28%	0.89%	0.902	12.1	
3x5	-0.13%	0.32%	-0.36%	-0.18%	0.37%	0.881	-5.7	
3x6	-0.48%	0.26%	-0.71%	-0.52%	0.00%	0.848	-27.5	
3x7	-0.67%	0.25%	-0.90%	-0.69%	-0.26%	0.852	-38.6	
4x1	1.77%	4.74%	0.67%	1.38%	3.79%	0.981	5.5	
4x2	1.40%	2.94%	0.67%	1.28%	2.54%	0.982	7.0	
4x3	0.91%	1.78%	0.34%	0.76%	1.78%	0.972	7.4	
4x4	0.45%	1.42%	-0.13%	0.28%	1.27%	0.965	4.6	
4x5	0.03%	1.17%	-0.45%	-0.10%	0.77%	0.961	0.3	
4x6	-0.32%	0.98%	-0.76%	-0.45%	0.32%	0.957	-4.8	
5x1	1.82%	6.05%	0.42%	1.36%	4.33%	0.984	4.4	
5x2	1.34%	3.77%	0.41%	1.15%	2.92%	0.983	5.2	
5x3	0.90%	2.76%	0.12%	0.71%	2.21%	0.979	4.7	
5x4	0.50%	2.13%	-0.24%	0.34%	1.59%	0.974	3.4	
5x5	0.09%	1.78%	-0.55%	-0.06%	1.04%	0.972	0.8	

Pls. Turn to next page

B "Low Intensity Period" (137 Observations)

Swaption	Mean	Standard		Median	Maximum	Autocorr.	t-Value
		Deviation.	Minimum				
1x1	-1.23%	0.44%	-2.14%	-1.24%	-0.61%	0.763	-33.1
1x2	-0.88%	1.03%	-2.70%	-0.79%	-0.04%	0.894	-10.0
1x3	-0.57%	1.04%	-1.99%	-0.50%	0.11%	0.924	-6.4
1x4	-0.49%	0.76%	-1.69%	-0.40%	-0.06%	0.912	-7.7
1x5	-0.76%	0.74%	-1.82%	-0.64%	-0.30%	0.912	-12.0
1x6	-1.13%	0.84%	-2.16%	-0.99%	-0.74%	0.93	-15.7
1x7	-1.32%	0.94%	-2.31%	-1.20%	-0.94%	0.939	-16.6
1x8	-1.35%	1.09%	-2.26%	-1.22%	-0.94%	0.952	-14.6
1x9	-1.29%	1.32%	-2.19%	-1.14%	-0.81%	0.963	-11.4
2x1	0.92%	0.36%	0.44%	0.91%	1.60%	0.818	29.9
2x2	0.88%	0.35%	0.50%	0.89%	1.31%	0.859	29.9
2x3	0.65%	0.24%	0.35%	0.61%	1.02%	0.833	31.2
2x4	0.30%	0.12%	0.10%	0.29%	0.54%	0.716	29.3
2x5	-0.19%	0.13%	-0.40%	-0.18%	-0.04%	0.756	-16.8
2x6	-0.59%	0.24%	-0.85%	-0.57%	-0.38%	0.877	-29.4
2x7	-0.80%	0.32%	-1.14%	-0.76%	-0.58%	0.91	-29.1
2x8	-0.88%	0.45%	-1.31%	-0.81%	-0.60%	0.932	-22.7
3x1	1.06%	0.38%	0.58%	1.03%	1.61%	0.806	32.8
3x2	1.01%	0.46%	0.66%	0.98%	1.56%	0.904	25.8
3x3	0.69%	0.34%	0.42%	0.66%	1.13%	0.899	23.6
3x4	0.25%	0.19%	0.05%	0.23%	0.66%	0.808	15.3
3x5	-0.20%	0.13%	-0.34%	-0.21%	0.19%	0.733	-18.6
3x6	-0.53%	0.09%	-0.71%	-0.54%	-0.24%	0.628	-68.5
3x7	-0.71%	0.12%	-0.90%	-0.70%	-0.54%	0.736	-72.2
4x1	1.20%	0.91%	0.67%	1.09%	2.35%	0.917	15.4
4x2	1.06%	0.86%	0.67%	1.00%	1.76%	0.948	14.4
4x3	0.65%	0.50%	0.34%	0.60%	1.29%	0.91	15.1
4x4	0.22%	0.39%	-0.13%	0.21%	0.91%	0.883	6.7
4x5	-0.17%	0.30%	-0.45%	-0.18%	0.51%	0.853	-6.5
4x6	-0.49%	0.22%	-0.76%	-0.50%	0.09%	0.817	-26.1
5x1	1.15%	1.23%	0.42%	1.04%	2.69%	0.929	11.0
5x2	0.91%	0.91%	0.41%	0.84%	1.86%	0.934	11.7
5x3	0.55%	0.65%	0.12%	0.55%	1.31%	0.918	9.9
5x4	0.20%	0.46%	-0.24%	0.18%	0.96%	0.877	5.2
5x5	-0.17%	0.34%	-0.55%	-0.17%	0.55%	0.852	-5.7

Pls. Turn to next page

C “High Intensity Period” (76 Observations)

Swaption	Standard		Minimum	Median	Maximum	Autocorr.	t-Value
	Mean	Deviation.					
1x1	-2.34%	0.64%	-3.99%	-2.35%	-1.21%	0.608	-32.0
1x2	-2.69%	1.73%	-3.94%	-3.07%	-0.98%	0.886	-13.7
1x3	-2.24%	2.14%	-3.26%	-2.45%	-0.66%	0.937	-9.2
1x4	-1.96%	1.85%	-2.84%	-2.18%	-0.52%	0.935	-9.3
1x5	-2.10%	1.50%	-2.91%	-2.28%	-0.83%	0.927	-12.3
1x6	-2.35%	1.37%	-3.04%	-2.52%	-1.27%	0.932	-15.1
1x7	-2.42%	1.21%	-3.04%	-2.58%	-1.43%	0.928	-17.6
1x8	-2.32%	1.04%	-2.89%	-2.41%	-1.38%	0.92	-19.6
1x9	-2.13%	0.98%	-2.63%	-2.23%	-1.36%	0.926	-19.1
2x1	1.16%	0.25%	0.65%	1.15%	1.77%	0.436	40.7
2x2	0.57%	0.46%	0.15%	0.50%	1.07%	0.858	10.7
2x3	0.35%	0.36%	0.02%	0.33%	0.77%	0.851	8.6
2x4	0.05%	0.24%	-0.22%	0.05%	0.38%	0.783	1.8
2x5	-0.42%	0.21%	-0.67%	-0.41%	-0.16%	0.788	-17.1
2x6	-0.83%	0.18%	-1.07%	-0.84%	-0.61%	0.776	-39.5
2x7	-1.03%	0.16%	-1.25%	-1.03%	-0.82%	0.717	-57.4
2x8	-1.08%	0.14%	-1.28%	-1.08%	-0.90%	0.702	-67.5
3x1	2.13%	0.93%	1.19%	2.26%	2.85%	0.859	20.0
3x2	1.51%	0.27%	1.11%	1.52%	1.84%	0.763	49.0
3x3	1.01%	0.22%	0.68%	1.00%	1.31%	0.717	40.4
3x4	0.50%	0.26%	0.13%	0.53%	0.89%	0.805	16.6
3x5	0.00%	0.30%	-0.36%	-0.01%	0.37%	0.834	0.0
3x6	-0.39%	0.30%	-0.71%	-0.38%	0.00%	0.833	-11.0
3x7	-0.59%	0.32%	-0.86%	-0.58%	-0.26%	0.845	-16.2
4x1	2.79%	1.89%	1.39%	3.06%	3.79%	0.935	12.9
4x2	2.02%	0.90%	1.21%	2.17%	2.54%	0.919	19.5
4x3	1.36%	0.64%	0.75%	1.42%	1.78%	0.898	18.6
4x4	0.84%	0.65%	0.22%	0.90%	1.27%	0.901	11.3
4x5	0.37%	0.57%	-0.22%	0.43%	0.77%	0.901	5.8
4x6	-0.03%	0.53%	-0.58%	0.04%	0.32%	0.895	-0.3
5x1	2.99%	2.34%	1.21%	3.27%	4.33%	0.939	11.2
5x2	2.10%	1.25%	1.11%	2.20%	2.92%	0.929	14.8
5x3	1.51%	1.04%	0.70%	1.52%	2.21%	0.925	12.8
5x4	1.03%	0.92%	0.32%	1.08%	1.59%	0.925	9.8
5x5	0.56%	0.69%	-0.08%	0.61%	1.04%	0.908	7.2

Table 10

Model Fit to Swaptions in the Diffusion-Model

The table reports the model fit to swaptions (model – market) for the whole sample period and the two subperiods assuming a diffusion process. The column “Autocorr” denotes first order autocorrelation. The t-values are the test statistic for the sample mean test. The t-values and the standard deviation are adjusted for first order autocorrelation and shaded grey if the null hypothesis (mean = 0) cannot be rejected at the 95% confidence level.

Pls. turn to next page.

A Full Sample Period (213 Observations)

Swaption	Standard						Autocorr.	t-Value
	Mean	Deviation.	Minimum	Median	Maximum			
1x1	-3.69%	8.31%	-8.74%	-2.74%	-1.55%	0.974	-6.5	
1x2	-1.81%	5.09%	-4.48%	-1.23%	-0.14%	0.971	-5.2	
1x3	-1.14%	4.87%	-3.14%	-0.71%	0.12%	0.981	-3.4	
1x4	-0.89%	3.92%	-2.57%	-0.56%	-0.01%	0.981	-3.3	
1x5	-1.08%	3.36%	-2.59%	-0.85%	-0.24%	0.98	-4.7	
1x6	-1.40%	3.17%	-2.74%	-1.21%	-0.68%	0.982	-6.4	
1x7	-1.54%	2.73%	-2.69%	-1.42%	-0.85%	0.98	-8.3	
1x8	-1.52%	2.41%	-2.58%	-1.44%	-0.84%	0.979	-9.2	
1x9	-1.41%	2.21%	-2.31%	-1.35%	-0.74%	0.979	-9.3	
2x1	0.28%	1.19%	-1.11%	0.37%	1.14%	0.925	3.4	
2x2	0.81%	0.54%	0.25%	0.83%	1.31%	0.903	21.7	
2x3	0.72%	0.21%	0.37%	0.71%	1.05%	0.796	49.9	
2x4	0.42%	0.12%	0.18%	0.41%	0.64%	0.642	52.2	
2x5	-0.06%	0.15%	-0.31%	-0.06%	0.21%	0.752	-5.9	
2x6	-0.47%	0.21%	-0.75%	-0.46%	-0.20%	0.839	-32.3	
2x7	-0.68%	0.25%	-0.94%	-0.67%	-0.41%	0.863	-39.1	
2x8	-0.74%	0.33%	-1.10%	-0.71%	-0.44%	0.898	-32.5	
3x1	1.01%	0.88%	0.28%	0.95%	1.95%	0.908	16.7	
3x2	1.31%	1.28%	0.76%	1.27%	2.09%	0.961	14.8	
3x3	1.00%	1.14%	0.56%	0.89%	1.86%	0.959	12.9	
3x4	0.56%	1.02%	0.13%	0.43%	1.26%	0.955	8.0	
3x5	0.08%	0.86%	-0.23%	-0.03%	0.77%	0.948	1.4	
3x6	-0.27%	0.74%	-0.62%	-0.36%	0.38%	0.94	-5.4	
3x7	-0.46%	0.69%	-0.81%	-0.54%	0.21%	0.936	-9.7	
4x1	1.42%	3.50%	0.50%	1.15%	3.01%	0.98	5.9	
4x2	1.51%	3.36%	0.71%	1.35%	2.79%	0.983	6.6	
4x3	1.10%	2.55%	0.41%	0.89%	2.31%	0.978	6.3	
4x4	0.65%	2.20%	-0.06%	0.43%	1.79%	0.974	4.3	
4x5	0.24%	1.92%	-0.38%	0.04%	1.26%	0.972	1.8	
4x6	-0.11%	1.72%	-0.67%	-0.31%	0.81%	0.971	-1.0	
5x1	1.55%	4.94%	0.38%	1.19%	3.74%	0.983	4.6	
5x2	1.47%	4.27%	0.46%	1.24%	3.18%	0.984	5.0	
5x3	1.10%	3.59%	0.15%	0.84%	2.65%	0.982	4.5	
5x4	0.71%	2.99%	-0.19%	0.48%	2.07%	0.979	3.5	
5x5	0.30%	2.62%	-0.50%	0.08%	1.52%	0.978	1.7	

Pls. Turn to next page

B "Low Intensity Period" (137 Observations)

Swaption	Mean	Standard		Minimum	Median	Maximum	Autocorr.	t-Value
		Deviation.						
1x1	-2.49%	0.91%		-5.26%	-2.49%	-1.55%	0.826	-32.0
1x2	-1.06%	1.11%		-3.10%	-0.98%	-0.14%	0.892	-11.2
1x3	-0.55%	1.02%		-1.92%	-0.48%	0.12%	0.924	-6.4
1x4	-0.42%	0.71%		-1.49%	-0.33%	-0.01%	0.914	-6.9
1x5	-0.66%	0.71%		-1.57%	-0.57%	-0.24%	0.917	-10.9
1x6	-1.03%	0.83%		-1.89%	-0.92%	-0.68%	0.936	-14.5
1x7	-1.22%	0.94%		-2.03%	-1.11%	-0.85%	0.946	-15.2
1x8	-1.25%	1.12%		-2.04%	-1.13%	-0.84%	0.959	-13.0
1x9	-1.18%	1.36%		-2.00%	-1.04%	-0.74%	0.968	-10.1
2x1	0.49%	0.64%		-0.22%	0.46%	1.14%	0.879	8.9
2x2	0.91%	0.33%		0.59%	0.91%	1.31%	0.86	32.1
2x3	0.76%	0.19%		0.47%	0.73%	1.05%	0.802	45.6
2x4	0.43%	0.11%		0.24%	0.42%	0.59%	0.709	43.6
2x5	-0.06%	0.13%		-0.24%	-0.05%	0.13%	0.761	-5.4
2x6	-0.46%	0.22%		-0.71%	-0.45%	-0.21%	0.873	-24.8
2x7	-0.68%	0.29%		-0.94%	-0.66%	-0.42%	0.902	-27.2
2x8	-0.75%	0.42%		-1.10%	-0.71%	-0.44%	0.932	-20.9
3x1	0.81%	0.39%		0.28%	0.84%	1.27%	0.82	24.6
3x2	1.09%	0.47%		0.76%	1.04%	1.67%	0.907	27.2
3x3	0.81%	0.39%		0.56%	0.76%	1.30%	0.906	24.3
3x4	0.38%	0.30%		0.13%	0.37%	0.99%	0.86	15.1
3x5	-0.07%	0.22%		-0.23%	-0.09%	0.51%	0.821	-3.7
3x6	-0.40%	0.17%		-0.62%	-0.41%	0.09%	0.776	-27.6
3x7	-0.58%	0.18%		-0.81%	-0.59%	-0.22%	0.805	-37.3
4x1	0.99%	0.87%		0.50%	0.89%	1.91%	0.926	13.5
4x2	1.13%	0.90%		0.71%	1.06%	1.93%	0.948	14.7
4x3	0.77%	0.59%		0.41%	0.72%	1.58%	0.914	15.3
4x4	0.35%	0.49%		-0.06%	0.34%	1.20%	0.894	8.3
4x5	-0.04%	0.41%		-0.38%	-0.05%	0.84%	0.875	-1.1
4x6	-0.36%	0.33%		-0.67%	-0.37%	0.41%	0.858	-12.9
5x1	0.99%	1.19%		0.38%	0.89%	2.27%	0.935	9.8
5x2	1.00%	0.95%		0.46%	0.95%	2.06%	0.933	12.3
5x3	0.67%	0.73%		0.15%	0.67%	1.62%	0.919	10.8
5x4	0.33%	0.56%		-0.19%	0.34%	1.28%	0.888	7.0
5x5	-0.04%	0.45%		-0.50%	-0.04%	0.87%	0.871	-1.0

Pls. turn to next page

C “High Intensity Period” (76 Observations)

Swaption	Standard		Minimum	Median	Maximum	Autocorr.	t-Value
	Mean	Deviation.					
1x1	-5.81%	3.60%	-8.74%	-5.90%	-2.86%	0.911	-14.2
1x2	-3.13%	2.09%	-4.48%	-3.49%	-1.19%	0.898	-13.2
1x3	-2.17%	2.05%	-3.14%	-2.38%	-0.66%	0.937	-9.3
1x4	-1.73%	1.62%	-2.57%	-1.89%	-0.45%	0.933	-9.4
1x5	-1.82%	1.23%	-2.59%	-1.95%	-0.70%	0.922	-13.0
1x6	-2.05%	1.08%	-2.74%	-2.13%	-1.14%	0.926	-16.6
1x7	-2.11%	0.93%	-2.69%	-2.20%	-1.30%	0.921	-19.8
1x8	-2.01%	0.79%	-2.58%	-2.01%	-1.23%	0.911	-22.3
1x9	-1.82%	0.75%	-2.31%	-1.82%	-1.23%	0.92	-21.4
2x1	-0.10%	0.81%	-1.11%	-0.10%	0.64%	0.858	-1.2
2x2	0.63%	0.43%	0.25%	0.56%	1.11%	0.854	12.7
2x3	0.65%	0.15%	0.37%	0.66%	0.91%	0.669	36.8
2x4	0.41%	0.13%	0.18%	0.41%	0.64%	0.563	28.2
2x5	-0.06%	0.18%	-0.31%	-0.07%	0.21%	0.742	-2.9
2x6	-0.48%	0.21%	-0.75%	-0.49%	-0.20%	0.787	-19.9
2x7	-0.68%	0.22%	-0.94%	-0.69%	-0.41%	0.798	-27.0
2x8	-0.73%	0.23%	-1.00%	-0.72%	-0.49%	0.817	-27.1
3x1	1.35%	0.50%	0.82%	1.36%	1.95%	0.782	23.6
3x2	1.69%	0.37%	1.22%	1.73%	2.09%	0.822	39.9
3x3	1.34%	0.46%	0.82%	1.38%	1.86%	0.857	25.7
3x4	0.86%	0.57%	0.31%	0.91%	1.26%	0.895	13.3
3x5	0.35%	0.58%	-0.19%	0.42%	0.77%	0.901	5.4
3x6	-0.03%	0.60%	-0.54%	0.03%	0.38%	0.903	-0.4
3x7	-0.24%	0.60%	-0.69%	-0.15%	0.21%	0.904	-3.4
4x1	2.18%	1.40%	1.11%	2.22%	3.01%	0.935	13.6
4x2	2.19%	1.10%	1.27%	2.38%	2.79%	0.929	17.5
4x3	1.68%	0.99%	0.88%	1.76%	2.31%	0.924	14.9
4x4	1.19%	1.03%	0.38%	1.29%	1.79%	0.926	10.2
4x5	0.72%	0.95%	-0.05%	0.84%	1.26%	0.93	6.7
4x6	0.32%	0.89%	-0.41%	0.46%	0.81%	0.925	3.3
5x1	2.52%	1.89%	1.01%	2.67%	3.74%	0.936	11.7
5x2	2.32%	1.48%	1.20%	2.45%	3.18%	0.937	13.7
5x3	1.84%	1.41%	0.85%	1.86%	2.65%	0.938	11.5
5x4	1.38%	1.32%	0.49%	1.44%	2.07%	0.94	9.2
5x5	0.91%	1.07%	0.06%	1.01%	1.52%	0.931	7.6

Table 11

Model Fit to Caps in the Jump-Diffusion-Model

The table reports the model fit (model – market) to caps for the whole sample period and the two subperiods assuming a jump-diffusion process. The column “Autocorr” denotes first order autocorrelation. The t-values are the test statistic for the sample mean test. The t-values and the standard deviation are adjusted for first order autocorrelation and shaded grey if the null hypothesis (mean = 0) cannot be rejected at the 95% confidence level.

A Full Sample Period (213 Observations)

Cap	Mean	Standard			Autocorr.	t-Value	
		Deviation.	Minimum	Median			Maximum
1-year	-1.66%	3.97%	-5.71%	-1.84%	3.07%	0.913	-6.11
2-year	-0.46%	7.67%	-2.98%	-0.93%	5.93%	0.963	-0.88
3-year	-0.24%	1.26%	-1.45%	-0.26%	1.75%	0.855	-2.80
4-year	0.44%	1.66%	-0.80%	0.26%	2.46%	0.905	3.89
5-year	0.77%	2.27%	-0.52%	0.49%	2.90%	0.936	4.96
7-year	0.88%	3.43%	-0.35%	0.49%	3.14%	0.963	3.76
10-year	0.89%	4.19%	-0.29%	0.41%	3.31%	0.971	3.12

B “Low Intensity Period” (137 Observations)

Cap	Mean	Standard			Autocorr.	t-Value	
		Deviation.	Minimum	Median			Maximum
1-year	-2.32%	3.15%	-5.71%	-2.40%	0.02%	0.902	-8.58
2-year	-1.48%	1.35%	-2.98%	-1.54%	-0.15%	0.85	-12.72
3-year	-0.50%	0.68%	-1.45%	-0.47%	0.36%	0.772	-8.64
4-year	0.07%	0.56%	-0.80%	0.12%	1.25%	0.758	1.56
5-year	0.30%	0.58%	-0.52%	0.32%	1.44%	0.786	6.10
7-year	0.30%	0.50%	-0.35%	0.35%	1.14%	0.789	7.07
10-year	0.25%	0.42%	-0.29%	0.27%	1.17%	0.768	7.06

Pls. turn to next page

C “High Intensity Period” (76 Observations)

Cap	Standard		Minimum	Median	Maximum	Autocorr.	t-Value
	Mean	Deviation.					
1-year	-0.50%	2.49%	-3.68%	-0.54%	3.07%	0.831	-1.74
2-year	1.32%	7.96%	-2.43%	0.50%	5.93%	0.952	1.48
3-year	0.22%	1.23%	-1.15%	0.29%	1.75%	0.808	1.62
4-year	1.09%	1.25%	-0.22%	1.11%	2.46%	0.835	7.71
5-year	1.61%	1.25%	0.20%	1.66%	2.90%	0.845	11.30
7-year	1.92%	1.56%	0.30%	1.96%	3.14%	0.889	10.79
10-year	2.03%	1.87%	0.30%	2.03%	3.31%	0.909	9.56

Table 12

Model Fit to Caps in the Diffusion-Model

The table reports the model fit to caps (model – market) for the whole sample period and the two subperiods assuming a diffusion process. The column “Autocorr” denotes first order autocorrelation. The t-values are the test statistic for the sample mean test. The t-values and the standard deviation are adjusted for first order autocorrelation and shaded grey if the null hypothesis (mean = 0) cannot be rejected at the 95% confidence level.

A Full Sample Period (213 Observations)

Cap	Mean	Standard				Autocorr.	t-Value
		Deviation.	Minimum	Median	Maximum		
1-year	-8.16%	10.99%	-14.87%	-7.09%	-4.86%	0.965	-10.83
2-year	-4.60%	2.97%	-7.97%	-4.26%	-3.09%	0.934	-22.66
3-year	-2.96%	4.68%	-6.02%	-2.35%	-1.48%	0.965	-9.22
4-year	-1.58%	2.01%	-3.31%	-1.38%	-0.49%	0.94	-11.42
5-year	-0.87%	0.74%	-1.98%	-0.84%	-0.06%	0.856	-17.10
7-year	-0.29%	0.56%	-0.97%	-0.30%	0.64%	0.833	-7.60
10-year	0.04%	1.48%	-0.67%	-0.09%	1.50%	0.941	0.38

B “Low Intensity Period” (137 Observations)

Cap	Mean	Standard				Autocorr.	t-Value
		Deviation.	Minimum	Median	Maximum		
1-year	-6.59%	2.95%	-13.16%	-6.10%	-4.86%	0.881	-26.15
2-year	-4.08%	1.43%	-7.97%	-3.93%	-3.09%	0.849	-33.43
3-year	-2.18%	0.69%	-4.32%	-2.18%	-1.48%	0.783	-36.95
4-year	-1.17%	0.48%	-2.17%	-1.20%	-0.49%	0.777	-28.54
5-year	-0.71%	0.41%	-1.38%	-0.76%	-0.07%	0.76	-20.47
7-year	-0.42%	0.38%	-4.89%	-2.54%	1.73%	0.772	-13.01
10-year	-0.27%	0.35%	-4.35%	-1.82%	2.21%	0.773	-9.17

Pls. turn to next page

C "High Intensity Period" (76 Observations)

Cap	Standard		Minimum	Median	Maximum	Autocorr.	t-Value
	Mean	Deviation.					
1-year	-10.98%	7.84%	-14.87%	-12.07%	-6.23%	0.938	-12.21
2-year	-5.55%	2.07%	-7.13%	-5.46%	-4.07%	0.91	-23.35
3-year	-4.35%	2.28%	-6.02%	-4.47%	-2.63%	0.915	-16.67
4-year	-2.30%	1.22%	-3.31%	-2.34%	-0.86%	0.88	-16.51
5-year	-1.15%	0.73%	-1.98%	-1.17%	-0.06%	0.831	-13.69
7-year	-0.05%	0.37%	-0.68%	-0.01%	0.64%	0.698	-1.13
10-year	0.59%	0.65%	-0.40%	0.64%	1.50%	0.827	7.94

Table 13

Valuation of Zero Coupon Bonds

The table reports the fit of the algorithm to the theoretical zero coupon bond prices on 2 January 2001 when 10'000 antithetic sample paths are simulated. The intensity for up-jumps and the first eigenvalue are 8.06 and 0.0052 respectively.

Maturity	Algorithm	Market
0.5	0.98384533	0.98384533
1	0.96724094	0.96727377
2	0.92739268	0.92745223
3	0.88443349	0.88452370
4	0.84066499	0.84081197
5	0.79710601	0.79728778
7	0.71353234	0.71364956
8	0.67459102	0.67467419
10	0.60237642	0.6024844

Table 14

Valuation of Swaptions

The table compares the prices of a payers and a receivers swaption on 2 January 2001 when 10'000 antithetic sample paths are simulated. The intensity for up-jumps and the first eigenvalue are 8.06 and 0.0052 respectively.

Swap	Payer	Receiver	Avarage	Standard Error
1x1	0.325	0.323	0.324	0.002
1x2	0.590	0.586	0.588	0.004
1x3	0.832	0.828	0.830	0.006
1x5	1.211	1.207	1.209	0.009
1x7	1.468	1.465	1.466	0.011
1x9	1.718	1.715	1.716	0.013
2x1	0.471	0.476	0.473	0.003
2x3	1.181	1.187	1.184	0.009
2x5	1.668	1.675	1.672	0.012
2x7	2.030	2.037	2.033	0.015
3x1	0.552	0.555	0.554	0.004
3x3	1.363	1.365	1.364	0.010
3x5	1.913	1.917	1.915	0.014
3x7	2.353	2.358	2.356	0.018
4x1	0.602	0.604	0.603	0.004
4x3	1.463	1.465	1.464	0.011
4x5	2.061	2.064	2.062	0.015
5x1	0.621	0.621	0.621	0.004
5x3	1.503	1.503	1.503	0.011
5x5	2.138	2.139	2.139	0.016

Table 15

Differences in Model fit to Swaptions Using 200'000 Antithetic Paths in the Jump-Diffusion Model

The table compares the results obtained when 200'000 antithetic sample paths are simulated to the results given in table 9 (10'000 antithetic sample paths). The table reports the differences (results with 200'000 antithetic variates – results with 10'000 variates) in the statistics for the whole sample period for selected swaptions (the others omitted are similar).

Swaption	Mean	Minimum	Median	Maximum
1x1	-0.02%	0.00%	-0.05%	-0.03%
1x2	-0.12%	-0.11%	-0.14%	-0.09%
1x3	-0.12%	-0.12%	-0.12%	-0.11%
1x5	-0.09%	-0.12%	-0.09%	-0.09%
1x7	-0.04%	-0.02%	-0.04%	-0.04%
1x9	0.00%	0.04%	0.03%	0.00%
2x1	0.01%	0.05%	0.02%	-0.12%
2x3	0.05%	0.03%	0.05%	0.04%
2x5	0.07%	0.10%	0.07%	0.01%
2x7	0.10%	0.11%	0.10%	0.08%
3x1	-0.08%	-0.05%	-0.07%	-0.14%
3x3	-0.03%	0.02%	-0.02%	-0.05%
3x5	0.03%	0.03%	0.02%	0.03%
3x7	0.08%	0.09%	0.08%	0.08%
4x1	0.01%	0.01%	0.01%	0.07%
4x3	0.03%	0.02%	0.03%	0.02%
4x5	0.06%	0.08%	0.07%	0.05%
5x1	0.02%	0.06%	0.03%	-0.01%
5x3	0.00%	0.02%	0.01%	-0.03%
5x5	0.03%	0.07%	0.03%	0.00%

Table 16

Differences in Model fit to Caps Using 200'000 Antithetic Paths in the Jump-Diffusion Model

The table compares the results obtained when 200'000 antithetic sample paths are simulated to the results given in table 11 (10'000 antithetic sample paths). The table reports the differences (results with 200'000 antithetic variats – results with 10'000 variates) in the statistics for the whole sample period.

Cap	Mean	Minimum	Median	Maximum
1-year	0.27%	0.13%	0.25%	0.31%
2-year	0.06%	0.01%	0.09%	0.09%
3-year	0.02%	-0.01%	0.03%	-0.03%
4-year	0.03%	0.02%	0.02%	0.13%
5-year	0.03%	0.01%	0.02%	0.23%
7-year	0.02%	0.00%	0.02%	0.48%
10-year	0.04%	0.01%	0.02%	0.60%

ⁱ Source: "Derivatives Statistics" of the Bank of International Settlement.

ⁱⁱ To address the issue of the possible unsuitability of the historical correlation matrix we experimented with a different specification: As the uncertainty at the short end of the forward curve seems to have a more significant pricing impact on interest rate derivatives, we estimated the model parameters using the results of a PCA which was carried out only in the second half of the turbulent year 2001 as input. However in this case the model fit was even worse for both caps and swaptions than the results reported in this paper.