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MONETARY POLICY AND STRUCTURAL CHANGES IN THE VOLATILITY OF US INTEREST RATES*

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Abstract
In this paper we analyze whether the dynamic behavior of the volatility of the US term structure of interest rates has changed significantly in the last five and a half decades and try to link those changes to relevant economic events and, more specifically, to changes in monetary policy. A first analysis suggests that volatility behaves in a different manner for short, medium and long interest rates: long-term rates have a higher persistence of volatility but are less sensitive to new information. The results of an endogenous breakpoint detection analysis show that structural breaks in the dynamic behavior of interest rate volatility may be associated with changes in the Fed's monetary policy procedures and with changes in inflation behavior, but short and long rates are affected differently. The dynamic properties of interest rate volatility change in these breaks: there is usually a trade-off between volatility persistence and sensitivity to news that can be related to the changes in monetary policy procedures.

Keywords: Interest rate, maturity, volatility, structural change, monetary policy procedures.
JEL Classification: G10, E43, C32.

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1. Introduction

One need only look at the reactions of financial markets to decisions –or, simply, to expectations- of policy interest rate changes to realize the importance of a correct understanding of interest rate behavior. Interest rates have been shown to have a substantial impact on all the major macroeconomic variables. For example, the level of the interest rate directly determines savings-consumption and investment decisions of households and firms: in most macro models, higher interest rates directly affect the level of consumption (see Rotemberg and Woodford, 1997 and Clarida et al., 1999 among others).[1] Also, changes in interest rates lead to adjustments in the prices of assets such as stocks (i.e., Rigobon and Sack, 2004 and, recently, Bernanke and Kuttner, 2005) or in the exchange rates (Eichenbaum and Evans, 1995). The interest rate is used as an explicit instrument of monetary policy (see, for example, the recent paper by McGough et al., 2005). Changes in policy interest rates affect both current and expected market short, medium and long-term interest rates (see Cook and Hahn, 1989, and Roley and Sellon, 1996 among others) and, through these market rates, the overall economy.[2] Finally, interest rates play an important role in the financial sector in contexts such as the valuation of fixed income instruments and derivatives, and therefore they are crucial for a correct management and allocation of financial resources.

Among the main features of interest rate behavior, volatility has been shown to deserve special attention. Interest rate volatility could affect the economy through a number of mechanisms (see, for example, Becketti and Sellon, 1990), the most important being through its impact on investment spending.[3] From the financial perspective, an increase in interest rate volatility reflects an increase in the risk of holding bonds. Empirical evidence shows that interest rate volatility has a significant negative effect on bond yields (see, for example, the recent paper by Sarkar and Ariff, 2002). Interest rate volatility may even have an impact on monetary policy decisions: economic agents and investors change their portfolios (money being one of the assets held in the portfolio) as interest rate volatility increases. These changes in money demand disrupt the functioning of monetary policy (see Garner, 1986 or Choudry, 1999

[1] See Deaton (1992), Muellbauer and Lattimore (1995) and Abel (2000) for a more extensive surveys of the consumption function.
[2] For a detailed desciption of the channels through which interest rates affect the economy (i.e. output and inflation among other variables) see, for example, *The Transmission Mechanism of Monetary Policy* in Bank of England (1999).
[3] Dutkowsky (1987) found that interest rate volatility also leads to significant increases in unemployment.

among others). Finally, interest rate volatility may harm the functioning of financial markets and the financial system in general (see Morris, 1989). For example, interest rate volatility can lead to liquidity crises in the financial system.

Furthermore, and in contrast to the weak behavior in mean –first moment-, from the statistical point of view the volatility –second moment- of interest rates has a much richer structure, which can be detected and analyzed (Pagan et al., 1996). Thus, a thorough analysis of interest rate volatility becomes a key element to further our understanding of interest rate behavior.

A number of recent papers have stressed the importance of taking into account the possibility of existence of structural breaks in the analysis of interest rate volatility (e.g., Hamilton and Susmel, 1994; Gray, 1996; Chapman and Pearson, 2001 and Sun, 2005, among others). Gray (1996) estimated a regime switching GARCH model and showed that the US short rate presented evidence of breaks in volatility. More recently, Sun (2005) analyzed short-term rates for the US, the UK, Japan and Canada and also found evidence on regime shifts in interest rate volatility. Empirical evidence has found that changes in interest rate volatility can be associated with factors such as changes in Federal Reserve operational procedures (see for example Cai, 1994; Gray, 1996; Chapman and Pearson, 2001, and Sun, 2005), real shocks such as oil price changes (i.e., Cai, 1994; Gray, 1996, and Sun, 2005) or NBER data revisions (Sun, 2005).

In this paper, and in the light of the above comments, we attempt to give a further step in the analysis of the dynamic behavior of interest rate volatility. More specifically, we study whether the dynamic behavior of US interest rate volatility -across different maturities- has changed significantly in the last five and a half decades. The choices of the US and the sample period make the analysis especially relevant. Our sample includes years of major changes in the US economy and, especially, the years of development and consolidation of US monetary policy operations and procedures. In that sense, a closer look at these data may shed light on how events in the monetary side of the economy affect the behavior of interest rate volatility and on whether these effects may differ depending on the maturity of the interest rate. Thus, our results could serve as guidance for what to expect in other countries that go through similar development processes. We attempt to ascertain, then, if significant changes in the structure of interest rate volatility happen through time, and, more relevantly, we locate the dates of these changes endogenously so we can identify from the data the possible events that have led to these changes and explicitly infer how they affected the dynamic behavior of interest rate volatility. We are particularly interested in addressing the following questions:

- How has interest rate volatility evolved in the last five and a half decades?
- How does the structure of interest rate volatility vary across maturities? In other words, is interest rate volatility behavior different for short and long term interest rates?
- What are the main events that have brought about changes in the dynamic behavior of interest rate volatility? Have these events affected different maturity rates in different ways?

We start our analysis with a descriptive look at the data: we estimate some statistics of interest rate volatility at different maturities and present a simple nonparametric measure of volatility which tracks its evolution over time. The analysis of this measure suggests the existence of structural changes and we proceed to identify these changes. Since we do not want to impose the dates of the breaks, we use methodologies of detection of endogenous breakpoints and relate the identified break dates with economic events.

The structure of the paper is as follows. Section 2 takes a first look at the evolution of interest rate volatility in the US economy. Section 3 describes alternative methodologies for the location of changes in variance behavior. Section 4 discusses the results of the breakpoint detection analysis, emphasizing the events that may have been associated with changes in volatility behavior and the specific direction of those changes. Finally, in Section 5 we offer some concluding remarks.

2. A first look at the data

We begin the analysis with a descriptive look at the data: we initially calculate some basic descriptive statistics and present a simple nonparametric measure which reproduces the behavior of interest rate volatility over time.

The data for the different interest rates used in this paper have been obtained from the Federal Reserve Economic Data (FRED) database in the Federal Reserve Bank of St. Louis website. Details about the number of observations and descriptions of the different interest rates are given in Appendix I. We use data at the monthly frequency.[4]

[4] We check the robustness of our results by using weekly data, which are also obtained from the FRED website. We do not report these results for the sake of brevity. Details on the weekly estimation are available upon request.

Table 1 reports basic univariate statistics for six different interest rates (Federal Funds, 3 and 6 month Treasury Bills, 1, 5 and 10 year Treasury Bonds) and for the changes in those interest rates.[5] Average levels of the rates during the sample period range between 5.56% for the 3 month rate to 7.01% for the 10 year rate. In terms of standard deviation, it is interesting to see the (inverse) relationship between the maturity of the rate and the volatility of interest rate changes. We comment on this below.

A simple look at the time evolution of interest rate volatility can be taken in Figure 1. The graphs show the interest rate data for the sample period along with a nonparametric measure of interest rate volatility, a 12-month rolling variance. This rolling variance is calculated as follows:

$$\boldsymbol{\sigma}^2\left(\Delta \mathbf{i}_{\mathbf{n,t}}\right)=\left[\sum_{\mathbf{k=1}}^{\mathbf{12}}\frac{\left(\Delta \mathbf{i}_{\mathbf{n,t-k}}-\boldsymbol{\mu}_{\mathbf{n,12}}\right)^2}{\mathbf{11}}\right], \quad (1)$$

where $\Delta i_{n,t}$ is the change in the rate of maturity n at period t and $\mu_{n,12}$ is the sample mean of interest rate changes over the 12-month window for a maturity n. This rolling variance gives a first idea of the evolution of both the conditional and the unconditional variance of the different rates. The graphs show the above mentioned feature of lower volatility levels for the longer-maturity rates –note the left-axis scale-, but other than that the behavior of volatility over time seems to be quite uniform across maturities, a result that we qualify further on. The graphs identify clearly the main episode of high instability, 1979-1982, which is common across maturities. No large spikes in interest rate volatility are detected after the mid-1980s: as we can see in Figure 1, volatility stays at a relatively low level after 1982-1985, although in recent years a few episodes of increased instability have occurred. The visual analysis therefore suggests the existence of two main events that seem to change significantly the behavior of volatility, one around 1979 and the other around 1982. In the 1970s, the US economy suffered from high oil prices, high inflation and unemployment rates at record levels. In view of these events, the Fed revised its monetary policy during Paul Volcker's tenure (1979-1982), implemented new operating procedures and placed the emphasis on growth targets for monetary aggregates, rather than on interest rates. These changes seem to have been reflected in changes in the behavior of volatility.[6]

[5] The data used to calculate the basic statistics in Table 1 and the rolling variance in Figure 1 extend from 1959:12 to 2005:12 for all interest rate maturities. Unit root tests give evidence of nonstationarity of the levels of the interest rate, but estimation of mean reverting processes yields weakly significant mean reversion, at very low speeds. This is a typical feature of interest rates, which makes the direct analysis of the level data more controversial than directly focusing on the changes.

[6] See Friedman (1984) for a description of the monetary policy experiment.

After 1982, the Federal Reserve returned to a policy centered on interest rates as the main monetary policy instrument.

This visual evidence may, however, give a misleading or incomplete picture. In fact, there are simple statistical models that account well for episodes of instability such as that of 1979-1982 without resorting to structural breaks or parameter changes. We move now to a more sound analysis where we explicitly locate the structural breaks in the statistical process that generates interest rate volatility.

3. Structural breaks in interest rate volatility

We formalize our analysis by imposing a specific structure on interest rate volatility, modeling its dynamic behavior via GARCH models.[7] This family of models has proved to be very useful in modeling the time-varying volatility of financial assets and other macroeconomic variables and it is by now widely accepted among academicians and practitioners. Although the GARCH structure allows for high order dynamics in volatility behavior –by setting the order of the moving average and autoregressive terms in the variance equation to values higher than one- in practice the simplest GARCH(1,1) is widely used: the parameters of higher-order GARCH models are difficult to identify uniquely and usually a GARCH(1,1) is enough to account for the evolution of conditional volatility.[8] Pagan and Schwert (1990) show that the GARCH model performs quite well in comparison with alternative methods of modeling conditional volatility.

In this section we estimate GARCH(1,1) models for the different interest rate maturities. We are interested in assessing the evidence for structural changes in the process that generates market volatility. That is, we look for changes in the parameters that describe the dynamic behavior of volatility and, consequently, the level of unconditional volatility. The previous section showed preliminary evidence in that direction, and in fact it already pointed at two possible dates, 1979 and 1982, for the changes in variance behavior. We use now techniques for the location of endogenous structural breaks in order to detect the times of these changes in the parameters of the variance equation of a GARCH(1,1) model.

[7] Bollerslev (1986). For surveys of the financial literature see, for example, Bollerslev, Chou and Kroner (1992), Bera and Higgins (1993), Bollerslev, Engle and Nelson (1994), Diebold and Lopez (1996) and more recently Andersen et al. (2006).

We assume that the interest rate i_t follows the Mean reverting-GARCH(1,1) process:

$$\Delta i_t = \delta_0 + \delta_1 i_{t-1} + u_t, \qquad u_t|I_{t-1} \rightarrow N(0,\sigma^2_t)$$

$$\sigma^2_t = \alpha + \beta\sigma^2_{t-1} + \gamma u^2_{t-1}, \qquad (2)$$

where α -the *level* parameter-, β -the *persistence* parameter- and γ –the *news effect*- are such that $\alpha>0$ and $1>\beta,\gamma \geq 0$, u_t is the innovation (news) to the mean equation and I_{t-1} is the set of past information. Note that we model the change in the interest rate as being a simple mean-reverting structure $\Delta i_t = \delta_0 + \delta_1 i_{t-1} + u_t$, a structure which has been traditionally used both in the macro and finance literature, even though the evidence for mean-reverting behavior tends to be weak (Pagan et al., 1996). The results for the volatility analysis are not affected significantly by the process used for the mean (see our comments below).

In order to capture the changing behavior we use this baseline GARCH model and test for breaks at unknown times in the three parameters of the variance equation. Thus, we do not impose a priori the dates of the breaks, but test simultaneously for the existence of a change in the parameters of the process – α, β and γ - and for the date of the change. We allow for the existence of more than one break in the parameters following a sequential process. Subsection 3.1 explains the procedure in greater detail.

In order to control for possible effects of the parameters of the mean equation, we have carried out two separate analyses. In the first one, we estimate the parameters of the mean equation and then do the volatility analysis on the residuals of that first estimation. In the second one, and given the possibility of changes in the parameters of the mean-equation, we apply a time-varying parameter model to the mean equation, that we estimate using the Kalman filter. The volatility analysis is subsequently carried out on the residuals of this procedure. Given the weak structure in mean of interest rates –the parameters δ_1 and δ_2 do not change significantly throughout the sample period: estimates of the time varying values of these parameters are basically flat- the results of both procedures are equivalent.[9] Additionally, the same two analyses

[8] In fact, the estimated evolution of the conditional variance coming from a simple GARCH(1,1) model parallels quite nicely the nonparametric rolling variance. We have not included this analysis, but it is available upon request.

[9] We present only results for the simpler estimation of the mean reverting process, and make those of the Kalman-filtered residuals available upon request. The correlation of the Kalman-filtered residuals with the simple constant-parameter residuals is above 0.8 for the federal funds rate and above 0.9 for all other rates. The structure assumed in the Kalman-filter exercise is (we omit the variance structure, which is the traditional diagonal matrix):

$$\Delta i_t = \delta_{0,t} + \delta_{1,t}\, i_{t-1} + u_t$$

$$\delta_{0,t} = \phi_0 + \phi_1\delta_{0,t-1} + v_t$$

have been carried out with a different process for the mean (an AR(1) in the changes of the rate, so that the second lag of the rate also enters in the mean equation) and the results do not change. This second set of estimations is also available upon request.

3.1. Locating the structural breaks

The location of endogenous structural breaks in time series has been a matter of intense research in the last few years: One can look at Banerjee et al. (1992), Ghysels et al. (1997), Bai et al. (1998), Dufour and Ghysels (1996) or Andrews (1993, 2003) to realize that the topic is still in its early development stages.

The issue of how to estimate the number and location of multiple endogenous structural breaks is also being currently researched and results on the procedure and properties of the tests involved are now being published. Papers by Andrews et al. (1996), García and Perron (1996), Bai (1997, 1999), Lumsdaine and Papell (1997) or Bai and Perron (1998, 2003) are some of the most noteworthy examples.

Most of the techniques in the above papers have been developed for estimation and location of endogenous breaks in the mean parameters of trend models. However, as Bai and Perron (1998) mention, they can also accommodate changes in the variance. Given the richer structure of the GARCH variance process, we have to be cautious about how immediately these tests can be extended to changes in the GARCH parameters.[10]

In this paper we use the critical values and limiting distributions of the tests for changes in the mean parameters but warn in advance that further results on the asymptotic distributions of our tests might modify the critical values or limiting distributions to be used. Therefore, with this caveat in mind and notwithstanding the fact that some of the results, such as the expression for the calculation of a confidence interval for the breakpoint cannot be directly applied, we use the general framework in Bai and Perron (1998, 2003) and use their sequential procedure and estimated critical values.

$\delta_{1,t} = \phi_2 + \phi_3\delta_{1,t-1} + w_t$

[10] Formal evidence that this type of tests can be extended to GARCH processes is cited in Andreou and Ghysels (2002). Also, it is well known that a GARCH(1,1) can be expressed as an ARMA(1,1) model on squared residuals. Thus, a change in the parameters of the variance equation should be parallel to an analysis of a change in the parameters of a linear process of the squared residuals, thus further justifying the use of Bai and Perron's procedure. Andrews' (1993) test would be more appropriate, but results are only available for detection of one break. In any case, the dates of the

This sequential procedure consists of locating the breaks one at a time, conditional on the breaks that have already been located. Thus, we locate the first break and test for its significance against the null hypothesis of no break. If the null hypothesis is rejected, we then look for the second break conditional on the first break being the one already found, and test for the existence of that second break against the null of one single break, and so on.

Our framework consists of a model for interest rate volatility of the form in (2). We believe that at some points in time, $\mathbf{t} = \{t_1, t_2, \ldots t_l\}$ the process generating the variance may change, that is, the parameters α, β and γ change at each of the t_i. The specific number of breaks allowed will be determined by the data through the application of the sequential process outlined above, so here we keep the discussion at a general level.

Given a set $\mathbf{t}$ of l points in time at which q of the parameters of the process change, we want to test if there is an additional break and, if so, when the break takes place and the value of the q parameters before and after the new break. The likelihood of the model that contains the l breaks in $\mathbf{t}$ is specified as $L(\mathbf{t},\theta)$. θ is the set of all parameters and it contains both the parameters that do not change over time and the l values of each of the q parameters allowed to change at the breakpoints. In our specific model, and disregarding some constants,

$$\mathbf{L}(\mathbf{t},\boldsymbol{\theta}) = -\frac{1}{2}\sum_{t=1}^{t_1}\left[\log\boldsymbol{\sigma}_{1,t}{}^2 + \frac{\mathbf{u}_{1,t}{}^2}{\boldsymbol{\sigma}_{1,t}{}^2}\right] - \frac{1}{2}\sum_{t=1+t_1}^{t_2}\left[\log\boldsymbol{\sigma}_{2,t}{}^2 + \frac{\mathbf{u}_{2,t}{}^2}{\boldsymbol{\sigma}_{2,t}{}^2}\right] - \ldots - \frac{1}{2}\sum_{t=t_l}^{T}\left[\log\boldsymbol{\sigma}_{l+1,t}{}^2 + \frac{\mathbf{u}_{l+1,t}{}^2}{\boldsymbol{\sigma}_{l+1,t}{}^2}\right] \quad (3)$$

where $u_{k,t} = \Delta i_t - \delta_0 - \delta_1 i_{t-1}$ and $\sigma^2_{k,t} = \alpha_{1,k} + \beta_{1,k}\sigma^2_{k,t-1} + \gamma_{1,k}u^2_{t-1}$.[11] The subscript k indexes the different periods determined by the l breaks.

The alternative model is specified as one which contains an additional break at time τ. Thus, the set of (l+1) breakpoints becomes now $\mathbf{t}^*=\{\mathbf{t},\tau\}$, and the log-likelihood associated with the alternative model is $L(\mathbf{t}^*,\theta(\mathbf{t}^*))$. The procedure for the detection and timing of the break consists in finding the series of likelihood-ratio statistics of the alternative (unrestricted model) of (l+1) breaks against the null (restricted model) of l breaks:

$$LR_\tau(l+1 \mid l) = -2[L(\mathbf{t}, \hat{\theta}(\mathbf{t})) - L(\mathbf{t}^*, \hat{\theta}(\mathbf{t}^*))], \quad (4)$$

breaks –i.e. the dates of the sup-value of the test- are the same using Andrews' procedure or Bai and Perron's.

[11] In the case of Kalman-filtered residuals, $u_{k,t} = \Delta i_t - \delta_{0,t} - \delta_{1,t} i_{t-1}$.

where $\mathbf{t}$ = {t_1,t_2,...t_l} is the first set of l breaks (under the null of no additional break) and $\mathbf{t}^*$ = {t_1,t_2,...t_l} is the set of l+1 breaks that includes τ as a new possible time for a break. L($\mathbf{t}$,$\hat{\theta}$($\mathbf{t}$)) is the value of the log-likelihood of a model that includes the breaks in $\mathbf{t}$, and $\hat{\theta}$($\mathbf{t}$) are the ML estimates of all the parameters of the model. The new breakpoint is located by using the supLR test:

$$\sup LR : \sup_{\tau \in T^*} LR_\tau \left(l+1 \middle| l\right), \qquad (5)$$

where $\mathbf{T}^*$ is the set of possible times for the new break. Of course, given the series of LR tests and the supLR test, the date of the new breakpoint $\hat{t}$ is:

$$\hat{t} = \arg\max_{\tau \in T^*} \, L\left(t^*, \hat{\theta}\left(t^*\right)\right) = \arg\max_{\tau \in T^*} \left[\sup LR_\tau \left(l+1 \middle| l\right)\right]. \qquad (6)$$

If the supLR test is above the critical value, then the null of no additional breakpoint is rejected and the date for the new breakpoint is estimated to be $\hat{t}$. The values of the parameters before and after the break correspond to the estimates in $\hat{\theta}$($\mathbf{t}^*$). The different versions of this statistic (Bai et al.,1998; Bai and Perron, 1998,2003) have a limiting distribution that depends on a q-dimensional Brownian motion, where q is the number of parameters allowed to change at the time of the break. Thus, the critical values of the LR(l+1 | l) test depend on l and on q and are usually calculated by simulation of the q dimensional Brownian motion.

One final comment is that $\mathbf{T}^*$ the set of possible times for the break, must exclude a number of observations around the initial and final dates and around the dates in $\mathbf{t}$ = {t_1,t_2,...t_l} that ensures that each subperiod defined by the breakpoints contains enough observations for the parameters to be accurately estimated. In our analysis we have used a trimming proportion of 0.15.[12] That is, we start by locating the first breakpoint in $\mathbf{T}^*$ ={0.15T, 0.85T} and then every time we locate a new breakpoint, we exclude from $\mathbf{T}^*$ the 15% observations to both sides of the last breakpoint estimated.

The critical values have been tabulated by the authors, and are available in their papers. It also has to be said that the tests explained above can consistently estimate not the dates of the breaks but the proportion of the total sample at which the breaks occur. That is, we estimate consistently that the break happens at "the 0.2 quantile" of the sample. Of course, one can then back

[12] This proportion is usually taken to be 0.15. The results are not sensitive to the choice of this trimming proportion, unless the break is located too close to the endpoints of the sample. In small samples or in settings where low frequency data are used a trimming proportion of 0.1 may be more advisable for reasons of data availability.

up the specific time of the event, given a fixed number of observations T in the sample.

3.2. Some robustness tests

Alternative tests for endogenous breaks in unconditional variance are available, although these tests are more nonconstructive in nature. The paper by Andreou and Ghysels (2002) reviews some of the most recently developed tests. We use two of those tests as robustness checks for our results on the endogenous breaks. Both tests are based on cumulative sums (CUSUM) of either the squared changes in interest rates or the absolute changes. As in traditional CUSUM tests, the tests rely on the fact that if there is a change in the behavior of the series, cumulative sums should depart at some point from what would be implied if the behavior over the full sample were uniform.

The two tests that we apply –see Appendix II for details- are those in Kokoszka and Leipus (KL, 2000) and Inclán and Tiao (IT, 1994). Both tests are designed to test for the most likely location of a change in the unconditional variance of the series. The asymptotic distribution of both tests is exactly the same, although the KL test is more general: the null under the IT test is that the series is i.i.d. and the alternative is that it has a level shift in variance. The KL test applies to a much wider range of series, including those with long memory or GARCH-effects and some non-linear time series. Thus, it is expected to be more powerful in a time series context, where the i.i.d. assumption is highly dubious.[13]

Both tests can be applied sequentially in order to find multiple breaks. The sequential procedure detects the first break, and then applies the test again to the two subperiods identified by the first break. The date of the larger value of the test of both subperiods is taken as the estimate of the second break, which in turn determines three subperiods and so on (see IT, 1994, for a description of the complete procedure).[14]

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[13] In fact, we have noticed that the IT test tends to give evidence of too many breaks (see Aggarwal et al., 1999 for an analysis of stock market volatility in some emerging economies that uses this test). The results of the two tests can be seen to be in line with the sup-LR, but the IT test is clearly biased towards detecting more breaks in time series.

[14] These tests have been shown to be sensitive to the presence of outliers (see for example Rodriguez and Rubia, 2005), quite frequent in financial time series.

4. Empirical results of the endogenous break analysis

We focus our comments on the results of the sup-LR procedure for alternative interest rate maturities. We then comment briefly on the results of the IT and KL tests.

4.1. Sup-LR estimation

We have initially fitted GARCH(1,1) models with no break to the different interest rate maturities, with the mean equation modeled as in (2). There are four relevant parameters in our analysis: the *level* of volatility -α-, the *persistence* of volatility -β-, the *news* effect -γ- and the *unconditional variance* implied by the estimates –UV = $\alpha/(1-\beta-\gamma)$–. The parameters of the QML estimation with u_t assumed to be conditionally normally distributed appear in Table 2. As we can see in the table, the dynamic behavior of interest rate volatility differs in a very consistent way across maturities. Estimates of the persistence parameter β increase with the maturity of the rate, whereas α and γ decrease: the estimated β goes from 0.674 for the Federal Funds rate to 0.874 for the 10-year rate and the news effect γ decreases from 0.308 to 0.148. The unconditional variance also varies consistently across maturities: its level decreases from 0.257 for short rates to 0.028 for long rates. These results are quite interesting and robust: short-rate volatility is less persistent and more subject to the impact of new information. Long-rate volatility, on the other hand, is more persistent and less sensitive to news. These effects induce lower unconditional volatility of long rates. All three of these results seem to be in line with the expectations-hypothesis argument that the long rate is a weighted sum of current and expected future rates.[15]

As mentioned before, we model the change in the interest rate with a simple mean-reverting structure $\Delta i_t = \delta_0 + \delta_1 i_{t-1} + u_t$. In Table 3 we present the estimates of δ_0 and δ_1. We note that the estimates of δ_1 are close to zero but significant for most of the interest rate maturities.

We comment now on the results of the endogenous break analysis. Parameter estimates of the estimations with one, two and three breaks are shown in Tables 4-6 respectively. One comment has to be made. Some of the estimates of the β and γ parameters in the subsamples identified by the breaks tend to go to the boundaries of the parameter space (i.e. close to zero or one).

[15] This does not imply that the expectations hypothesis holds exactly, but it suggests that term premia are not highly relevant in the US rates. If there were deviations from the expectations hypothesis due to large and volatile risk or term premia, one should find the volatility of long rates to be higher than that of short rates.

This suggests that persistence (mainly measured by β) or the news effect (measured by γ) become the predominant driver of interest rate volatility in some of the subsamples, so that the estimated parameters could be effectively constrained by the feasible range [0,1).

Before we comment on the results, we mention two qualifications to our results that are due to the necessary trimming of the sample that needs to be carried out (see Section 3.1). First, this trimming effectively restricts the maximum number of breaks that can be located to three. It may then be possible that we cannot confirm whether all dates identified as breaks apply to all maturities: some dates may have affected some maturities in a more noticeable way, and therefore these breaks are identified first in the estimation for certain maturities but do not show for others. We present in our discussion the breaks as if they potentially affected all rates, but also explicitly comment on which maturities show more clearly the effect of the break: we believe that some of the findings in this regard are noteworthy. Second, the trimming prevents us from locating breaks that are too close to one another.[16]

For most of the maturities we find evidence of two structural breaks in interest rate volatility, whereas the Federal Funds rate and the 5-year rate present three significant breaks. The value of the sup-LR test in Table 4 is 41.93 for the Federal Funds rate and 29.62 for the 5 year rate, well above the critical value.[17]

The different dates of the detected breaks are 1965:07 or 1965:09 (for the 3 month, 1, 5 and 10 year rates); 1979:10 (for the Federal Funds rate, 5 and 10 year rates); 1982:09 (for the 6 month rate); 1989:03 (for the Federal Funds and 5 year rates) and 1992:07 or 1993:01 (for the 3 and 6 month and the 1 year rates).

The first break is detected in 1965, and it is consistently found in the long-term rates. In the mid 1960s, the US economy experienced over-expansionary monetary and fiscal policies in the context of the Vietnam War and President Johnson's Great Society initiatives. Both policies generated significant federal government deficits and modified the behavior of the rate of inflation. The price stability that had characterized the 1950s was lost and inflation started to be perceived as a problem by the mid 1960s (Atkins, 2002, detected a structural break in the US inflation rate in 1965 and Aïssa and Jouini, 2003, found the

[16] This is the main cause for our procedure not detecting a possible break in 1982 in most of the maturities (see below).
[17] See Table II in Bai and Perron (1998) for the asymptotic critical values of the sequential LR(l+1 | l) test for a change in q = 3 parameters.

break in 1968).[18] In this context, during 1965 the funds rate first rose above the discount rate, and the volatility of interest rates increased. In the following years, i.e. in the second half of the 1960s, a shift in Fed preferences towards inflation -in response to the large fiscal deficits- signified a real change in Fed behavior that may be behind the identified break.[19] We find that the news effect and the unconditional variance are higher after the break whereas the persistence is lower. The fact that it is the long-term rates that show this break suggests that indeed inflation may be the cause behind this break. Obviously, long-term rates are more intensely affected by the expected evolution of inflation, so a change in inflation behavior –and one which implied higher inflation volatility: see footnote 18- should show up mostly in the long-rates, which is precisely what we find. The fact that the news effect goes up is also quite nicely aligned with the story, since new information that leads to changes in future inflation expectations will feed more intensely into the long term rates, and thus subject them to increased sensitivity to current information. Therefore, one could expect volatility of long rates to be more sensitive to news, and therefore less persistent.

The second break identified by the sup-LR procedure corresponds to 1979. We associate this break (that appears for both short and long term rates) with the beginning of Paul Volcker's tenure as chairman of the Fed and the strong disinflationary policy that was implemented subsequently.[20] This date has been traditionally associated with a significant change in Fed's policy (see Taylor, 1999; Clarida et al., 2000; and, recently, Lubik and Schorfheide, 2004 among others). In fact, it is probably the main event in the monetary policy history of the US that has been identified as generating a major change in interest rate and inflation behavior.[21] For this break, and consistently so across maturities, we find that the estimated persistence parameters –and implied unconditional volatility- are higher after the break whereas the news effect is lower. In other words, during the Volcker years interest rate volatility was high, but less subject to the

[18] In the light of this finding, we have tested the existence of structural breaks –this time, exogenously determined- in the volatility of the US inflation rate. The results indeed support that there is a significant change in volatility (specifically, in the level) after 1965, although the cause behind the change in behavior is probably the appearance of large oil price shocks. The results of the estimation and the evolution of the US inflation volatility are omitted to save space but are available upon request.

[19] Duffy and Engle-Warnick (2006) also found a significant break in 1968. They interpret the 1968 break as a shift in Fed policy toward inflation in response to the large deficits originated by the Vietnam War and Great Society programs.

[20] There are several studies that document US monetary policy in the 1979-1982 years (see the *Proceedings of a Special Conference of the Federal Reserve Bank of St. Louis (2005),* Reflections on Monetary Policy 25 Years After October 1979 for a recent contribution to this literature).

[21] The break date in 1979 is also included in Clarida et al. (2000), Beyer and Farmer (2003), and Sims and Zha (2006) among others.

upcoming news. Two economic facts nicely provide for the reasons behind these statistical effects on the interest rate process. First, the Fed was not explicitly targeting interest rates but rather a monetary aggregate, so that interest rate movements became less sensitive to month-by-month developments. Second, the Fed's policy stance was in any case quite aggressive in its disinflationary measures, and interest rates were on average higher, so that the unconditional volatility of these rates would indeed most likely increase.[22]

Tables 5 and 6 show that only one rate seems to have been affected by the end of the anti-inflation strategy in 1982 (the 6 month rate). As we mentioned above, this result is a consequence of the impossibility of locating two breaks that are too close in the sample (less than seven years apart). In any case, for the 6 month rate, for which 1979 seemed to have had the least impact, 1982 appears as a moment in which volatility changed significantly, and in the opposite direction to the changes detected for other rates in 1979: interest rate volatility "goes back" to having lower persistence and higher sensitivity to news, once the interest rate became again the main policy instrument. This result very nicely complements the evidence on the 1979 break.

The fourth break is detected in 1989. In the second half of 1988, inflation became the more pressing concern, and the Fed started raising interest rates. These moves pushed the economy into a recession. Afterwards, the Fed reacted by flooding the economy with liquidity and lowering interest rates. For example, Hamilton and Jorda (2002), Basistha and Startz (2004) and Demiralp and Jorda (2004) fixed 1989 as a main structural breakpoint in the Fed's operating procedures. Our analysis detects this effect, and shows how interest rate volatility was affected by these developments. In particular, rates became more subject again to news –they became again the immediate reference for monetary policy actions- and consequently volatility persistence diminishes.

Finally, the last break detected is in 1993 and shows up mainly in the short-term rates. This break is relatively close –within sample variation- to the FMOC decision of publicly announcing the level of the Federal Funds target as the main driver of monetary policy stance (February, 1994). The Fed's federal funds rate moved sharply during this period in order to slow down inflationary pressures due to the rapid expansion in economic activity. After 1994, with few exceptions all adjustments have been made at regularly scheduled meetings. In this break, we find that the persistence and the unconditional variance are lower

[22] This is related to the well documented *level* effect of interest rate volatility (Pagan et al., 1996).

after the break –so the rates seem to become more stable- but the news effect is higher, which again fits nicely with a story of interest rates being the focus of policy decisions: market rates react more strongly to new information. Some recent papers also have found significant changes in volatility behavior around this period: see, for example, Lee (2006) and Bomfim (2003).

In summary, we suggest that most of the breaks in interest rate volatility behavior, except for the one in the mid-1960s, which we attribute to a change in inflation behavior, are mainly driven by changes in monetary policy procedures: the 1979 and 1982 breaks correspond to the beginning and end of the Volcker disinflation. The 1989 break is associated with a change in the Fed's operating procedures and the 1993 break is relatively close to early 1994, when the FMOC established the policy of publicly announcing the level of the Federal Funds. We believe that the different changes in the *news* (γ) and *persistence* (β) parameters that we have identified, and the fact that they usually move in opposite directions, are quite in line with the policy developments: as we have been emphasizing through the discussion, the changes in these parameters seem to be consistent with whether interest rates are the main focus of monetary policy actions.

Finally, and from a more general perspective, our results also suggest the existence of marked differences in the behavior of rates across maturities. Three different groups of interest rates are identified, whose behavior changes in a more or less parallel way: (1) the Fed Funds rate; (2) short rates (i.e., 3 and 6 months, and 1 year) and (3) long rates (5 and 10 years). The values of the parameters across maturities show that the unconditional variance –average level of volatility- tends to be lower for long rates, a consequence mainly of the news effect being lower.

4.2. More results based on robustness tests

We have carried out the KL and IT tests for alternative maturities of the US interest rates. As we can see in Table 6, the IT test tends to find too many breaks: for example, it locates four breaks for the 10 year interest rate and seven for the 6 month rate.[23]

Notice that the results of the sup-LR test mostly agree with those of the IT test, although some discrepancies are still present for different maturities. One main result can be mentioned. For most of the interest rates (Federal Funds, 1, 5 and 10 year interest rates), the IT test detects quite well the Federal Reserve experiment in the 1979-1982 period. The KL test only generates significant

[23] Similar IT tests have been used in a recent paper by Fernandez (2004).

breaks for the 10 year interest rate. This result is quite usual: the KL test seems to be quite restrictive in finding parameter changes, especially if there are outliers (Rodrigues and Rubia, 2005). In any case, the breaks detected by this test are quite parallel to those found in the 5 and 10 year rates, thus supporting the relevance of the three dates identified.

5. Conclusions

Our analysis of US interest rate volatility across maturities has yielded quite interesting conclusions, which open a number of potential avenues for future research. We carried out first a simple comparison of volatility evolution across maturities, and showed that the persistence of volatility increases for long interest rates whereas the news effect and unconditional variance decrease, a result in line with the expectations-hypothesis. The results also suggest a clustering of interest rate volatility according to maturity: (1) the Fed Funds rate; (2) short rates (i.e., 3 and 6 months, and 1 year) and (3) long rates (5 and 10 years).

We then proceeded to locate endogenously the changes in unconditional variance and the dynamic behavior of volatility. First, we found that the above clustering of rates seemed to be consistent with the structural breaks detected. As mentioned before, this does not imply that all the breaks do not apply to the different maturities –we are constrained by a maximum of three breaks per series- but it suggests that some events affect more strongly the rates of certain maturities.

Most of the breaks detected are associated with changes in the Fed's monetary policy procedures, the exception being the break in the mid-1960s, which we associate with a significant change in inflation behavior, and which affected mainly the long-term rates. The breaks detected in 1979, 1982 and 1989 are indeed related to major changes in the Fed's operating procedures and we believe that the 1993 break is relatively close to the establishment by the FOMC of the public announcement of the Federal Funds rate which, as expected, affected mainly the short-term rates and made them more subject to news volatility. We have been able to account also for the different changes in the parameters that measure the dynamic behavior, which we believe reinforces the relevance of the results.

The empirical findings suggest one main implication for monetary policy Short term interest rate volatility are mainly driven by monetary policy decisions that would modify its behavior over time while long term interest rates are mainly driven by inflation rate. In this context, monetary policy could affect short interest rate volatility directly and long interest rate volatility indirectly through inflation.

Given the importance of interest rate volatility and its implications for many relevant macroeconomic and financial variables, efforts towards understanding the factors that influence volatility are likely to yield much fruit both for researchers and for people involved in economic policy. A more thorough analysis of the causes of changes in volatility, and of the direction of the impact, is of key importance for policymakers, practitioners and investors. The results in this paper also suggest several potential areas for future research, both from the economic perspective -the extension to other economies with different monetary policy procedures, such as inflation targeting- and from the methodological perspective -such as the necessity for the development of more robust tests for changes in volatility or of frameworks that account better for the mean when the variance is the main objective of the analysis.

Appendix I

Variable	Sample period	Comments
Effective Federal Funds rate	1954:07 to 2005:12	Averages of daily dates
3 month Treasury Bill: Secondary market rate	1953:04 to 2005:12	Averages of business days, discount basis
6 month Treasury Bill: Secondary market rate	1958:12 to 2005:12	Averages of business days, discount basis
1 year Treasury constant maturity rate	1953:04 to 2005:12	Averages of business days (1)
5 year Treasury constant maturity rate	1953:04 to 2005:12	Averages of business days (1)
10 year Treasury constant maturity rate	1953:04 to 2005:12	Averages of business days (1)

Source: Board of Governors of the Federal Reserve System. (1) For further information regarding treasury please refer to: http://www.federalreserve.gov/releases/h15/current/h15.pdf and http://www.treas.gov/offices/domestic-finance/debt-management/interest-rate/index.html.

Appendix II

The KL test for existence of a break in the variance of a series of interest rate changes Δi_t is constructed by first calculating the series of cumulative sums:

$$U_T(k) = \left(1/\sqrt{T}S_k - K/\left(T\sqrt{T}\right)S_T\right), \quad (1)$$

where $S_k = \sum_{t=1}^{k} X_t$ and X_t is either the squared change $(\Delta i_t)^2$ or the absolute change $|\Delta i_t|$ at time t. The estimator of the date of the break is then taken to be the maximum of the values of the normalized test:

$$KL = \sup\{|U_T(k)|\}/\hat{\sigma}, \quad (2)$$

where $\hat{\sigma}$ is some estimate of the long-run variance of the series. We use a Newey-West heteroskedasticity and autocorrelation-consistent estimator of long run variance, with truncation lag determined by the rule $4(T/100)^{2/9}$.

The asymptotic distribution of the normalized test is a Kolmogorov-Smirnov-type distribution, with critical values 1.22 and 1.36 for the 90% and 95% confidence levels respectively.

The IT test assumes that the series has a constant conditional variance (i.e., $\Delta i_t \rightarrow N(0,\sigma_t^2)$). The test is constructed with a different transformation of the cumulative sums:

$$D_k = \left(\frac{S_k}{S_T} - k/T\right) \quad (3)$$

and again the date of the break is taken to be that of the maximum D_k, with the test statistic being rescaled as follows:

$$IT = \sqrt{T/2}\, \max_k D_k \, . \quad (4)$$

The asymptotic distribution followed by this rescaled IT test is exactly the same as that of the normalized KL test.

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Table 1. Some basic statistics of interest rates

	Federal Funds	3 months	6 months	1 year	5 years	10 years
Level of the interest rate						
Mean	6.113	5.561	5.715	6.152	6.793	7.012
Changes in interest rates						
Mean	0.00318	0.00281	0.00281	0.00235	0.00107	0.00099
SD	0.586	0.476	0.448	0.469	0.351	0.298
SK	-2.105	-1.726	-1.711	-1.426	-0.429	-0.391
κ	39.703	26.414	22.416	17.762	9.132	8.715
ρ_1	0.381	0.332	0.345	0.356	0.347	0.311
Q(4)	93.49**	70.22**	76.58**	85.83**	77.69**	60.79**
JB	30767**	12627**	8762*	5093**	862**	749**

Sample period: 1959:12-2005:12.
Number of observations: 553.
SD: standard deviation.
SK: skewness coefficient.
κ: kurtosis coefficient.
ρ_1: first order autocorrelation coefficient.
Q(4): Ljung-Box(4) statistic for autocorrelation of returns.
JB: Jarque-Bera normality test.
* and ** denote statistical significance at the 10% and 5% levels, respectively.

Table 2. Changes in interest rates

$\Delta \mathbf{i_t} = \delta_{0,k} + \delta_{1,k}\mathbf{i}_{t-1} + \mathbf{e_t}$

	Federal Funds	3 months	6 months	1 year	5 years	10 years
δ_0	0.093	0.079	0.074	0.075	0.055	0.045
	(1.80)	(1.75)	(1.68)	(1.63)	(1.35)	(1.23)
δ_1	-0.015	-0.014	-0.013	-0.012	-0.008	-0.006
	(-2.05)	(-1.98)	(-1.89)	(-1.84)	(-1.48)	(-1.32)

Sample period: 1960:01 to 2005:12

Table 3. GARCH (1,1) model for interest rates without break

$\sigma^2_t = \alpha + \beta\, \sigma^2_{t-1} + \gamma\, u^2_{t-1}$

	Federal Funds	3 months	6 months	1 year	5 years	10 years
α	0.005	0.002	0.007	0.003	0.0004	0.0001
	(0.25)	(0.22)	(0.21)	(0.239)	(0.09)	(0.06)
β	0.674	0.739	0.767	0.748	0.846	0.847
	(8.28)	(11.8)	(5.73)	(11.63)	(12.26)	(13.07)
γ	0.308	0.249	0.228	0.231	0.146	0.148
	(2.69)	(2.53)	(0.98)	(2.29)	(0.95)	(1.01)
UV	0.2572	0.170	0.346	0.145	0.059	0.028

Note: the sample size for each interest rate is detailed in the data appendix. t-statistics use QML standard errors assuming Gaussian distributions for σ_t. The parameters are the following: the level of volatility -α-, the persistence of volatility -β-, the news effect -γ- and the unconditional variance -UV -.

Table 4. GARCH (1,1) model for interest rates with one break

$\sigma^2_t = \alpha + \beta\,\sigma^2_{t-1} + \gamma\,u^2_{t-1}$

	Federal Funds	3 months	6 months	1 year	5 years	10 years
α_1	0.007	0.001	0.001	0.001	0.0001	4E-5
	(0.31)	(0.17)	(0.16)	(0.18)	(0.06)	(0.04)
β_1	0.420	0.768	0.795	0.790	0.800	0.793
	(1.42)	(12.5)	(6.94)	(13.24)	(6.14)	(4.84)
γ_1	0.542	0.222	0.201	0.196	0.196	0.204
	(2.05)	(0.71)	(0.22)	(0.53)	(0.26)	(0.24)
UV_1	0.191	0.155	0.309	0.132	0.034	0.022
α_2	0.004	0.014	0.015	0.021	0.007	0.003
	(0.24)	(5.51)	(4.47)	(4.39)	(1.60)	(2.27)
β_2	0.691	2e-9	0.022	0.066	0.791	0.837
	(6.98)	(5e-5)	(0.28)	(0.98)	(7.32)	(13.47)
γ_2	0.305	0.713	0.617	0.523	0.147	0.124
	(2.11)	(2.56)	(3.15)	(3.34)	(0.87)	(1.09)
UV_2	1.654	0.047	0.043	0.051	0.121	0.092
Break	1969:06	1992:07	1993:01	1993:01	1965:09	1965:09
SupLR	16.429	16.37	18.99	20.52	45.18	39.74

Note: the sample size for each interest rate is detailed in the data appendix. t-statistics use QML standard errors assuming Gaussian distributions for σ_t. The parameters are the following: the level of volatility -α-, the persistence of volatility -β-, the news effect -γ- and the unconditional variance -UV -.

Table 5. GARCH (1,1) model for interest rates with two breaks

$\sigma^2_t = \alpha + \beta\,\sigma^2_{t-1} + \gamma\, u^2_{t-1}$

	Federal Funds	3 months	6 months	1 year	5 years	10 years
α_1	0.007	0.00079	0.0009	0.0002	9e-5	3e-5
	(0.31)	(0.12)	(0.14)	(0.04)	(0.06)	(0.04)
β_1	0.420	0.729	0.807	0.852	0.801	0.794
	(1.42)	(4.35)	(7.53)	(2.57)	(6.07)	(5.02)
γ_1	0.542	0.261	0.190	0.144	0.196	0.204
	(2.05)	(1.01)	(0.89)	(0.19)	(0.76)	(0.66)
UV_1	0.191	0.077	0.293	0.056	0.034	0.022
α_2	0.091	0.0065	0.058	0.009	0.033	0.009
	(0.61)	(0.30)	(0.81)	(0.32)	(0.47)	(0.13)
β_2	0.019	0.731	1e-8	0.760	0.179	0.504
	(0.12)	(0.58)	(0.001)	(6.33)	(1.14)	(0.62)
γ_2	0.735	0.265	0.283	0.215	0.553	0.474
	(3.46)	(0.13)	(2.26)	(1.23)	(3.89)	(4.32)
UV_2	0.369	2.191	0.081	0.341	0.124	0.438
α_3	0.004	0.0136	0.015	0.021	0.002	0.001
	(0.22)	(0.57)	(0.53)	(0.56)	(0.30)	(0.18)
β_3	0.661	1e-9	0.020	0.065	0.969	0.976
	(4.78)	(5e-5)	(0.26)	(0.97)	(183)	(93.6)
γ_3	0.339	0.713	0.618	0.524	1e-11	1e-9
	(1.77)	(2.56)	(3.15)	(3.34)	(1e-5)	(6e-5)
UV_3	27.89	0.0476	0.042	0.051	0.063	0.05
Break 1	1969:06	1965:09	1982:09	1965:07	1965:09	1965:09
Break 2	1979:10	1992:07	1993:01	1993:01	1979:10	1979:10
Sup-LR	41.93	19.666	12.89	17.38	29.62	22.35

Note: the sample size for each interest rate is detailed in the data appendix. t-statistics use QML standard errors assuming Gaussian distributions for σ_t. The parameters are the following: the level of volatility -α-, the persistence of volatility -β-, the news effect -γ- and the unconditional variance -UV-.

Table 6. GARCH (1,1) model for interest rates with three breaks

$\sigma^2_t = \alpha + \beta\sigma^2_{t-1} + \gamma u^2_{t-1}$

	Federal Funds	5 years
α_1	0.007	0.0001
	(0.30)	(0.06)
β_1	0.438	0.800
	(4.95)	(6.17)
γ_1	0.521	0.196
	(5.88)	(0.77)
UV_1	0.185	0.034
α_2	0.099	0.033
	(0.75)	(0.48)
β_2	9e-10	0.172
	(3e-5)	(1.03)
γ_2	0.999	0.571
	(207)	(3.46)
UV_2	1940	0.130
α_3	0.006	0.04
	(0.34)	(0.21)
β_3	0.934	0.963
	(114)	(69)
γ_3	2e-11	1e-8
	(4e-5)	(0.0003)
UV_3	0.086	0.112
α_4	0.009	0.053
	(0.31)	(0.99)
β_4	0.400	5e-8
	(2.09)	(0.006)
γ_4	0.361	0.189
	(2.68)	(2.82)
UV_4	0.039	0.065
Break 1	1969:06	1965:09
Break 2	1979:10	1979:10
Break 3	1989:03	1988:04
Sup-LR	22.62	7.31

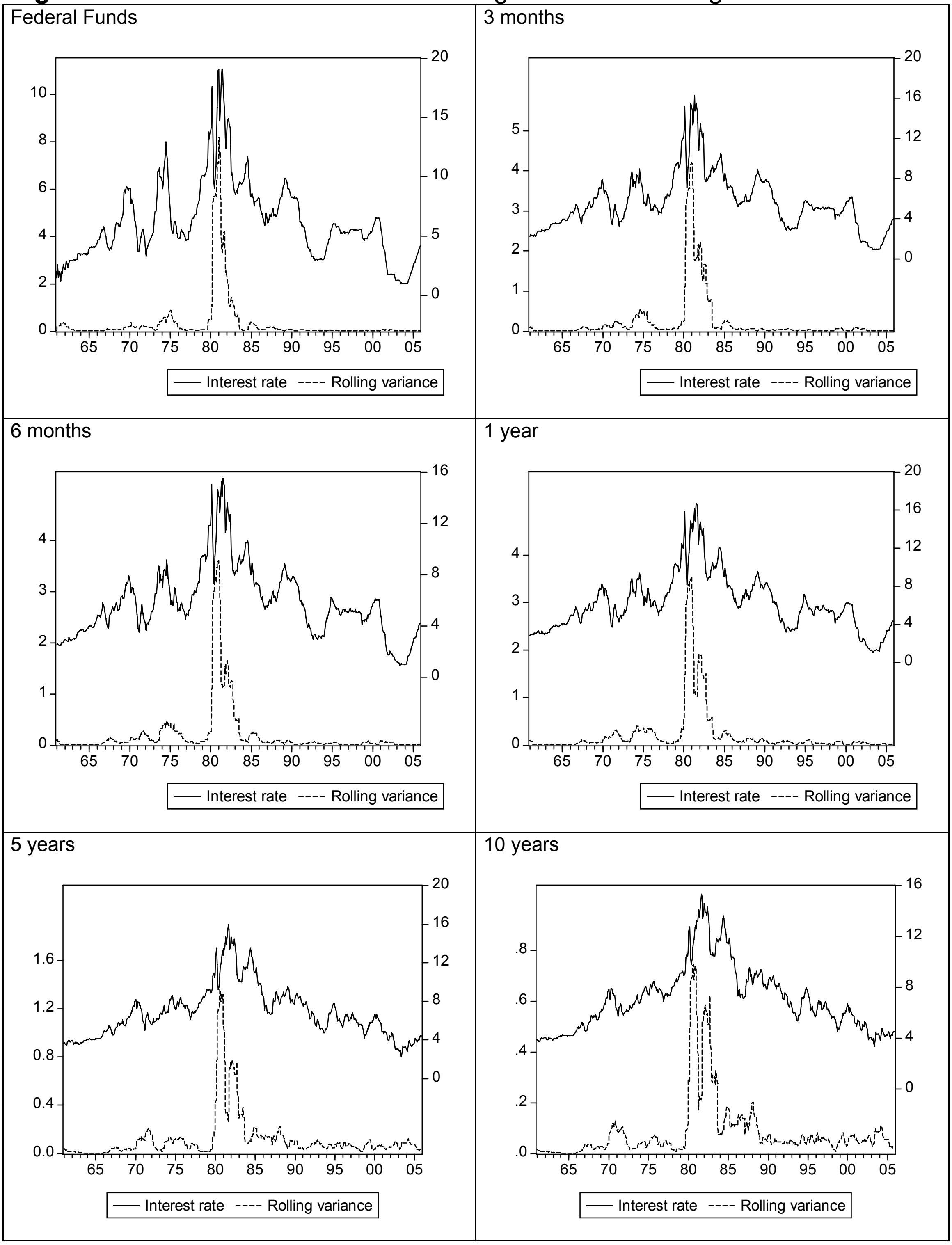
Note: the sample size for each interest rate is detailed in the data appendix. t-statistics use QML standard errors assuming Gaussian distributions for σ_t. The parameters are the following: the level of volatility -α-, the persistence of volatility -β-, the news effect -γ- and the unconditional variance -UV -.

Table 7. IT and KL tests for changes in interest rates

	Federal Funds	3 months	6 months	1 year	5 years	10 years
IT	1958:01	1957:12	1966:06	1957:10	1957:10	1969:08
	1962:06	1960:06	1973:05	1960:06	1960:07	**1979:09**
	1969:03	**1969:11**	1980:01	1969:05	1969:08	1982:10
	1979:03	1980:01	1981:11	1979:08	**1979:09**	1988:05
	1982:08	1982:08	1985:06	1982:01	1982:10	
	1989:03	1986:09	1994:12	1985:06	**1989:07**	
				1995:06		
KL	No break	No break	No break	No break	No break	**1969:08**
						1979:09
						1987:11

Note: dates in bold are also detected by sup-LR tests (see Tables 4 and 5).

Figure 1. Interest rate evolution and rolling variance of changes in interest rates



Note: The sample period used to calculate the rolling variance extends from 1959:12 to 2005:12 for all interest rates maturities. The right axis shows the interest rate whereas the left axis shows the rolling variance of changes in interest rates.

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