
Money market operations and volatility in UK money market rates⁽¹⁾

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The Bank of England implements UK monetary policy by influencing short-term interest rates in its money market operations. The way in which the Bank operates in the market has changed significantly over time, but the aim throughout has been to ensure that the behaviour of short-term interest rates is consistent with monetary policy decisions, whether made by the Chancellor of the Exchequer or, since 1997, by the Bank's own Monetary Policy Committee. Operational choices by the central bank, together with developments in the markets themselves, are likely to have affected the volatility of short-term interest rates. This article outlines various measures of volatility in sterling money markets.

Introduction

In different countries and at different times, monetary policy has had various strategic objectives—including targets for inflation, the exchange rate or monetary growth, or more general aims for growth and price stability. But in recent years, irrespective of their strategic aims, most major central banks have chosen to pursue them either by operating at a set official interest rate or by targeting a short-term money market rate. In setting rates, central banks have a choice of instruments, typically grouped under three headings: open market operations, standing facilities, and reserve requirements.

A simple model of operational policy⁽²⁾

To understand how central banks influence short-term market interest rates, it is useful to consider the market for commercial bank balances at the central bank. Its market-clearing rate is closely related to the central bank policy rate.⁽³⁾

Commercial bank balances at the central bank are the ultimate means of settlement. Commercial banks have a demand for such balances in order to be able to settle transactions among themselves or between their respective customers. And it is from these balances that commercial banks pay for central bank notes, if their customers wish to withdraw cash from their accounts. Central banks may also require commercial banks to maintain these balances at a defined level, either on a

daily basis or on average over a period (reserve requirements). By trading with each other in the interbank market commercial banks can manage the liquidity needs that arise from customer transactions, and can, individually, seek to avoid costly overdrafts on their end-of-day balances with the central bank.

But for the system as a whole, the supply of balances at the central bank stems from the central bank itself, which is the sole supplier. In many cases, central banks manage their own balance sheets so that commercial banks are short-term debtors to the central bank. As this debt matures, if commercial bank balances are to be maintained at the required level, the central bank needs to provide new finance, typically through its money market operations. In this way, the central bank implements monetary policy by setting the rate at which these funds are provided.

But some items in central banks' balance sheets are typically not controlled directly. These items (often called 'autonomous factors') include changes in the note issue and, in some systems, changes in net foreign assets (brought about by exchange market intervention). These autonomous factors can cause significant day-to-day variations in the central bank's balance sheet, and potentially affect the equilibrium interest rate in the market for commercial bank balances.

If the demand for commercial bank balances exceeds the supply, a shortage arises, and banks will bid for funds in

(1) A more technical version of this article appears as a *Bank of England Working Paper* (Vila Wetherilt (forthcoming)).

(2) See Borio (1997) for a summary of theoretical models of central bank operational policies.

(3) The model most easily applies to situations where the policy rate is of a longer maturity, then a richer model is needed to explain the link between the policy rate and the overnight rate.

the market at higher interest rates. The central bank will need to supply funds if it wants to avoid a large departure of the market rate from its policy rate. If the demand for central bank reserves falls short of supply, a surplus arises and the central bank will need to drain funds from the market to prevent the market rate from falling too much. Hence an important part of the central bank's task is the forecast of future demand for commercial bank balances, reflecting movements in autonomous factors.

The past decade has witnessed a number of changes in the operational framework for monetary policy across developed countries. Most noteworthy are the trend towards reducing or removing reserve requirements, changes in the mix of assets used in open market operations and the preference for greater transparency in official rate setting instead of signalling through open market operations.

The operational framework in the United Kingdom

Since March 1997, the Bank of England has implemented its monetary policy via the official two-week repo rate.⁽¹⁾ This is the rate at which the Bank conducts repo transactions with its counterparties as part of its daily open market operations (OMOs). Commercial banks with settlement accounts at the Bank of England are required to have a positive balance on their accounts at the end of each day, and otherwise pay a penalty rate. The Bank of England manages its own balance sheet to ensure that on most days the banking system needs to borrow from the Bank. In the daily open market operations, the Bank's OMO counterparties can submit bids for funds at the official repo rate up to the size of the forecast of this liquidity shortage announced by the Bank every day. The Bank supplies sufficient funds to leave the settlement banks collectively with small positive end-of-day balances.

Although the Bank's OMO counterparties include settlement banks, which hold balances on accounts at the Bank, a settlement bank does not need to be a counterparty and an OMO counterparty does not need to be a settlement bank. Irrespective of the type of organisation that takes the funds in the Bank's money

market operations, those funds will eventually find their way on to a settlement bank's account at the Bank. In this way, the Bank's operations provide to the market the net amount of liquidity needed by the system as a whole.

Counterparties have the choice between entering into repo agreements with the Bank, or selling securities on an 'outright basis'. The use of repo in the open market operations has grown markedly in recent years. This is partly the result of the 1996 reforms that removed restrictions on the development of an open gilt repo market.⁽²⁾ Most of the open market operations are undertaken at a two-week maturity, though variations occur, depending on the time profile of the market's liquidity needs.⁽³⁾

Prior to 1997, open market operations were mainly conducted with discount houses via outright purchases or sales of eligible bank bills and sterling Treasury bills. A key rate was the so-called minimum Band 1 dealing rate, which was the minimum rate at which the Bank was willing to discount bills with up to 14 days maturity. After the September 1992 Exchange Rate Mechanism crisis when foreign exchange intervention caused a massive drain of liquidity from the market that had to be recycled, the Bank introduced temporary repo facilities for assets including gilts, available to a wider range of counterparties. These were re-offered on a number of occasions thereafter, and from January 1994, became a regular part of the Bank's open market operations. They were conducted twice a month with a maturity generally of two or four weeks, and were open to a selected group of market participants. When in 1997 two-week repo operations were introduced into the Bank's daily operations, the twice-monthly repo facility was put into abeyance.

The 1997 reforms also broadened the group of eligible counterparties, to include a wide range of banks and dealers that are active in the sterling money markets. Counterparties can use a range of securities as collateral in the open market transactions, including gilts and eligible bills (Treasury bills and eligible bank bills). Since 1997 the pool of securities that can be used as collateral has been extended, most notably in August 1999, when euro-denominated securities issued

(1) For more detail, see 'The Bank of England's operations in the sterling money markets', *Bank of England Quarterly Bulletin*, Summer 2002, pages 153–61.

(2) Prior to 1996, gilt repo was available to a limited group of market participants only, at fixed fees, and could only be used to cover short positions.

(3) For example, between October 1999 and February 2000, the Bank offered repos with up to three-month maturity to assist in managing liquidity needs over the millennium date change.

by governments and central banks in the European Economic Area were added to the list. After the 1997 reforms, it remained possible for the Bank to provide liquidity through channels other than the daily repo auctions, in particular via the use of foreign exchange swaps.⁽¹⁾

From 1997 to 1998, there were two daily rounds where the Bank's counterparties could bid for funds (12.00 noon and 2.30 pm), and sometimes an additional early round (9.45 am) depending on liquidity conditions. In June 1998, this was modified to two regular daily rounds (9.45 am and 2.30 pm) for two-week repo and outright sales.⁽²⁾ In addition, the Bank introduced two end-of-day facilities for overnight repo that could be used by market participants who found themselves with unforeseen liquidity needs towards the end of the day. At 3.30 pm, OMO counterparties can bid for the necessary additional funds at a penal rate (currently 100 basis points above the Bank's repo rate).⁽³⁾ The Bank thereby effectively introduced a ceiling for the overnight rate.⁽⁴⁾ After the close of the money markets, the 4.20 pm facility allows settlement banks that are subject to the daily maintenance requirement to obtain additional funds (at a penal rate of 150 basis points above the official repo rate) which might be needed in order to balance their account with the Bank at the end of the day.⁽⁵⁾ In June 2001, the Bank introduced an overnight deposit facility (remunerated at 100 basis points below the Bank's repo rate). This facility is made available to the Bank's OMO counterparties at 3.30 pm. This policy change, however, falls outside the sample period considered in this article.

Operational policy and the behavior of money market rates

Some fluctuations of market interest rates around the policy rate are a normal feature of a well-functioning market. But evidence of changing longer-term patterns in the spreads of money market rates over the policy rate can be indicative of changes in the effectiveness of operational procedures. In this respect, evidence of changes in these rates and their volatility following policy reforms might be particularly illuminating.

In this article, the behavior of money market rates is viewed from two angles. First, fluctuations of market rates around the policy rate are examined, with particular attention to their volatility and their persistence. In the context of the United Kingdom, the main variable of interest is the spread of two-week market rates over the Bank's official repo rate.

But the spread of overnight rates over the official rate might also serve as an indicator of effectiveness. Those rates are affected by some aspects of the operational framework (most notably the overnight facilities). Furthermore, market participants' behaviour in the overnight market is typically influenced by their views on current and future expected policy rates, as well as the prevailing two-week market rates. For example, when market participants expect official rates to rise, they may want to borrow from the Bank for the longest possible period (ie two weeks) to lock in the prevailing official rate. This will cause demand for overnight money to fall. Overnight rates will therefore fall prior to the expected rate rise, only to catch up thereafter.⁽⁶⁾

If central banks implement policy in such a way that market rates remain close to the official rate, they will also keep volatility of these rates low and stable over time. Measuring the volatility of these rates is then just another way of assessing an operational policy.

Both spreads and rate volatility can also depend on market participants' perception of the central bank's attitude towards money market rate volatility. If market participants expect that the central bank will not tolerate large differences between market rates and the policy rate, then they themselves might be less inclined to trade at rates away from the policy rate. By the same token, should large divergences arise, then they would be expected to be short-lived as the central bank would be expected to act promptly.⁽⁷⁾ Any increases in volatility of market rates would then be expected to be temporary. In other words, in assessing the impact of operational policy on the shortest money market rates, both the level and the persistence of their volatility need to be examined.

(1) See for example *Bank of England Quarterly Bulletin*, May 1999, page 110.

(2) On days when the MPC announces its repo rate decision, the early round is not held until 12.15 pm.

(3) No penalty is incurred if these liquidity needs arise from late changes to the Bank's liquidity forecast.

(4) Prior to June 1998, only a limited number of market participants had access to a late lending facility and their access was limited by quotas. Hence, the late lending rate did not effectively cap the overnight rate.

(5) Again, funds are provided at the normal repo rate if there was a late revision to the Bank's forecast of the daily shortage.

(6) This is referred to as pivoting.

(7) See for example Guthrie and Wright (2000).

A second question about overnight and two-week rate volatility is the extent to which it affects the volatility of rates further along the money market yield curve. To see how this transmission of volatility can be measured, it is helpful to use a standard model of interest rates that links the behaviour of such longer-term rates to current and future short-term rates (the expectations model with a constant risk premium). In such a model, volatility of longer rates is closely related to volatility of the shortest rates.

But variability in short rates does not always lead to proportional variability in long rates. If the variability in short rates is high, but short-lived, then the effect on longer-term variability will be weak.⁽¹⁾ In contrast, if short-term volatility tends to persist over time, so that prolonged episodes of high volatility occur, then even small increases in this volatility will result in high variability of longer-term rates.

Volatility of UK money market rates at the short end

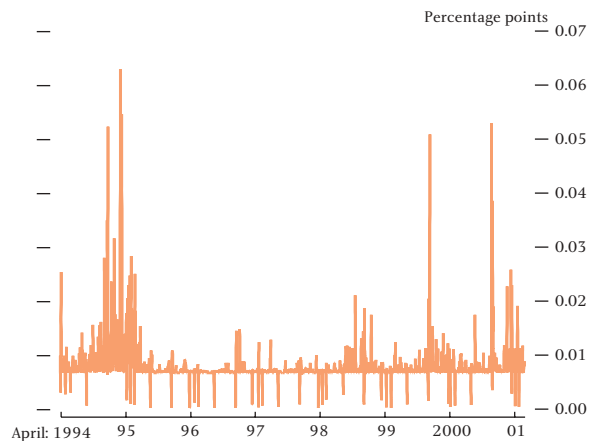
To examine volatility in UK money markets, this article employs daily data for UK unsecured interbank market rates (Libor) over a long sample period (April 1994 to June 2001) and computes spreads over the official repo rate. Rate volatility is measured using the well-established Generalised Autoregressive Conditional Heteroskedasticity (GARCH) method (see the appendix for more details).

Chart 1 shows the volatility of the two-week rate, while Chart 2 reports the spread of the two-week rate over the official repo rate. The charts show significant variations in both rate volatility and the spread over the period 1994–2001. In this period, the United Kingdom's operational framework underwent a number of important changes. Hence the data for this period might be used to examine the impact of operational choices on the behaviour of market interest rates. However, operational choices were in part a response to actual or anticipated changes in volatility, so that it might not always be possible to disentangle causal effects in the data.

In Chart 1, the most distinct change in two-week volatility was a marked break in mid-1995, as volatility fell and peaks became less frequent and shorter-lived. Two-week spreads in Chart 2 tell a similar story. They

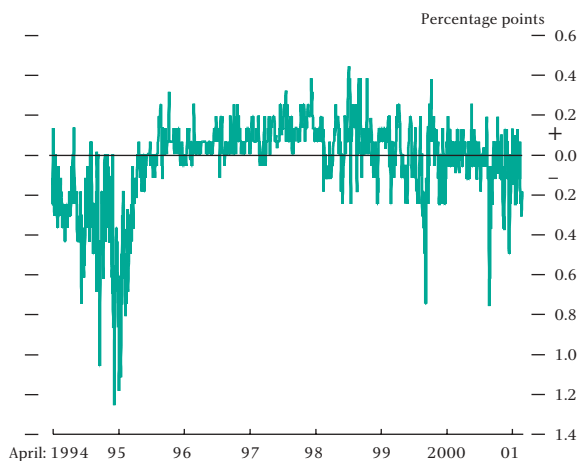
were much narrower from the second half of 1995 onwards, and whenever they widened, they seemed to return much faster to their long-run average. Hence, after mid-1995, the relationship between the two-week unsecured interbank market rate and the official rate seems more stable. It is only towards the end of the sample period that wider and longer-lived deviations between market and official rates occurred.

Chart 1
Volatility of two-week unsecured market interest rates, conditional variance estimated from GARCH model, April 1994–June 2001



Note: Volatility is estimated using a GARCH model (see the appendix).
Sources: Thomson Financial Datastream and Bank of England.

Chart 2
Spread of two-week unsecured market interest rate over official rate, April 1994–June 2001



Note: The spread is calculated as the difference between the two-week rate and the Bank's policy rate (the minimum Band 1 dealing rate before March 1997 and the two-week official repo rate thereafter).

Sources: Thomson Financial Datastream and Bank of England.

The ERM crisis of September 1992 and the subsequent suspension of the United Kingdom's participation in this monetary framework, together with high variability in

(1) See for example Watson (1999).

both government and private sector borrowing, had created rather volatile conditions in the money markets throughout 1992 and 1993 (not shown in Chart 1).⁽¹⁾ Daily shortages were often high and market participation in open market operations low, either because of expectations of official rate reductions, or because of a shortage of eligible securities. Technical changes in the Bank's balance sheet, together with the permanent adoption of the two-week repo facility in January 1994, contributed to a sharp reduction in volatility in the first half of 1994.⁽²⁾ The market continued, however, to experience peaks in volatility, as can be seen from Chart 1. These occurred at the end of 1994, and again in early 1995, when in the wake of the Barings crisis, the Bank was willing to allow slightly larger deviations between the two-week unsecured interbank rate and the policy rate. By late 1995 the Bank decided to return to a less accommodative operational policy.⁽³⁾ Spreads narrowed and rate volatility declined as a result.

Two-week rate volatility was relatively low and stable from early 1996 to late 1999, except for a low and short-lived peak in late 1998. Likewise, two-week spreads were narrow and stable. Summary statistics in Table A are calculated for the periods just preceding and following each of the money market reforms. From these numbers it is not possible to detect any net effects from the 1997 reforms (the withdrawal of the twice-monthly repos and the introduction of repos in the daily open market operations) on either volatility or on the average spread. The same appears to be true of the 1998 reform (introduction of the end-of-day facility). But any volatility-reducing effects of the 1997 and 1998 reforms could have been masked by other factors. First, a fortnightly repo facility was effective before 1997, especially after the 1996 introduction of the gilt repo market widened participation in this facility. And second, rates were affected by the Bank's money market tactics after the 1997 reform in the transition to the new operating framework.

Table A also shows that the persistence of volatility at the two-week maturity was unchanged. The statistics further indicate that two-week spreads became slightly more persistent after 1997, but the effect is barely visible from Chart 2. Finally, the statistics in the table seem to

suggest that the 1996 introduction of the gilt repo market had a significant impact on the behaviour of two-week unsecured interbank rates. But when comparing with Charts 1 and 2, it appears that the summary statistics pick up the effect of the mid-1995 fall in volatility, rather than any effect associated with the 1996 reform.

Table A
Two-week interest rate volatility and interest rate spread (April 1994–June 2001)

	Two-week volatility		Two-week spread	
	Average (a)	Persistence	Average (a)	Persistence
Pre-1996	0.0140	0.58	-0.25	0.86
Jan. 1996: Gilt repo market	0.002	0.26	0.05	0.61
Mar. 1997: Reform to daily open market operations (OMOs)	0.002	0.24	0.11	0.77
June 1998: Late lending facility	0.005	0.24	0.06	0.77
Aug. 1999: Collateral changes	0.008	0.49	-0.05	0.79

Note: Each subperiod starts with the reform mentioned after the date and ends immediately prior to the next reform. The pre-1996 period starts in April 1994. Volatility and its persistence are estimated using the GARCH model (see the appendix). Spreads are calculated as the difference between the two-week unsecured interbank rate and the Bank's policy rate (the minimum Band 1 dealing rate before March 1997 and the two-week official repo rate thereafter). Spread persistence is calculated as the first-order autocorrelation coefficient.

Sources: Thomson Financial Datastream and Bank of England.

(a) Percentage points.

After 1999, two-week volatility increased slightly and became more persistent. Some, but not all, of this rise could be attributed to end-of-year effects, in particular the millennium changeover. Two-week spreads reflected this increased rate volatility, even though the mean was relatively unaffected. Finally, the data do not show any volatility-reducing effects that could be associated with the 1999 expansion of the pool of eligible collateral.

Turning to the behaviour of overnight unsecured interbank market rates during this period, Chart 3 shows that volatility of this rate has fallen since 1994, with the exception of a short-lived peak in the fourth quarter of 1997 and the first quarter of 1998. Overnight volatility declined in 1994 and 1995. As in the case of the two-week rate, a combination of balance sheet factors and policy considerations (post-Barings) contributed to a more stable overnight rate. So the precise impact of the 1996 reforms is again not visible in the data. The earlier mentioned balance sheet factors contributed to heightened overnight volatility in the final quarter of 1997, thereby undoing any volatility-reducing impact the 1997 reforms may have had.⁽⁴⁾ This volatility may also have been related to the

(1) See 'Market operations since September 1992', *Bank of England Quarterly Bulletin*, February 1995, pages 12–13.

(2) This reform also occurred outside our sample period and therefore its impact is not formally tested.

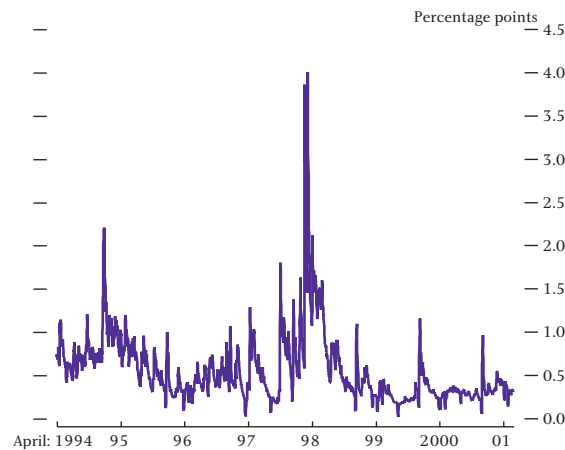
(3) See *Bank of England Quarterly Bulletin*, August 1995, pages 225–27, and November 1995, pages 319–22.

(4) This volatility increase was attributed to large daily shortages (linked to gilt sales and government spending), which in turn led to higher-than-normal use of the late-day lending facility. See *Bank of England Quarterly Bulletin*, February 1998, pages 11–12, and May 1998, pages 109–11. Until June 1998, this facility was restricted to a small group of market participants (see above), and as such did not constitute an effective ceiling for the overnight rate.

earlier mentioned gradual phasing out of transitional arrangements that had been in place since the March 1997 reforms.

But Chart 3 reveals a clear break in the middle of 1998: up to this break, average overnight volatility was generally higher and sudden peaks occurred frequently, even though they were mostly short-lived. Thereafter, such peaks occurred less frequently (they were almost all related to end-of-year effects), and average volatility was lower. This seems to suggest that the late-round lending facility introduced in July 1998 was effective in constraining overnight volatility.

Chart 3
Volatility of overnight unsecured market interest rates, conditional variance estimated from GARCH model, April 1994–June 2001



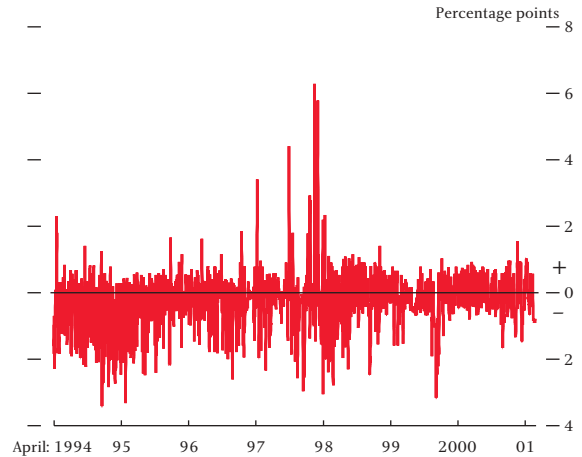
Note: Volatility is estimated using a GARCH model (see the appendix).
Sources: Thomson Financial Datastream and Bank of England.

Chart 4 and the summary statistics in Table B show that the overnight spread narrowed during the period 1994–2001. The chart also shows that overnight spread volatility declined, in line with overnight rate volatility. Throughout the 1994–2001 period, volatility of the overnight rate was generally highly persistent, meaning that a rise in volatility was not immediately reversed. In contrast, two-week volatility (shown in Table A) was much less persistent. Spreads over the policy rate show the opposite pattern. Two-week spreads over the policy rate were less negative, but more persistent than overnight spreads.

Taken together, Charts 1 to 4 suggest that, over the period analysed as a whole, the Bank of England's operational policy has resulted in greater alignment of short-term market rates with the official policy rate. This in turn has contributed to lower volatility in short-term

money market rates. But within this longer period, shorter episodes of heightened volatility could be observed. Mostly, they reflected unusual market circumstances, and their effect on the money market was usually short-lived.

Chart 4
Spread of overnight unsecured market interest rate over official rate, April 1994–June 2001



Note: The spread is calculated as the difference between the overnight rate and the Bank's policy rate (the minimum Band 1 dealing rate before March 1997 and the two-week official repo rate thereafter).
Sources: Thomson Financial Datastream and Bank of England.

Table B
Overnight interest rate volatility and interest rate spread (April 1994–June 2001)

	Overnight volatility		Overnight spread	
	Average (a)	Persistence	Average (a)	Persistence
Pre-1996	0.69	0.77	-0.67	0.16
Jan. 1996: Gilt repo market	0.40	0.93	-0.29	0.06
Mar. 1997: Reform to daily OMOs	0.85	0.98	-0.25	0.11
June 1998: Late lending facility	0.42	0.90	-0.25	0.25
Aug. 1999: Collateral changes	0.25	0.96	-0.20	0.58

Note: Each subperiod starts with the reform mentioned after the date and ends immediately prior to the next reform. The pre-1996 period starts in April 1994. Volatility and its persistence are estimated using the GARCH model (see the appendix). Spreads are calculated as the difference between the overnight unsecured interbank rate and the Bank's policy rate (the minimum Band 1 dealing rate before March 1997 and the two-week official repo rate thereafter). Spread persistence is calculated as the first-order autocorrelation coefficient.

Sources: Thomson Financial Datastream and Bank of England.

(a) Percentage points.

Finally, although the trend has been for greater conformity of market rates with the policy rate, the techniques used in this article do not enable us to allocate that progress between the individual reforms, except perhaps that those of 1998 were effective in altering the behavior of overnight rates.

Volatility transmission

The transmission of volatility in the shortest rates to volatility of longer rates can be measured as follows. First, a GARCH regression model for two-week rates is estimated to obtain a measure of two-week volatility.

Second, similar regression models for the longer maturities (up to twelve months) are estimated, with the GARCH estimate of two-week volatility as an additional explanatory variable. A similar procedure is employed to estimate the transmission of overnight volatility.

For each maturity, Table C reports the proportion of volatility in longer-term interest rates that is directly related to two-week volatility (column 1) or overnight volatility (column 2).⁽¹⁾ The results indicate that there is little transmission of two-week volatility. Though positive at most maturities, the coefficients of the regression are very small and significant only at the one-week maturity.⁽²⁾ The results in Table C further show that the impact of overnight volatility is even smaller, and never statistically significant.

Table C
Volatility transmission (April 1994–June 2001)

Impact on volatility of rates at:	Two-week volatility	Overnight volatility
1 week	0.40*	0.06
2 weeks	—	0.01
1 month	0.01	0.001
3 months	0.003	0.0001
6 months	-0.002	-0.00001
12 months	0.01	-0.003

Note: The entries in Table C are the coefficients on two-week volatility (column 1) or overnight volatility (column 2) in the regressions with volatilities of between one week and twelve months as the dependent variable. The regression coefficients are estimated using the GARCH procedure outlined in the appendix and use data for the period April 1994 to June 2001. A * indicates statistical significance at the conventional 95% level.

So during the 1994–2001 period neither two-week, nor overnight volatility contributed to volatility of the longer-dated money market rates. There is also no evidence of a change in this transmission process following any of the money market reforms during this period.⁽³⁾ Even though there were short periods of higher volatility in overnight and two-week rates, this

volatility was not transmitted and as such left the higher maturities unaffected. In that sense, operational policy was effective.

Conclusion

This article has illustrated how money market volatility declined between 1994 and 2001, and how spreads around the policy rate narrowed and became more stable. Short periods of sharp rises in volatility, perhaps reflecting unusual market circumstances, are shown to have become less frequent.

The research also shows that it is very difficult to identify precisely the impact of specific policy reforms in the data. The interest rates studied here are set in markets that have been influenced by many factors besides changes to central bank operations. These include not only the introduction of the repo market, mentioned above, but also changes in payment and settlement systems and in the regulatory framework for the management of banks' liquidity.⁽⁴⁾ Moreover, changes to central bank operations have not been wholly exogenous, but have responded in part to developments in markets.

Finally, the article suggests that one measure of the effectiveness of an operational policy is whether it minimises the transmission of any short-term volatility to the remainder of the money market yield curve. Using a simple statistical model to measure this transmission process, operational policy is shown to have been successful, in that volatility of the longer UK money market rates was unaffected by volatility in very short-term rates over the 1994–2001 period.

(1) For more detail, see Vila Wetherilt (forthcoming).

(2) This significance result is highly unstable, in that it frequently vanishes when calendar dummies are added or removed.

(3) More details are in Vila Wetherilt (forthcoming).

(4) See Chaplin, Emblow and Michael (2000).

Appendix

Estimating the transmission of interest rate volatility

In this article, volatility is measured using the GARCH method. On an intuitive level, this method can be explained as follows. First, a simple regression model for daily rate changes is estimated. Second, the variance of the model's residuals is calculated. This variance is assumed to change over time, and to vary with the size of the actual errors. This represents a departure from the classical regression model, which assumes that errors have constant variance. The model also incorporates the 'volatility clustering' often observed in financial data (prolonged periods of high volatility).

To capture these features of the data, the GARCH model estimates an additional equation for the variance. This includes estimates of the variance calculated over earlier periods, together with the squared residuals from the first equation. The model also gives some (small) weight to the long-run mean of the variance process. The GARCH method is preferable to calculating a simple rolling standard deviation, as it allows the data to select the weights given to past observations.

A simple GARCH model for money market rates looks as follows:

$$\Delta r_t = \alpha + \sum_{i=1}^m \beta_i \Delta r_{t-i} + \sum_{i=0}^n \gamma_i \Delta o_{t-i} + \delta (r_{t-1} - o_{t-1}) + \sum_{s=1}^S \lambda_s d_s + \varepsilon_t \quad (1)$$

$$\varepsilon_t \sim N(0, h_t) \quad (2)$$

$$h_t = \psi_0 + \psi \varepsilon_{t-1}^2 + \phi h_{t-1} + \sum_{k=1}^K \kappa_k d_k \quad (3)$$

Equation **(1)** is the mean equation. It shows how average changes in money market rates (Δr_t) are explained by their own lags (Δr_{t-i}) and by contemporaneous and lagged changes in the policy rate (Δo_{t-i}). The long-term relationship between money market rates and the official rate is also allowed to affect the dynamic behaviour of money market rates. Indeed, if on day t , market rates deviate much from the policy rate, then one would expect them to move a lot in subsequent periods in order to restore the long-term relationship, thereby creating larger short-term movements. This is captured by the term $(r_{t-1} - o_{t-1})$. Dummies d_s are included to account for calendar effects (namely bank holidays and the end of the calendar year) that are known to produce outliers.

In the GARCH model, volatility of money market rates (h_t) is explained by the estimated variance from earlier periods and shocks to volatility observed in earlier periods (the squared residuals). In line with most finance applications, a simple GARCH (1,1) model is estimated that includes one lag only of both the estimated variance (h_{t-1}) and the squared residuals ε_{t-1} (see equation **(3)**). Estimates of h_t and ϕ are presented in Tables A and B. The higher the coefficients ψ and ϕ in equation **(3)**, the longer-lived the effect of past shocks on volatility. This is how the GARCH model can explain prolonged periods of high volatility. The estimated variance h_t is often referred to as the conditional variance, as it is conditional on information available at time t . This implies that volatility is time varying, and that estimating volatility over different sample periods is likely to produce different results. As in equation **(1)**, dummies d_k capture calendar effects.

Engle and Lee (1999), however, point out that in many cases the conditional volatility is better characterised by a stochastic trend, with short-term deviations around this trend. To capture these dynamics, they propose to decompose the variance h_t into a permanent component (trend) and a transitory component, which is mean reverting to the permanent component. The estimates presented in this article employ this approach, which is explained in detail in Vila Wetherilt (forthcoming).

To estimate the impact of two-week volatility on any of the longer-term money market rates, a two-step method is employed (see Table C). First, the conditional variance of two-week rates is estimated. Second, having obtained an estimate for two-week volatility (h_t), the same system of equations is run for selected higher maturities, with two-week volatility as an additional regressor. A similar procedure is used to estimate the impact of overnight volatility on longer-term money market volatility.

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