Monetary policy procedures and volatility transmission along the yield curve

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Abstract

This paper examines the degree to which volatility in overnight interest rates leads to volatility in other short-term interest rates, and whether this relationship differs in countries with different monetary policy operating procedures. In six of the nine countries, a significantly positive relationship is found between the variance of the overnight rate and the variance of two or more longer-term rates, although in Germany the relationship was negative. Countries which directly target overnight rates tend to have a lower variance, not just for the overnight rate, but also for other short-term interest rates, than countries which target a repo rate. The relationship between overnight-rate volatility and volatility at other maturities is stronger for countries which set reserve requirements. To the extent that market volatility is an indicator of illiquidity, these results suggest that liquidity spillovers do exist across different maturities in the money-market, and that central banks can influence liquidity conditions in the money market at maturities different from that of their targeted rate.

1. Introduction

Most central banks in developed countries target a designated policy rate both in their day-to-day liquidity operations and in their "signalling operations", i.e. public statements. They tend to differ, however, in how aggressively they act to stabilise overnight interbank rates at or near the policy rate. One of the justifications for an aggressive defence of the target rate in the overnight market is that this will add stability to money markets considered more broadly – that is, at other maturities than the one for which a policy rate is specified. Opposed to this is the view that since interest rates at the one or three month level are more important for economic decision making, and since market participants ignore fluctuations in extremely short-term markets when setting the prices for longer-term claims, the stability of overnight markets is irrelevant to the goals of monetary policy.

This paper attempts to assess the degree to which volatility in overnight interbank rates affects volatility patterns of short-term interbank rates at other maturities in nine developed economies. Specifically, it examines the overall level of volatility of daily movements in short-term interest rates at five maturities, and the effect of volatility in overnight markets on volatility at the other maturities. To do this, generalised autoregressive conditional heteroskedasticity (GARCH) models are estimated for the overnight interest rate. The effects of the fitted GARCH variances on the variances of other interest rates with maturities up to one year are then estimated.

In six of the nine countries studied, a significantly positive relationship (at the 95% level) is found between the variance of the overnight rate and the variance of two or more longer-term rates. In four of the remaining five countries, the coefficients are nearly always positive. This seems to confirm the hypothesis that, ***within*** the experiences of different countries, periods of volatility in overnight rates correspond to periods of volatility in non-targeted rates. Germany was the only country where the relationship between overnight-rate volatility and volatility at other maturities was consistently negative.

When estimated variances are compared ***between*** countries, however, it is found that countries which directly target overnight rates tend to have a lower variance, not just for the overnight rate, but also for other short-term interest rates, than countries which target a repo rate of up to 30 days. This first group also sees a more rapid incorporation of the policy rate into overnight rates. Countries with reserve requirements, including members of both of these groups, tend to have a stronger relationship between overnight-rate volatility and the volatility of interest rates at other maturities than countries without reserve requirements, suggesting that banks' efforts to meet reserve requirements through balance-sheet adjustment lead to a coincidence in episodes of interest-rate uncertainty at different maturities.

To the extent that market volatility is an indicator of illiquidity (a proposition discussed below), these results should have a number of implications for the liquidity characteristics of short-term money-markets. For one thing, the results suggest that these markets are indeed linked to one another, so that disruptions to the supply or demand of funds at one maturity (for example, through insufficient or excessive injections of overnight funds by the central bank) can cause volatility spillovers to the markets for funds at other maturities. Second, central banks can influence liquidity conditions in the money market both through their "conduct" of monetary policy, and through the market "structure" they create by setting reserve requirements.

The remainder of the paper is organised as follows. The next section discusses the relevance of the present work to the broader analysis of the determinants of market liquidity. Section 3 reviews the techniques used by different central banks to control short-term interest rates. Section 4 describes the data and the GARCH estimation technique used and presents results of the "within country" analysis. Section 5 discusses differences in these results across countries, and suggests institutional features that could account for them. Section 6 concludes.

2. Interest-rate volatility and money-market liquidity

The primary volatility measure examined in this paper is the variance of the estimated residuals from a regression of daily market interest rate changes on daily changes in policy rates. These variances should exclude, to a large extent, volatility resulting directly from rapid contemporaneous movements in policy rates. This leaves three possible sources for this volatility measure: uncertainty about the future direction of policy, that is, fluctuations in the expected path of future rates; fluctuations in term premia, including risk premia; and fluctuations in the supply and/or demand for funds at the corresponding maturity.

In a fully liquid money-market, the underlying supply and demand for funds should not have an effect on market interest rates, because marginal participants should be willing to lend or borrow as needed when rates depart from fundamental values reflecting current and expected policy rates and term premia. Thus, if a link can be found between supply and demand conditions and rate fluctuations, a high degree of interest-rate volatility could be interpreted as indicating a low level of market liquidity.

Central banks can affect these patterns of supply and demand in two primary ways: through their own practices in effecting the supply of central bank money, and through reserve requirements. If it can be shown that there are systematic differences in interest-rate volatility that correspond to differences in monetary policy operating procedures, this would be evidence that interest-rate volatility at least to some extent results from supply and demand fluctuations.

For overnight rates, term premia and the expected path of future rates are irrelevant. Liquidity conditions are thus likely to be the primary source of volatility for these rates, so we can use volatility as a rough indicator of market liquidity. For other short-term interest rates, in the absence of reliable measures of the market's degree of certainty about the future path of monetary policy, the impact of uncertainty about expected rates and of fluctuating term premia cannot be excluded. Any conclusions that are drawn relating the volatility of these rates, through market liquidity, to monetary policy operating procedures must thus be regarded as purely indicative and suggestive of areas for further research.

3. The overnight rate and monetary-policy tactics

In recent years, several authors have examined and compared the effects of monetary policy procedures on the stochastic characteristics of the interest rate process. These include Hamilton (1996) and Roberds, Runkle and Whiteman (1996) for the US; Ayuso, Haldane and Restoy (1997) for the UK, Spain, France and Germany; Panigirtzoglou, Proudman and Spicer (1998) for Germany, Italy and the UK; and Escrivá and Fagan (1996) for the European Union countries. The present paper attempts to build on this literature by expanding its geographic scope, specifically through a systematic analysis of these effects in countries in North America, Europe and Japan, and by relating cross-country differences in the observed effects more directly to the characteristics of monetary policy operating procedures.

Table 1, reprinted from Borio (1997) and based on a BIS survey of central banks, identifies some of the key features of monetary policy operating procedures for a selection of industrialised countries in the period studied.[1] While no two central banks are strictly identical in terms of all the policy features listed, it is useful to divide the countries listed into three broad groupings.[2]

[1] To a large degree, monetary policy procedures in the nine central banks studied remained essentially the same over the 1990-98 period, though strategies and many details of implementation were not always constant.

[2] At the time Table 1 was constructed, Switzerland was unique among the countries surveyed in that it targeted a quantity (transactions deposits) at the operational level rather than setting an explicit policy rate. Since that time, however, it has moved closer to a repo-tendering regime.

The first group specifies an overnight rate target as its policy rate. This group includes Australia, Canada, Japan and the US In order to ensure that the actual market overnight rate does not deviate excessively from the target, countries in this group tend to intervene in the money markets daily or more frequently. Instruments used for these interventions include repurchase agreements (repos), outright transactions, and shifts in the placement of government deposits.

The second group specifies a repo rate with a maturity of between one day and one month as its policy rate, but also endeavours to stabilise the overnight rate. This group includes Austria, France, Germany, Italy, Spain and Sweden. The repo rate for transactions at the specified maturity(ies) is either explicitly set through fixed-rate tenders, or targeted through decisions about the quantity offered under variable-rate tenders. At the same time, the overnight rate is stabilised through such means as periodic discretionary operations, signalling mechanisms or reserve requirements. Central banks in this group tend to conduct their tendering operations once or a few times a week, i.e. less frequently than those in the first group, though discretionary operations may take place more often.

The third group uses repo or repo-like transactions at one set of maturities (generally less than one month) to target a policy rate for a different set of maturities (generally one to three months). This group includes Belgium, the Netherlands and the UK, though operational methods and frequencies vary widely among these three countries. For the purposes of this paper, an important consequence of this framework is that these central banks take little or no action to stabilise overnight rates.

An alternative way of classifying these countries is according to their use of reserve requirements. Two of the countries in our first group (the US and Japan) and five of the six in the second group (all except Sweden) set reserve requirements of some kind. Two members of the first group (Canada and Australia), Sweden, and the three members of the third group either have no reserve requirements or require only that banks maintain on average a positive level of "working balances" with the central bank over some period.

Central banks also differ in the use of interest rates on official standing facilities as ceilings, floors, and/or signals regarding the policy rate. However, differences (both among countries and over time) in the conditions of access to such facilities and in banks' willingness to avail themselves of them make it difficult to establish a clear classification of countries on this basis.

There are a number of possible ways in which the institutional characteristics described so far could influence interest-rate volatility. Regarding the *choice of target*, one would normally expect relatively low volatility for the targeted policy rate itself. As discussed above, overnight rates are nevertheless usually quite volatile even if actively targeted, because of uncertainties about the supply and demand for funds in the very short run.

Even if the overnight rate is not targeted, excessive volatility in this rate could induce market participants to borrow and lend outside of their preferred habitat, leading to higher volatility in these other maturities as conditions adjust. This channel might be less likely to operate if large banks and other specialised participants dominate the overnight market, so that other participants are unable or unwilling to take advantage of overnight-rate pricing anomalies.

One way to test for the presence of volatility transmission from overnight rates to other rates would be to examine countries in our third group, which neither target the overnight rate nor attempt to stabilise it through other means. If the central bank does not take an active interest in stabilising overnight rates, such rates are likely to be more volatile, but markets are less likely to take overnight-rate movements as signals about the stance of monetary policy. Thus, if volatility transmission results from monetary policy uncertainty, such countries should not have unusually high volatility at non-overnight maturities. However, if overnight rate volatility leads ***ipso facto*** to volatility for other maturities, for example through the shifting of participants into and out of their preferred maturity habitats, then countries which do not attempt to stabilise overnight rates should have more volatile money markets at all maturities.

Reserve requirements could potentially help to buffer interest-rate movements, by reducing the sensitivity of bank activities to inflows and outflows of deposits. The tendency of banks to scramble for or to dump reserves at the end of reserve-maintenance periods, however, often leads to higher overnight-rate volatility at these times. Again, the degree of transmission from the overnight market to other markets will depend on the range of participation in these markets and the ease of arbitrage among them.

The variety of monetary policy procedures pursued by central banks thus could potentially affect short-term interest rate volatility through a number of different channels. Given that there are sound theoretical arguments for the existence of each of these channels, empirical analysis is needed to determine which channels are in fact relevant to observed interest-rate volatility patterns and which are not.

4. A GARCH model of volatility transmission

Modelling the overnight rate

Daily short-term interest rate data (policy rate, overnight rate, and 1, 3, 6 and 12-month rates) were compiled for nine of the countries discussed above: Australia, Canada, France, Germany, Italy, Japan, Spain, the UK and the US Data were available for periods of between four and eight years, starting at different dates but all ending at or close to May 31 1998. Where possible, domestic interbank rates were used. The specific rates used are presented in Table 2.[3] Simple statistics for the series (levels and first differences) are shown in Table 3.

As with many financial series, money market interest rates display periods of volatility and periods of calm. Sharp movements in rates usually are not isolated occurrences, but are accompanied by further (but usually diminishing) volatility as the market seeks to discover a new equilibrium level. This suggests that an appropriate model for analysing the volatility of these rates would be the generalised autoregressive conditional heteroskedasticity (GARCH) model developed by Engle (1982) and Bollerslev (1986).

Following Ayuso, Haldane and Restoy (1997), the relationship between the overnight rate and the policy rate is modelled as an autoregressive error-correction process with GARCH (1,1) residuals.[4] Specifically, the following model is used to express the daily change in the overnight rate i_o as a function of its own past innovations, current and past innovations of the policy rate i_p, and the lagged difference between the overnight and the policy rate:

$$\Delta i_{o,t} = a + b(i_{o,t-1} - i_{p,t-1}) + \sum_{j=1}^{5} c_j \Delta i_{o,t-j} + \sum_{j=0}^{5} d_j \Delta i_{p,t-j} + e(seasonals) + \eta_t$$

$$\eta_t \sim N(0, \sigma_t{}^2)$$

$$\sigma_t^2 = \omega + \beta\sigma_{t-1}^2 + \alpha\eta_t^2 + \delta(seasonals) + \gamma t$$

This specification has a number of attractive features. It allows the overnight rate to converge towards the target rate at a rate related to b. It allows changes in the policy rate i_p to be incorporated into the overnight rate partly contemporaneously (through the effect of d_o, the coefficient on $\Delta i_{p,t}$) and partly over a period of adjustment lasting up to five days, that is, one business week. Because it is a

3 Japan did not explicitly announce a policy rate target until recently. For the purpose of this exercise, a synthetic target rate was constructed by examining patterns of plateaus and jumps in overnight rate levels.

4 The exponential (EGARCH) model used by Ayuso, Haldane and Restoy, and the GARCH-in-mean (GARCH-M) model of Engle, Lilien and Robins (1987) were experimented with and found not to add much to what is presented here.

GARCH(1,1) model, the coefficients from the variance equation can be conveniently interpreted as the autocorrelation (α) and the persistence ($\alpha + \beta$) of volatility. One or more seasonal dummies can be inserted into the mean and/or variance equations, so that we can allow for day-of-the-month, reserve-maintenance and other periodic effects both in the level of overnight rates and their variances. Table 4 identifies the seasonal dummies that were used for each country; these were chosen essentially through trial and error, informed by knowledge about the reserve-maintenance schedules in the different countries.[5] A trend term is included in the variance equation for certain series (namely those where it was found to be significant), in order to capture the tendency for money-market volatility to fall in the course of the estimated time-sample. In some cases, a seasonal dummy is interacted with a time-trend, to capture the tendency of seasonal effects to rise or fall over the sample period.

For several of the countries examined, the history of short-term rates over the period includes a small number of very sharp rate increases and falls. This is especially true for the European countries during 1992 and 1993. To reduce the influence of these observations, without biasing the sample by removing them entirely, any rate increase of more than one percentage point in absolute value is re-defined to be equal to one or negative one. The number of affected observations for each country is given in the last column of Table 3. The series with the largest number of such censored observations is the UK overnight rate, for which 92 of 2,123, or about 4%, are censored. In no other series are more than 2% of observations censored.

Table 5 presents the key coefficients from the estimated models for overnight rates for the nine countries. Coefficients found to be significantly different from zero at a 95% confidence level, using the quasi-maximum-likelihood standard errors proposed by Bollerslev and Wooldridge (1992), are in boldface. A number of observations are worth mentioning about these results.

First, an error-correction mechanism seems to be at play in each case, although the strength of the effect varies widely. The coefficient varies from –0.07 in the case of France and Italy to –0.76 in the case of the US

Second, with some manipulation of the estimated coefficients, we can approximate the "medium-run" sensitivity of the overnight rate to the policy rate. Of course, in the long term, given an error-correction coefficient that is between zero and minus one, a one-unit increase in the policy rate will always lead to a one-unit increase in the overnight rate. A statistic indicating how quick this happens, however, can be developed first by expressing the basic model in terms of lag polynomials, where L represents the lag operator ($Lx_t = x_{t-1}$) and f(L) represents the lag polynomial $f_o + f_1 L + f_2 L^2 + \ldots$.

$$(1-L)i_{o,t} = a + bL(i_{o,t} - i_{p,t}) + c(L)(1-L)i_{o,t} + d(L)(1-L)i_{p,t} + \eta_t$$

$$i_{o,t} = \frac{d(L)i_{p,t}}{1-c(L)} + \frac{a + bL(i_{o,t} - i_{p,t}) + \eta_t}{(1-L)(1-c(L))}$$

$$\frac{\partial i_{o,t}}{\partial i_{p,t}} \approx \frac{d(L)}{1-c(L)}$$

The last, approximate equality is justified if we can drop the second term in the second equation. This in turn will be the case if the two interest rates, i_o and i_p are sufficiently "close" to each other, relative to their size, and if the error-correction coefficient *b* is sufficiently small. Assuming these conditions

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[5] Interestingly, month-end effects were present even in countries, such as the US, where the reserve-maintenance period does not coincide with the calendar month. Hamilton (1996), who finds significant quarter-end and year-end effects for the US Federal Funds rate, suggests that this reflects "window-dressing" activities by corporations at fiscal year-ends. Estimated values for the seasonal dummy terms are available from the author.

hold, and replacing L by one, we can obtain the approximate medium-run sensitivity of the overnight rate to a one-unit change in the policy rate, namely:

$$\frac{\partial i_{o,t}}{\partial i_{p,t}} \approx \frac{\sum_{j=0}^{5} d_j}{1 - \sum_{j=1}^{5} c_j}$$

The countries separate into two fairly well-defined groups in terms of the values of this statistic (Table 5). For Australia, the UK, Japan, Canada and Spain, a one-unit change in the policy rate shows up, on average, as a close-to-one unit change in the overnight rate after five days. For the US, France, Germany and Italy, no more than 50% of a policy-rate change is reflected in the overnight rate after five days. Of these four, however, the sensitivity measure is probably least accurate for the US, because its error-correction figure of 0.76 is relatively high. Indeed, this figure suggests that 76% of the difference between overnight and policy rates in the US disappears after *one* day. As for France, Italy and Germany, it would not be true to say that the overnight rate in these does not respond to the policy rate, only that overnight rates are so "noisy" that the effect of a policy rate is swamped by other effects in a given five-day time period.

A third observation about the results in Table 5 is that the variance models for all nine countries show significant ARCH effects (i.e. the α's are significantly different from zero). Six of them also show GARCH effects (i.e. the β's are significantly different from zero). Three (Australia, the UK and Germany) have a persistence statistic ($\alpha + \beta$) greater than one, meaning that the variance process does not tend towards a mean value in a predictable way.[6]

Finally, trend terms were found to be significant for three of the nine countries: France, Canada and Spain. In each case, the trend was negative.

Modelling money-market rates

Similar models to that used for the overnight rate, only without error-correction terms, were then estimated for one, three, six and twelve-month interbank rates. The fitted GARCH variances ($\hat{\sigma}^2$) from the overnight-rate model were used as right-hand side variables in the variance equations for the longer-term interest rates. Trend terms were not used, because these created severe instability for the estimated coefficients. [7] Table 6 lists the values of the key variables of interest, from the variance equations of the estimated systems.

The first column of Table 6 gives the average fitted GARCH variances for the one to twelve-month rates. These tend to fall as maturity rises (except in the case of Canada), suggesting that uncertainty about the path of future rates and risk premia, which are normally thought to rise as one travels out the yield curve, are not the primary source of day-to-day volatility in these interest rates. As discussed in Section 2, this implies that market liquidity conditions may well play the primary role in determining the observed volatility levels.

The ARCH and GARCH coefficients for the money-market rates indicate both strong autocorrelation (α) and strong persistence ($\alpha + \beta$). Both parameters tend to be lower at longer maturities than shorter ones. This suggests that, at longer maturities, shocks to volatility do not feed as strongly into

6 As Nelson (1990) points out, this does not necessarily mean that the variance process is nonstationary, so statistical inference can still be performed on the estimated parameters.

7 Including a trend term in the variance equation was found to produce instability in the estimated coefficients for the one to twelve-month interest rate models, though not for the overnight-rate models. It is not clear why this should have been so.

subsequent periods of volatility but also die out more slowly. In other words, high and short-lived "spikes" are more common at short maturities than at long ones. However, as suggested by Lamoureux and Lastrapes (1990), the very high persistence levels found for several of the overnight rates and for most of the other money-market rates may imply a misspecification of the volatility process resulting from structural change in the course of the time period studied.

The fourth column of Table 6 presents the estimated coefficients on the fitted overnight-rate GARCH variances. These measure the "transmission" of volatility from overnight rates to rates at other maturities. Most of these coefficients (29 out of 36) are positive, of which ten are significantly so. Of the seven negative coefficients, however, six are significantly negative, including all four of those for the German rates. Ayuso, Haldane and Restoy (1997) find similar results for Germany. This suggests that the possibility of "volatility transfer" cannot be ruled out.

5. Interpreting the results

This section will attempt to relate some of the stylised facts about volatility in overnight rates and other money-market rates identified in the previous section to the characteristics of monetary policy procedures discussed in Section 3.

Policy rate target

France, Germany, Italy, Spain and the UK target a tender rate with a maturity between one day and one month, while for the other countries in this study the overnight rate itself is targeted. It thus comes as no surprise that policy rate changes tended to be more rapidly incorporated into overnight rates for the second set of countries than the first (Table 5). As noted above, Australia, Canada and Japan have figures for the sensitivity of overnight to policy rates that are close to one, while the US has a high error-correction term, suggesting that the central banks in these countries generally succeed over a one-week horizon in their efforts to target overnight rates.

Table 7 takes average values of the variables of interest for countries in the three groups outlined in Section 3. It comes as no surprise that overnight rate volatility tends to be lower in the overnight-rate-targeting group than among the repo-rate targeters. It is interesting to note, however, that fitted variances at the other four maturities were also lower, on average, for the overnight rate targeters, even though the country with the lowest average fitted variance (Germany) is a member of the repo-rate targeting group. A tentative conclusion that may be drawn from this is that targeting the overnight rate stabilises not just the overnight market, but also other money markets as well. This conclusion is supported by the fact that there is no systematic difference between the two groups in volatility-transmission parameters (the coefficient on overnight fitted variance). Other things being equal, more stable overnight rates do lead to more stable rates at other maturities; this seems to be the case both for countries that target overnight rates and for countries that do not.

The UK is listed separately because, unlike the other repo-rate targeters, it does not attempt to stabilise the overnight rate. As might be expected, the level and persistence of the volatility of this rate is higher for the UK than for other countries. The low coefficients on the variance of the UK overnight rate, however, indicate that there is relatively little transmission of this volatility to other points on the yield curve.

The frequency of intervention

The three countries that have both a low long-run sensitivity of policy and overnight rates and a low error-correction coefficient, France, Italy and Germany, do not normally intervene at a daily frequency (Table 3). This may explain why the UK, where interventions occur several times a day, sees a more rapid incorporation of the policy rate into the overnight rate, even though it does not explicitly target overnight rates. It is unclear why policy rates are also rapidly incorporated into overnight rates in

Spain, which according to Table 1 intervenes at roughly the same frequency as the other continental European countries studied.

Reserve requirements

Three of the countries studied, Australia, the UK and Canada, have "working balance requirements" rather than reserve requirements. Australia and Canada are the only countries where no transmission effect was found between overnight-rate volatility and volatility at other maturities. The UK has relatively low coefficients of volatility transmission between overnight and other rates, though two of these are significant (Table 6). This may suggest that strict reserve requirements somehow work to tie overnight rates more closely to other interbank rates, so that periods of volatility in the overnight market are more likely to lead banks to adjust their assets and liabilities at other parts of the maturity spectrum as well.

"Volatility transfer"

The negative coefficients on overnight-rate volatility in the variance models for Germany, Japan and Italy represent a puzzle. One possibility is that they reflect hidden trend effects. For example, if overnight-rate volatility trended downward over the sample period while the volatility of other rates rose, and if these trends were insufficiently incorporated into the model, this might produce a negative coefficient. This might especially be the case if, as in the case of Germany, month-end effects are strong and variable. While attempts were made to account for changes in the size of month-end effects over time, it is possible that the residuals still contain trends of this kind.

Another possibility is that uncertain conditions in overnight markets cause a withdrawal of activity from other short-term markets, leading to smaller rate-movements in the latter. However, it is just as plausible that thin trading conditions in these markets should lead to ***higher*** volatility.

6. Conclusion

This paper has analysed the volatility characteristics of daily changes in overnight rates and in four other short-term interest rates in nine countries, as well as the effect of overnight-rate volatility on the volatility of the other short-term rates. It is found that, in countries where monetary policy involves the direct targeting of overnight rates, changes in policy rates are more rapidly incorporated into overnight rates than in countries that do not. One exception to this pattern seems to be the UK, where overnight rates are very volatile but incorporate policy rate changes relatively quickly. It is also found that, on average, countries in the overnight-rate-targeting group have less volatile interest rates at all maturities, from overnight to one year, and that there is no consistent pattern in the transmission of volatility from overnight rates to other rates in either group.

Reserve requirements are not found to have a direct effect on volatility. However, transmission of volatility across interest rates at different maturities seemed to be lower among countries without reserve requirements. This may suggest that attempts to maintain required reserves affect bank balance sheets more broadly, rather than just the supply of and demand for overnight funds, so that periods of uncertainty in the overnight funds market are more likely to spill over to the market for funds at other maturities.

A number of puzzles emerge from the study, suggesting avenues for further analysis. One is the presence of "volatility transfer" in some countries, where times of unusually high volatility in overnight markets correspond to unusually low volatility at other maturities and vice versa. Another is the high level of persistence found in the volatility processes for most of the interest rate series studied, which suggests the need for specifications that more explicitly account for the possibility of structural change in the underlying stochastic process.

Finally, as noted in Section 2, techniques need to be found for separating the effects of market uncertainty about the path of interest rates from the effects of fluctuations in the supply and demand for funds at different maturities. This would enable us to ascertain more precisely the extent to which the patterns identified here reflect differences in conditions of market liquidity across countries.

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Table 1

Key features of operating procedures

	AU	AT	BE	CA	FR	DE	IT	JP	NL	ES	SE	CH	UK	US
Key policy rate	O/N target	tender	tender	O/N target	tender	tender	tender	O/N	tender	tender	tender	–	tender	O/N target
• maturity (days)	1	14	7-15	1	7	14	<30	1	2-8	10	7	–	1-33	1
Operating target[1]	O/N	O/N	S-T	O/N	O/N	O/N	O/N	O/N	S-T	O/N	O/N	giro deps.	S-T	O/N[2]
• maturity (days)	1	1	30-90	1	1	1	1	1	30	1	1	–	30-90	1
Corridor[3] (bp)		225	225	50	150	200	150			[4]	150[5]		[6]	
Working balances	*		*	*[7]					*[8]		*		*	
Reserve requirements		*			*	*	*	*		*		*		*
• maintenance period)		1m			1m	1m	1m	1m		10d		1m		2w
Main operation	RT	RP	RP[9]	TGD	RP	RP	RT	RT	CL[10]	RP	RT	FXS	OT	RT
• maturity (days)	av. 7	14	7-15	1[11]	7	14	≤30	1-90	2-8	10	7	80-120	1-33	1-15
• regular interval	*	*	*	*	*	*	[12]	[13]	*[14]	*	*		*[14]	[15]
• frequency	1 x d	1 x w	1 x w	1 x d	2 x w	1 x w	≥1 x w	≤3 x d	1 x 4d	1 x 10d	1 x w	≈1 x w	≤3 x d	≈1 x d
Overall frequency	1 x d	≈1 x w	>1 x d	>1 x d	>1 x w	≈1 x w	>1 x w	>1 x d	>1 x w	>1 x w	>1 x w	≈1 x d	>1 x d	≈1 x d
Key signals														
• announcement target	*			*[16]										*
• tender[17]		*	*[18]		*	*	*		*	*	*		*	
• standing facility		*	*		*	*	*	*	*		*	*		[19]
• other			*[20]	*[20]		*[20]	*[20]	*[20]				*[20]		

Note: Abbreviations used: RT = reversed transaction (repo or reverse repo); RP = reversed purchase (repo); TGD = transfer of government deposits; CL = collateralised loan; FXS = foreign exchange swap; * = yes; (blank) = no; O/N = overnight; S-T = short-term.

[1] Interest rate unless otherwise stated. [2] Federal funds rate. [3] Either largely self-enforcing or requiring active steering of the overnight rate by the central bank; width measured in basis points, end-September 1996. [4] Overnight rate normally steered within an unpublished corridor of 20-50 basis points, depending on circumstances. [5] Since September 1996 the overnight rate has been steered within a +/-10 basis points range via fine-tuning transactions at the corresponding rates. [6] Deviations of one to three-month rates from the stop rate monitored closely. [7] Averaging around a zero reserve requirement (one month). [8] Demand for overdraft credit granted under the quota scheme to effect payments. [9] Or collateralised loans, depending on assets backing the transaction. [10] Special advances, which are granted through a tender procedure and can be viewed as equivalent to RP transactions. [11] Transfer of demand deposits. [12] On average, every four days. [13] At least two operations per day. [14] Not completely fixed. [15] Almost every day. [16] Bounds of operating band; normally the market takes the midpoint as the target. [17] Refers to the main operation shown above. [18] Tenders are conducted at the central rate, which can be changed at any time. [19] The discount rate had a clear signalling role until the announcement of the target rate. [20] Largely quantity signals.

Table 2

Short-term interest rates

Country	Policy rate	Overnight rate	1-month interbank	3-month interbank	6-month interbank	1-year interbank
Australia	Policy target rate (23.1.90)	Unofficial overnight rate	1-month interbank rate	3-month interbank rate	6-month interbank rate	1-month interbank rate
Canada	Operating band, low (15.4.94)	Overnight money market financing	1-month euro-rate	3-month euro-rate	6-month euro-rate	12-month euro-rate
France	BoF tender rate	Day-to-day loans	1-month PIBOR	3-month PIBOR	6-month PIBOR	12-month PIBOR
Germany	Bbk repo rate	Day-to-day money	1-month FIBOR (2.7.90)	3-month FIBOR	6-month FIBOR	12-month FIBOR (2.7.90)
Italy	BdI, bill purchases (min rate) and BdI, bill sales (max rate)	Overnight interbank deposits	1-month euro-rate	3-month interbank loans (27.2.90)	6-month interbank	12-month interbank (30.7.93)
Japan	Constructed series from obvious jumps in overnight rate (25.2.91)	Overnight call money	1-month call money (1.3.93)	3-month certificates of deposit	6-month interbank offered rate	1-year interbank offered rate
Spain	Bank of Spain 10-day repo (14.5.90)	Overnight interbank deposits	1-month interbank (19.12.91)	3-month interbank deposits	6-month interbank rate (19.12.91)	1-year interbank rate (19.12.91)
United Kingdom	BoE Band 1 bank bills	Overnight stlg interbank deposits	1-month interbank deposits	3-month interbank deposits	6-month interbank deposits	12-month interbank deposits
United States	Fed funds target rate	Federal funds	1-month finance company paper	3-month certificates of deposit	6-month Certificate of deposits	1-year Certificate of deposits

Note: All rates available from 2 January 1990 through 31 May 1998, except where a different starting date is shown in parentheses.

Table 3

Simple statistics

Australia (sample: 1.23.90 – 5.22.98, 2,128 observations)

	Mean	**Std. dev.**	**Maximum**	**Minimum**	**No. of obs. censored at 1 or –1**
			Levels		
Policy rate	7.588	3.097	17.00	4.75	
Overnight	7.602	3.104	17.50	4.68	
1-month	7.546	2.922	16.62	4.73	
3-month	7.518	2.847	16.00	4.60	
6-month	7.550	2.810	15.62	4.64	
12-month	7.729	2.765	15.81	4.17	
			First differences		
Policy rate	– 0.0053	0.0812	1.00	– 1.00	1
Overnight	– 0.0056	0.0926	0.96	– 1.00	4
1-month	– 0.0053	0.0856	0.81	– 1.00	2
3-month	– 0.0051	0.0776	0.56	– 0.81	0
6-month	– 0.0049	0.0715	0.41	– 0.66	0
12-month	– 0.0048	0.1002	1.00	– 1.00	4

Canada (sample: 4.15.94 – 5.29.98, 1,028 observations)

	Mean	**Std. dev.**	**Maximum**	**Minimum**	**No. of obs. censored at 1 or –1**
			Levels		
Policy rate	4.691	1.464	7.75	2.75	
Overnight	4.953	1.466	8.38	2.88	
1-month	4.871	1.433	8.19	2.78	
3-month	5.027	1.447	8.37	2.75	
6-month	5.240	1.462	8.56	2.81	
12-month	5.593	1.460	9.12	3.06	
			First differences		
Policy rate	– 0.0097	0.0584	0.50	– 0.25	0
Overnight	– 0.0008	0.1313	0.56	– 0.54	0
1-month	– 0.0007	0.1031	0.83	– 0.50	0
3-month	– 0.0006	0.1207	0.88	– 0.82	0
6-month	– 0.0010	0.1190	0.75	– 0.57	0
12-month	– 0.0013	0.1226	0.57	– 0.56	0

Table 3 (cont.)

Japan (sample: 3.2.93 – 5.27.98, 1,278 observations)

	Mean	**Std. dev.**	**Maximum**	**Minimum**	**No. of obs. censored at 1 or –1**
			Levels		
Policy rate	1.311	0.996	3.19	0.45	
Overnight	1.339	1.010	4.50	0.22	
1-month	1.426	0.975	3.59	0.48	
3-month	1.402	0.937	3.27	0.48	
6-month	1.478	0.936	3.44	0.53	
12-month	1.579	0.948	3.50	0.57	
			First differences		
Policy rate	– 0.0021	0.0291	0.00	– 0.50	0
Overnight	– 0.0022	0.0761	1.00	– 1.00	4
1-month	– 0.0022	0.0536	0.45	– 0.48	0
3-month	– 0.0021	0.0205	0.11	– 0.39	0
6-month	– 0.0020	0.0271	0.18	– 0.22	0
12-month	– 0.0020	0.0294	0.17	– 0.18	0

United States (sample: 1.2.90 – 5.28.98, 2,096 observations)

	Mean	**Std. dev.**	**Maximum**	**Minimum**	**No. of obs. censored at 1 or –1**
			Levels		
Policy rate	5.131	1.493	8.25	3.00	
Overnight	5.186	1.519	10.39	2.58	
1-month	5.192	1.443	8.37	3.00	
3-month	5.310	1.465	8.61	3.03	
6-month	5.028	1.488	8.02	2.68	
12-month	5.247	1.490	8.36	2.80	
			First differences		
Policy rate	– 0.0013	0.0405	0.75	– 0.20	0
Overnight	– 0.0034	0.2603	1.00	– 1.00	39
1-month	– 0.0013	0.0484	0.73	– 0.49	0
3-month	– 0.0013	0.0465	0.42	– 0.58	0
6-month	– 0.0010	0.0344	0.30	– 0.43	0
12-month	– 0.0009	0.0417	0.30	– 0.37	0

Table 3 (cont.)

France (sample 1.1.90 – 5.20.98, 2,135 observations)

	Mean	**Std. dev.**	**Maximum**	**Minimum**	**No. of obs. censored at 1 or –1**
			Levels		
Policy rate	6.509	2.576	10.00	3.10	
Overnight	7.064	2.891	24.06	3.19	
1-month	7.199	2.848	18.81	3.31	
3-month	7.123	2.799	15.20	3.31	
6-month	7.159	2.699	13.28	3.28	
12-month	7.129	2.610	11.75	3.28	
			First differences		
Policy rate	– 0.0031	0.0309	0.50	– 0.35	0
Overnight	– 0.0073	0.1333	1.00	– 1.00	14
1-month	– 0.0047	0.1649	1.00	– 1.00	24
3-month	– 0.0035	0.1418	1.00	– 1.00	14
6-month	– 0.0036	0.1150	1.00	– 1.00	6
12-month	– 0.0034	0.0822	0.75	– 0.92	0

Germany (sample: 7.2.90 – 5.25.98, 1,978 observations)

	Mean	**Std. dev.**	**Maximum**	**Minimum**	**No. of obs. censored at 1 or –1**
			Levels		
Policy rate	5.93	2.42	9.70	3.00	
Overnight	6.01	2.42	9.80	2.50	
1-month	6.10	2.46	9.90	3.09	
3-month	6.12	2.47	9.93	3.10	
6-month	6.11	2.45	9.95	3.12	
12-month	6.12	2.38	9.94	3.19	
			First differences		
Policy rate	– 0.0023	0.0315	0.50	– 0.50	0
Overnight	– 0.0034	0.2075	1.00	– 1.00	37
1-month	– 0.0023	0.0360	0.85	– 0.31	0
3-month	– 0.0023	0.0267	0.24	– 0.35	0
6-month	– 0.0024	0.0264	0.24	– 0.36	0
12-month	– 0.0025	0.0295	0.28	– 0.32	0

Table 3 (cont.)

Italy (sample 5.28.93 – 5.20.98, 1,247 observations)

	Mean	**Std. dev.**	**Maximum**	**Minimum**	**No. of obs. censored at 1 or –1**
			Levels		
Policy rate	8.488	1.410	10.86	5.51	
Overnight	8.499	1.410	11.08	4.79	
1-month	8.354	1.411	11.63	5.20	
3-month	8.513	1.539	11.93	5.01	
6-month	8.509	1.713	12.31	4.73	
12-month	8.535	1.961	12.63	4.56	
			First differences		
Policy rate	– 0.0042	0.1117	1.00	– 0.84	1
Overnight	– 0.0035	0.2037	1.00	– 1.00	18
1-month	– 0.0044	0.1275	1.00	– 1.00	2
3-month	– 0.0046	0.0926	1.00	– 0.47	1
6-month	– 0.0050	0.1184	1.00	– 0.94	1
12-month	– 0.0053	0.1182	1.00	– 0.94	2

Spain (sample: 12.19.91 – 5.22.98, 1,593 observations)

	Mean	**Std. dev.**	**Maximum**	**Minimum**	**No. of obs. censored at 1 or –1**
			Levels		
Policy rate	8.690	2.722	13.75	4.25	
Overnight	8.964	3.024	26.48	4.27	
1-month	9.011	3.046	17.88	4.35	
3-month	8.963	2.984	15.55	4.30	
6-month	8.907	2.942	15.38	1.18	
12-month	8.936	2.938	15.20	4.05	
			First differences		
Policy rate	– 0.0052	0.0711	0.75	– 1.00	1
Overnight	– 0.0075	0.2090	1.00	– 1.00	28
1-month	– 0.0052	0.1588	1.00	– 1.00	10
3-month	– 0.0050	0.0983	1.00	– 1.00	2
6-month	– 0.0053	0.1033	1.00	– 1.00	4
12-month	– 0.0055	0.0986	0.95	– 1.05	0

Table 3 (cont.)

United Kingdom (sample 1.2.90 – 5.26.98, 2,123 observations)

	Mean	Std. dev.	Maximum	Minimum	No. of obs. censored at 1 or –1
			Levels		
Policy rate	8.191	3.137	14.88	5.13	
Overnight	8.204	3.266	15.63	3.44	
1-month	8.287	3.190	15.96	4.88	
3-month	8.321	3.115	15.47	5.05	
6-month	8.331	3.024	15.66	5.02	
12-month	8.423	2.872	15.94	5.03	
			First differences		
Policy rate	– 0.0036	0.0639	0.50	– 1.00	2
Overnight	– 0.0028	0.3700	1.00	– 1.00	92
1-month	– 0.0031	0.0993	1.00	– 1.00	5
3-month	– 0.0031	0.0770	0.99	– 1.00	2
6-month	– 0.0029	0.0798	0.84	– 1.00	2
12-month	– 0.0029	0.0896	0.78	– 1.00	2

Table 4

Seasonal dummies

	Dummies in mean equation	**Dummies in variance equation**
Australia	First day of month Last day of month	First or last day of month
Canada	First day of month Last day of month	First or last day of month
Japan	First day of month First day of month * time trend Last day of month Last day of month * time trend Last day of March First day of April	First or last day of month Last of March or first of April
United States	First day of month Last day of month Mon. of settlement week Wed. of settlement week	First or last day of month Mon. or Tue. of settlement week Wed. or Thur. of settlement week
France	First day of month Last day of month 15th or 16th of month	First or last day of month 15th or 16th of month
Germany	Last two days of month Last two days of month * time trend First day of month First day of month * time trend	First day or last two days of month
Italy	First day of month 14th of month 15th of month Last day of month	First or last day of month 14th or 15th of month
Spain	First day of month Last day of month	First or last day of month
Italy	First day of month Last day of month	First or last day of month

Table 5

Selected coefficients from overnight-rate model estimation

	AU	CA	JP	US	FR	DE	IT	ES	UK
					Mean equation				
b	**– 0.28**	**– 0.39**	**– 0.10**	**– 0.76**	**– 0.07**	**– 0.20**	**– 0.07**	**– 0.09**	**– 0.20**
	(9.73)	(8.08)	(4.19)	(13.33)	(10.22)	(4.57)	(3.34)	(3.35)	(9.94)
$\sum c$	– 0.51	– 0.86	– 0.72	– 0.22	0.20	– 0.32	– 0.49	– 0.38	– 0.94
$\sum d$	1.42	1.88	1.73	0.21	0.40	0.24	0.38	1.17	1.88
"$\Delta i_o/\Delta i_p$"	0.94	1.01	1.00	0.27	0.50	0.18	0.26	0.85	0.97
					Variance equation				
ω	**4.6e-5**	**0.01**	**0.002**	**0.01**	**0.03**	**0.01**	**0.004**	**0.16**	2.9e-4
	(3.75)	(2.30)	(3.52)	(7.86)	(4.00)	(7.35)	(5.66)	(3.78)	(1.39)
α	**0.41**	**0.13**	**0.47**	**0.33**	**0.19**	**0.66**	**1.27**	**0.36**	**0.23**
	(4.91)	(3.32)	(4.07)	(4.25)	(2.44)	(2.57)	(6.43)	(3.42)	(8.93)
β	**0.67**	**0.52**	**0.45**	0.01	**0.55**	**– 0.01**	**0.08**	0.02	**0.79**
	(16.71)	(3.05)	(4.60)	(0.58)	(4.80)	(2.42)	(2.296)	(0.11)	(41.04)
α+β	1.08	0.65	0.92	0.34	0.74	0.65	1.35	0.38	1.02
γ		**– 3.7e-6**			**– 4.6e-6**			**– 3.1e-5**	
		(2.30)			(3.91)			(3.13)	
Mean $\hat{\sigma}^2$	0.004	0.007	0.004	0.041	0.007	0.031	0.062	0.044	0.113

Bold-faced figures are significant at the 95% level. T-statistics using standard errors calculated according to Bollerslev and Wooldridge (1992) are in parentheses.

The table reports estimated coefficients from the following model:

$$\Delta i_{o,t} = a + b(i_{o,t-1} - i_{p,t-1}) + \sum_{j=1}^{5} c_j \Delta i_{o,t-j} + \sum_{j=0}^{5} d_j \Delta i_{p,t-j} + \eta_t$$

$$\eta_t \sim N(0, \sigma_t^2)$$

$$\sigma_t^2 = \varpi + \beta\sigma_{t-1}^2 + \alpha\eta_t^2 + \gamma t$$

The sensitivity figure ($\Delta i_o/\Delta i_p$) is approximated from the coefficients using the following formula, as explained in the text:

$$\frac{\partial i_{o,t}}{\partial i_{p,t}} \approx \frac{\sum_{j=0}^{5} d_j}{1 - \sum_{j=1}^{5} c_j}$$

"Mean $\hat{\sigma}^2$" is the average fitted value for σ_t^2 from this estimation.

Table 6

Results from models of money-market interest rates

	Average fitted variance ($\hat{\sigma}^2$)	**Autocorrelation (α)**	**Persistence (α+β)**	**Coefficient on overnight fitted variance**
		Australia		
1-month	0.0126	**0.6123**	1.288	0.0104
3-month	0.0084	**0.3479**	1.097	0.0233
6-month	0.0051	**0.0775**	0.984	0.0066
12-month	0.0082	**0.1470**	0.737	0.0477
		Canada		
1-month	0.0089	**0.2203**	0.920	0.0003
3-month	0.0117	**0.1096**	0.920	0.0394
6-month	0.0124	**0.1880**	0.771	0.1083
12-month	0.0165	**0.0240**	0.950	0.0121
		Japan		
1-month	0.0027	**0.4680**	0.879	**– 0.0092**
3-month	0.0004	**0.3445**	0.975	0.0118
6-month	0.0009	**0.2856**	1.017	0.0027
12-month	0.0011	**0.3029**	1.053	0.0006
		United States		
1-month	0.0023	**0.4921**	1.030	**0.0073**
3-month	0.0019	**0.1184**	0.992	– 0.0003
6-month	0.0011	**0.1368**	0.951	**0.0038**
12-month	0.0012	**0.0236**	0.976	0.0014
		France		
1-month	0.0360	**0.3603**	1.081	**0.0090**
3-month	0.0229	**0.2349**	1.023	**0.0075**
6-month	0.0142	**0.2009**	1.001	**0.0127**
12-month	0.0072	**0.2197**	0.963	0.0119
		Germany		
1-month	0.0017	0.3328	0.480	**– 0.0012**
3-month	0.0008	**0.0290**	0.919	**– 0.0003**
6-month	0.0007	**0.0493**	0.906	**– 0.0002**
12-month	0.0008	**0.0976**	0.911	**– 0.0002**

Table 6 (cont.)

	Average fitted variance ($\hat{\sigma}^2$)	Autocorrelation (α)	Persistence (α+β)	Coefficient on overnight fitted variance
Italy				
1-month	0.0158	**0.0857**	0.963	0.0001
3-month	0.0101	**0.2231**	1.015	0.0008
6-month	0.0161	**0.1839**	1.000	**– 0.0015**
12-month	0.0144	**0.0899**	0.974	– 0.0014
Spain				
1-month	0.0309	**0.7414**	0.976	**0.0379**
3-month	0.0117	**0.2149**	1.038	0.0009
6-month	0.0114	**0.2192**	0.988	**0.0072**
12-month	0.0115	**0.2043**	0.708	**0.0707**
United Kingdom				
1-month	0.0182	**0.9512**	1.363	**0.0041**
3-month	0.0070	**0.3223**	0.971	0.0010
6-month	0.0077	**0.3151**	1.027	**0.0012**
12-month	0.0092	**0.3754**	0.934	0.0023

Bold-faced figures are significant at the 95% level

The table reports estimated coefficients from the following model (estimated on daily interbank rates from Jan. 1994 through May 1998):

$$\Delta i_t = a + \sum_{j=1}^{5} c_j \Delta i_{t-j} + \sum_{j=0}^{5} d_j \Delta i_{p,t-j} + \eta_t$$

$$\eta_t \sim N(0, \sigma_t^2)$$

$$\sigma_t^2 = \varpi + \beta\sigma_{t-1}^2 + \alpha\eta_t^2 + \gamma d_{95-98} + \delta(seasonals) + \phi\hat{\sigma}_{ON}^2$$

where i_t is the 1, 3, 6 or 12-month interest rate; $d_{95\text{-}98}$ is a dummy variable equalling one for observations in 1995 or later; and $\hat{\sigma}_{ON}^2$ is the fitted variance from that country's overnight-rate estimation (see Table 1).

"Mean $\hat{\sigma}^2$" is the average fitted value for σ_t^2 from this estimation.

Table 7

Volatility parameters for the United States, Japan, Canada and Australia

	Average fitted variance ($\hat{\sigma}^2$)	Autocorrelation (α)	Persistence (α+β)	Coefficient on overnight fitted variance
Overnight rate	0.0141	0.3383	0.7514	
1-month	0.0066	0.4482	1.0292	0.0022
3-month	0.0056	0.2301	0.9958	0.0185
6-month	0.0049	0.1720	0.9315	0.0303
12-month	0.0068	0.1244	0.9288	0.0155

Volatility parameters for France, Germany, Italy and Spain

	Average fitted variance ($\hat{\sigma}^2$)	Autocorrelation (α)	Persistence (α+β)	Coefficient on overnight fitted variance
Overnight rate	0.0399	0.6231	0.7813	
1-month	0.0211	0.3801	0.8749	0.0114
3-month	0.0114	0.1754	0.9986	0.0022
6-month	0.0106	0.1633	0.9739	0.0046
12-month	0.0085	0.1529	0.8890	0.0203

Volatility parameters for the United Kingdom

	Average fitted variance ($\hat{\sigma}^2$)	Autocorrelation (α)	Persistence (α+β)	Coefficient on overnight fitted variance
Overnight rate	0.1127	0.2256	1.0135	
1-month	0.0182	0.9512	1.3630	0.0041
3-month	0.0070	0.3223	0.9706	0.0010
6-month	0.0077	0.3151	1.0267	0.0012
12-month	0.0092	0.3754	0.9335	0.0023