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Staff Working Paper No. 588
Monetary policy and volatility in the sterling money market

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Abstract

Money market volatility may disrupt the transmission mechanism of monetary policy as well as increase uncertainty for market participants. This paper assesses the impact of reforms to the Bank of England's operating framework over the last two decades. These reforms have been successful in reducing overnight volatility. A new framework in 2006 which introduced reserves averaging and voluntary reserve targets was associated with lower volatility of overnight rates. Further reductions in volatility were associated with interim reforms and communications prior to the launch of this new framework. The injection of excess reserves under the floor system introduced in 2009 has been associated with a further reduction in volatility. Despite these encouraging findings, further analysis shows that the volatility of overnight rates had little effect on the volatility of longer-term rates except in the pre-2006 'zero reserves' period and no effect at all on three-month Libor rates, which are the key benchmark for many derivatives and bank loans. Since longer-term rates are more important than overnight rates for the transmission of monetary policy to the real economy, the results provide limited support for prioritising the reduction of volatility in the design of central banks' operating frameworks. The results also suggest that additional communication regarding likely future monetary policy decisions is associated with lower volatility of term rates.

Key words: Money market, monetary policy, interest rates, Bank of England.

JEL classification: E43, E44, E52, E58, G21.

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1. Introduction

This paper assesses the role of the central bank's money market operating framework in determining the level and volatility of money market interest rates, that is, those rates of up to one year in maturity. The design of operational frameworks is likely to be a key focus for central banks over the next few years as they consider whether and how to roll back the operating frameworks adopted during the financial crisis in the course of adopting "unconventional" policy tools such as quantitative easing (QE). Money market volatility matters for the central bank's objectives for at least two reasons. First, varying deviations of overnight market rates from the target rate may impede the transmission mechanism of monetary policy, reducing the central bank's ability to accurately control monetary conditions in the real economy. Second, volatility increases uncertainty for market participants. This may raise the costs to firms of managing their liquidity and, in the extreme, may even dissuade firms from participating in these markets altogether.

Central banks generally implement monetary policy by communicating a target for a given short-term interest rate (usually the overnight rate) and then applying a set of instruments, including standing facilities, open market operations and reserve requirements, to achieve market interest rates close to that target on a daily basis (Bindseil 2004). Theory suggests that the design of the central bank operating framework can act to reduce money market volatility. First, Whitesell (2006) argued that introducing targets for banks' reserves balances to be met within a pre-set tolerance band can introduce a flat portion into the demand curve for central bank reserves, reducing volatility around the policy rate arising from fluctuations in banks' reserves. Second, injecting reserves in excess of banks' voluntary demand may reduce money market volatility. The injection of excess reserves has become a reality in several advanced economies (e.g. the US, UK and the euro area) as a result of large-scale asset purchases funded by the creation of central bank reserves (Borio and Disyatat 2010). In terms of the operating framework, this has resulted in a 'floor system' for monetary policy implementation, whereby market rates are driven down to the rate paid by the central bank on deposits which becomes the *de facto* policy rate (Keister et al 2008). Such a system tends to deliver short-term interest rates that are very close to the policy rate (Jackson and Sim 2013). But large-scale injections of reserves into the banking system alongside a floor system disincentivises activity in the money market (Bech and Monnet 2013) and, in time, central banks are likely to reverse large-scale asset purchases policies in order to withdraw exceptional economic stimulus. This has begun to prompt discussion amongst central bankers of the tradeoffs required when choosing different monetary control frameworks (see e.g. Cœuré 2013, Potter 2015).

A large empirical literature documents how central bank operating frameworks may affect money market volatility. Beginning with Hamilton (1996), GARCH models have been used to estimate conditional volatility equations which account for the effects of features of central banks' operating frameworks. Nautz and Schmidt (2009) and Mariscal and Howells (2010) show that successive reforms to improve the transparency of the Federal Reserve's operating framework have reduced money market volatility. For the euro area, Moschitz (2009), Bindseil et al (2003) and Würtz (2003) show that features of the ECB's operational framework significantly affect money market rates in the euro area. Pérez-Quiros and Rodrígez-Mendizabál (2006) found that euro-area money market volatility was not lower than German experience prior to the creation of the European Central Bank (ECB), while Jardet and Le Fol (2010) found that volatility fell following reforms introduced by the ECB in 2004, such as the more frequent allotment of liquidity at shorter maturities and the alignment of liquidity supply operations with monetary policy maintenance periods. Colarossi and Zaghini (2009) found that overnight volatility in the US and euro-area had fallen following the introduction of a forward-looking 'balance of risks' assessment by the Federal Reserve in 2000 and the ECB's 2004 reforms. For the UK, Wetherilt (2003) showed that volatility fell significantly following reforms including the creation of the gilt repo market in 1996 and the introduction of new liquidity providing operations in 1998 which had helped place a ceiling on market rates. Over the last couple of decades, a number of central banks have introduced rate corridors which use central bank facilities to place upper and lower bounds on target interest rates (Bindseil and Jablecki 2011). Looking at a wide sample of countries, Bartolini and Prati (2006) found that volatility is significantly affected by the width of the corridor set by the central bank, although the direction of the effect varies across countries.

For effective monetary policy transmission the volatility of term rates probably matters more than the volatility of overnight rates, since term rates are more likely to influence the interest rates that prevail in the real economy. Several studies have addressed this question by examining whether the estimated conditional volatility of short-term interest rates is correlated with that of longer-term rates. Moschitz (2009) found that volatility of the euro-area overnight rate (EONIA) significantly affects the volatility of longer-term rates up to six months in maturity. Colarossi and Zaghini (2009) find that volatility in overnight rates is transmitted to longer-term rates in the US (1994-2007) and the euro area (1999-2007), but found that the level of longer-term rates is not significantly affected by overnight volatility in either region. Ayuso, Haldane and Restoy (1997) found evidence that overnight volatility was transmitted into volatility of longer term rates in France, Spain, Germany and the UK over the period 1988-93. By contrast, Wetherilt (2003) found no evidence that the volatility of overnight or two-week Libor rates in the UK transmitted into the volatility of longer-term rates in the period 1994-2001.

A separate strand of literature addresses how central banks' policy communications affect short-term interest rates. The central bank may influence term rates by communicating information on its view of economic conditions or on its policy reaction function, which the market can use in forming expectations about the likely path of the policy rate. A particular focus for central banks has been whether improvements in transparency regarding the policymakers' reaction functions and forecasts increases the volatility of longer-term rates (Goodfriend, 1986, Haldane and Read, 2000). Recently, the 2014 Warsh review concluded that the monetary policy process in the UK would benefit from further reforms to increase transparency of the MPC's decision making[1], and there has also been a lively debate concerning whether central banks should use forward guidance to improve clarity regarding their likely future policy intentions. Empirical studies suggest that the market's anticipation of future changes in the policy rate set by the BOE rose following reforms to increase the transparency of the BOE's policy making (including inflation targeting) in 1992 (Haldane and Read, 2000; Lildholdt and Wetherilt, 2004; Mariscal and Howells, 2007). Clare and Courtenay (2001) and Lasaosa (2005) found that the granting of operational independence to the BOE in 1997 did not change the sensitivity of short-term interest rates to monetary policy communications, though interest rates were found to be sensitive to macroeconomic data releases, particularly when these surprised relative to economists' expectations. Sun and Sutcliffe (2003) and Reeves and Sawicki (2007) found that short-term interest rates are significantly affected by macroeconomic data surprises and monetary policy communications. Similar studies confirm the importance of monetary policy communications in the Eurozone (Nautz and Offermans, 2007; and Nautz and Scheithauer, 2011).

This study uses data from the UK unsecured money market over the period 1997-2014 to make two contributions to the literature. First, it draws on the diverse experiences of the BOE, which during the sample period has used three distinct operating frameworks, to assess the impact of reforms to central banks' operating frameworks. In the late 1990s, the BOE operated a zero-reserves system in which

[1] "Transparency and the Bank of England's Monetary Policy Committee" by Kevin Warsh (2014). See http://www.bankofengland.co.uk/publications/Documents/news/2014/warsh.pdf.

settlement banks were incentivized to hold a near-zero balance on their reserve accounts overnight and the BOE provided the required liquidity via open market operations (OMOs) at the policy rate, Bank Rate. This is denoted the “pre-reserves averaging framework” (pre-RAF). In 2006, a new “reserves averaging framework” (RAF) was introduced in which banks set voluntary reserve targets which they had to meet on average over reserves maintenance periods, subject to a given tolerance range and within a corridor system. In 2009, the BOE began large-scale asset purchases funded by the creation of reserves and the RAF was suspended. In the floor framework, all banks’ reserves were remunerated at Bank Rate, which together with the creation of a large volume of new reserves ensured that market rates remained close to Bank Rate. The impact of these reforms on the volatility of overnight and term rates is assessed. The sample period is then divided into three periods corresponding to the three operating frameworks in order to assess the relative performance of these different frameworks in delivering effective control of market interest rates.

The second contribution is to bring together the two strands of the existing empirical literature surveyed above by modelling term money market rates (1 month, 3 month and 12 month maturities) as a function of design features of the operational framework and factors affecting monetary policy expectations, such as MPC communications and macroeconomic data surprises. This enables us to compare the relative importance of these factors, using a decomposition of changes in one-year interest rates over the sample period. The MPC’s three main methods of communications are included: its monthly MPC decisions, the minutes of its meetings and its quarterly *Inflation Reports*. Changes in Bank Rate are divided into expected and unexpected components, using market-implied forward rates, in order to assess how the predictability of the MPC’s decisions may affect the subsequent market response to those decisions. The MPC’s forward rate guidance policies are also included, the first of which was introduced in August 2013 and aimed to provide more information to help people understand the conditions under which the MPC would maintain its highly stimulative policy stance.[2] Other relevant economic news variables which are included are surprises in UK macroeconomic data releases and, since the UK is a small open economy which is strongly affected by global rate moves, news in the US and euro-area which are proxied with rates from those economies at corresponding maturities.[3] Co-movement with the US and euro area may result from global economic developments

[2] See the MPC’s report, Monetary policy trade-offs and forward guidance, August 2013.

[3] This implicitly assumes that correlation between UK rates and rates in the US and euro area reflects causation from the latter to the former, rather than the other way around. This is probably reasonable given the small size of the UK economy relative to those of the US and euro area.

which affect inflationary pressures in the UK or from other global cyclical factors such as "flight-to-quality" in which global investors increase demand for "safe" assets such as those denominated in sterling, dollar or euro.

The findings are as follows. There are significant differences over time in the volatility of the spread of overnight rates to Bank Rate associated with changes in the SMF. Volatility was significantly lower under the reserves averaging framework that was introduced in 2006, consistent with the aims of that reform. Volatility fell further following the introduction of QE and the floor framework in March 2009. This is likely to partly reflect the creation of large volumes of new reserves which reduced incentives for banks to actively manage their reserves and reduced trading in the interbank money market (Jackson and Sim 2013). In a robustness test, the structural breaks in volatility are allowed to be determined by the data in a framework that allows for multiple breaks at unknown dates. The results suggest that reductions in volatility were associated not only with the two major frameworks noted above but also with the announcement of a review into the SMF in 2003 and with the implementation of a set of interim reforms in 2005. The results also show that, while the reserves averaging framework used from 2006 to 2009 was generally associated with lower volatility than the previous systems, there was a significant increase in volatility in late 2008 around the time of heightened liquidity concerns and dislocation in money markets.

Turning to term rates, some evidence is found of transmission of volatility of overnight rates into that of longer-term rates in earlier regimes. Overnight volatility affected the volatility of 1 month and 3 month OIS rates prior to the introduction of the RAF in 2006, suggesting that a 100% increase in the volatility of overnight rates may have increased the volatility of term rates by 20-60%. However, there is no evidence that overnight volatility affects that of longer-term rates under the reserves averaging system or the floor system. Over the whole sample period, a 100% increase in the volatility of overnight rates is associated with 2-4.5% higher volatility of 3 month OIS rates and 1.5-3% higher volatility of 12 month OIS rates. Furthermore, there is no evidence in any period that overnight volatility affected the volatility of the 3 month Libor rate, which is the most common reference rate for corporate lending and is therefore key to the transmission mechanism. Overnight volatility was, however, negatively correlated with changes in the *level* of 1 month and 3 month OIS rates in both the pre-RAF and RAF periods. This may reflect a preference for market participants to receive fixed rather than floating interest rates when interest rate risk is higher (in other words, negative term premia), or could reflect a link between increased volatility in overnight interest rates as a result of deteriorating financial conditions and downwards revisions in the expected path of Bank Rate.

MPC communications were found to be significant drivers of term rates. In the RAF period, *Inflation Reports* had no effect on the volatility of market rates, though they were associated with falls in rates. The latter finding suggests that, in this period, MPC communications tended to impart a more accommodative stance than expected by the market. The publication of MPC minutes show no consistent pattern in terms of changes in market rates, but are found to be associated with higher volatility of longer-term (6-12 month) rates in the RAF period.

Unlike overnight rates, term rates are found to react much more strongly to unexpected changes in Bank Rate, suggesting that unexpected changes in Bank Rate are interpreted as a signal about the future path of Bank rate. In the floor period, all MPC communications were associated with lower volatility of term rates, perhaps suggesting that they tended to validate the expectations of market participants or to exert a calming influence on market rates. Forward guidance policies introduced from mid-2013 coincided with a period of lower volatility, perhaps reflecting the greater clarity provided by the MPC about future policy moves. Changes in rates of equivalent maturity in the US and euro area and surprises in macroeconomic data have statistically and economically significant effects on term rates. UK rates co-moved more closely with euro-area rates than US rates pre-crisis, but this was reversed in the post-crisis period with US rates playing a greater role. A decomposition of the variance of 3 month rates suggests that changes in Bank Rate and in US and EA rates are the most economically important drivers, while MPC communications, data surprises and volatility in overnight rates play relatively minor roles.

The structure of the paper is as follows. Section 1 describes developments in the monetary control framework applied by the BOE. Section 2 introduces the data sources and the empirical model of the first moment of interest rates (i.e. the mean equation) at several maturities. Section 3 then summarises the results of the second moment analysis (i.e. variance equations). Section 4 concludes.

2. Developments in the Sterling Monetary Framework (SMF)

The period between 1997 and 2014 saw considerable changes in the BOE's Sterling Monetary Framework (SMF) and, in part as a result of these reforms, the volatility of the spread of the overnight rate to Bank Rate varied greatly. Figure 1 shows the spread from 1997 to 2014 indicating (with vertical lines) various reforms described above. The BOE was given operational independence for setting monetary policy in 1997. At that time, the BOE was implementing monetary policy using a "zero reserves" system in which settlement banks were required to hold a zero balance in their reserve accounts with the central bank at the end of each day.[4] The reserves required to offset autonomous factors and maturing operations were provided via frequent Open Market Operations (between 2 and 4 each day). These were conducted with a small number of counterparties (fewer than 20) known as discount houses, at the official policy rate, Bank Rate. Reserve balances were not remunerated and there were no reserve requirements.[5]

Prior to gaining operational independence, the BOE had begun to reform its operational framework in order to contain volatility in money market rates. Open market operations were made available to a wider range of counterparties, including banks and securities dealers, and eligible collateral in daily operations was extended to include gilts obtained in reverse-repo operations.[6] In 1998, a borrowing facility was created to place a ceiling on overnight rates. In 1999, the collateral pool was widened further to include a wider range of EEA government and supranational securities. In 2001, an overnight deposit facility was introduced. Together with the borrowing facility which had been created in 1998, this was intended to moderate the extent to which market rates traded outside a "corridor" of 100bps below and above Bank Rate. Corridor systems, which had been introduced by many central banks in the years preceding the BOE's reforms, are intended to reduce volatility by placing limits on the range of market rates (e.g. see Whitesell, 2006; Bindseil and Jablecki, 2011).[7]

Figure 1 suggests that the volatility of the overnight rate spread was particularly high in the late 1990s and early 2000s. Volatility did not fall following the reforms of the late 1990s and early 2000s, including the introduction of a rate corridor in 2001. There are several reasons why the introduction of a corridor may not have resulted in lower volatility in this case. While corridor systems are generally considered to required unlimited access to facilities (Bindseil 2004), the amount of liquidity available in the end-of-day lending facility was limited to what the BOE forecast would be required.[8] Hence, volatility could result from forecasting errors by the BOE or from market concentration which allowed

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[4] Banks were actually encouraged to hold small positive balances as a precaution against unexpected payments shocks. See the BOE's 2002 "Red Book", p.5.

[5] Banks are required to deposit cash with the BOE, known as Cash Ratio Deposits (CRDs), which is invested in UK government bonds in order to fund the policy functions of the BOE. Whitesell (2006) identifies this as a reserve requirement, although the cash invested is not equivalent to other central bank money since it is not available for use in settlement transactions.

[6] See BOE (1997), Reform of the BOE's operations in the sterling money markets, available at www.bankofengland.co.uk/markets/Documents/money/stermm2.pdf.

[7] Further discussion of the 2001-04 and earlier frameworks may be found in Tucker (2004). Wetherilt (2003) discusses a number of reforms in the mid-1990s.

[8] See the 2002 Red Book, p. 11, available at http://www.bankofengland.co.uk/markets/Documents/money/stermm3.pdf.

some large counterparties to obtain a large part of the fixed allocation of liquidity and then become the marginal supplier to the rest of the market. Additionally, the BOE's OMOs took the form of two-week repos which often overlapped with the monthly decisions of the MPC. This meant that market participants would anticipate a change of rates during the term of the repo, resulting in spikes in interest rates.

As a result of the high level of volatility, in October 2003 the Governor announced a review of monetary policy implementation.[9] Over the next two years the BOE carried out a consultation on a new operational framework. In the meantime, a number of interim reforms were carried out.[10] In 2005, the range between the overnight lending and deposit facilities was narrowed from ±100bps to ±25 bps, and OMOs were indexed to Bank Rate and no longer included outright purchases of securities. The new framework was introduced in 2006.[11] Banks set voluntary targets for the level of reserves they would hold on average over each maintenance period and all reserves were remunerated at Bank Rate so long as they fell within a specified range of the target. Such a "reserves averaging" system is intended to smooth out transitory liquidity shocks, ensuring that rates are flat within each monetary policy maintenance period (Whitesell 2006; Bindseil 2004). Voluntary reserves targets are used for the purpose of averaging rather than formal reserve requirements since the BOE aimed to ensure that reserves would be truly usable and also wanted to avoid the socially wasteful avoidance activities which had been associated with reserve requirements in other countries (see, e.g. Kohn 2004). Overnight Standing Facilities (OSFs) were made available for banks that were unable to meet the target and these allowed unlimited usage, setting an upper and lower limit for market rates of ±100bps around Bank Rate and 25bps on the final day of the maintenance period. The BOE supplied via OMOs the amount of reserves targeted by the banking system in aggregate and also undertook "fine tuning" OMOs toward the end of the maintenance period.

Volatility of overnight rates fell sharply in May 2004 following the launch of the BOE's review of the SMF. It is interesting that the fall in volatility occurs at the time of the launch of the review, with a comparatively smaller fall around the implementation of interim reforms in 2005 or the new RAF in

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[9] See http://www.bankofengland.co.uk/archive/Documents/historicpubs/speeches/2003/speech204.pdf.

[10] See http://www.bankofengland.co.uk/archive/Documents/historicpubs/news/2005/014.pdf.

[11] The new framework is described in the 2006 Red Book, available at http://www.bankofengland.co.uk/markets/Documents/money/publications/redbook0506.pdf. Also see "Reform of the Bank of England's operations in the sterling money market", April 2005, available at http://www.bankofengland.co.uk/markets/Documents/money/smmreform050404.pdf and "Reform of the BOE's operations in the sterling money markets", available at www.bankofengland.co.uk/markets/Documents/money/smmreform040507.pdf.

2006. Since there were no changes in the operational framework at this time, it is possible that this reflects a signalling effect of the BOE's review. For example, if, as a result of the review, market participants adjusted their perception of the BOE's tolerance for volatility and therefore its willingness to intervene in order to limit deviations from the policy rate, this may limit the extent to which transactions would occur away from Bank Rate. Volatility seemed to fall slightly again in 2006 following the implementation of the new framework and remained low through 2006 and 2007. But, in the aftermath of the bankruptcy of Lehman Brothers in September 2008, volatility increased considerably; in fact it returned to levels last seen prior to the 2004 review. Several factors played a role in this increase in volatility. Banks' demand for reserves became larger and less predictable, they were less willing to make use of reserves averaging since they needed to maintain their liquidity each day due to market pressure, and they were also less willing to use the Overnight Lending Facility for fear of being stigmatised.[12] As a result, the Bank relaxed the parameters of the reserves averaging framework, conducting more frequent supply operations and widening the permitted average deviation of reserves from banks' voluntary targets.

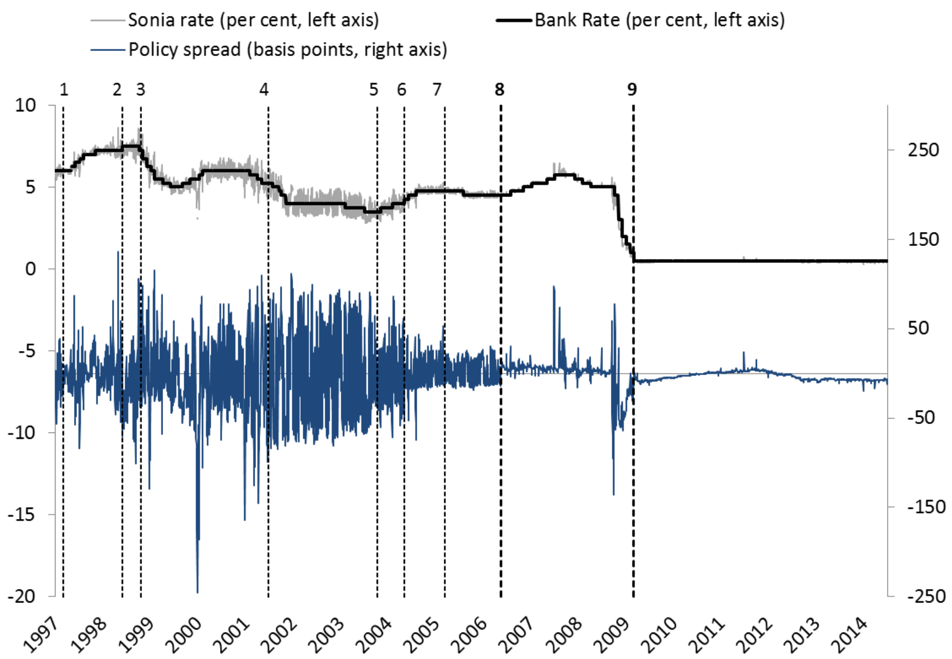
Between August 2008 and March 2009, Bank Rate was cut by 4.5 percentage points as financial and economic conditions deteriorated further. The SMF was altered again in March 2009 as the Monetary Policy Committee launched large-scale asset purchases funded by the creation of central bank reserves (also known as Quantitative Easing or QE). The RAF was suspended and replaced by a floor system in which all reserves were remunerated at Bank Rate.[13] This system meant that banks would not lend reserves in the market below Bank Rate, while the supply of excess reserves meant that banks had no incentive to borrow at rates above Bank Rate. The floor system reduced banks' incentives to trade with one another in the money market since they had no need to bid for additional reserves. The money market during this period comprised mostly of non-SMF members (such as Money Market Funds, corporate treasuries and some banks), who did not have access to a reserves account, lending to SMF members. Volatility under the floor system was (and continues to be) very low, though there was a small wedge between market rates and Bank Rate, reflecting the relative bargaining power of SMF

[12] See "Development of the Bank of England's Market Operations", October 2008, available at http://www.bankofengland.co.uk/markets/money/publications/condococt08.pdf.

[13] See Market Notice at http://www.bankofengland.co.uk/markets/Documents/marketnotice090806smf.pdf

and non-SMF members and pressures on banks' balance sheets partly stemming from post-crisis reforms to bank regulation (Jackson and Sim 2013).[14]

Figure 1: SONIA rate and spread to Bank Rate



Key to events

1	Gilts obtained via reverse repo accepted in OMOs and access widened
2	Collateral eligibility further expanded
3	Access to borrowing facility extended to banks
4	Deposit facility introduced, completing corridor system
5	Governor announces review of Sterling Monetary Framework
6	First consultation paper on SMF review
7	Interim reforms including narrower corridor
8	Reserves averaging framework introduced
9	Start of large-scale asset purchases and floor framework introduced

3. An empirical model of the money market

The aim is to model the level and drivers of volatility in each of the main regimes within the SMF. Hence, separate models are estimated for the period prior to the RAF, the RAF period itself and the floor period. The dates for these three periods are chosen based on the implementation dates of these

[14] On the role of post-crisis regulatory reform in affecting money markets, see also "Regulatory Change and Monetary Policy", Report by the Committee on the Global Financial System and the Markets Committee of the Bank for International Settlements, available at https://www.bis.org/publ/cgfs54.pdf.

operational frameworks. Each money market rate r_t^j with maturity j is modelled using an error correction framework in which daily changes are a function of past changes in the rate, unexpected and expected changes in Bank Rate (Δo_t^U and Δo_t^E) and a long-run relationship capturing co-movement with Bank Rate (o_t).

$$\Delta r_t \;= \alpha + \sum_{j=1}^{J} \beta_j \; \Delta r_{t-j} + \sum_{k=0}^{K} \gamma_k^U \Delta o_{t-k}^U + \sum_{k=0}^{K} \gamma_k^E \Delta o_{t-k}^E + \delta\left(r_{t-l} - o_{t-l}\right) + \varphi X_t + \varepsilon_t \tag{1}$$

The Sterling Overnight Index Average (SONIA) is used as the measure of overnight interest rates. SONIA is the weighted average rate of all unsecured sterling overnight cash loans brokered in London by members of the Wholesale Markets Brokers' Association (WMBA). A possible alternative is the London Interbank Offer Rate (LIBOR), which measures the average rates at which banks report that they may obtain unsecured funding in the London interbank market and which is used as the measure of sterling overnight rates by Wetherilt (2003) and Bartolini and Prati (2006). Bank estimates suggest that £250bn of corporate loans and £25 trillion notional of derivatives reference sterling Libor.[15] Using overnight Libor has several disadvantages, however. Historically LIBOR has reflected banks' judgements about the rates at which they may borrow rather than the rates at which funds are borrowed, which means the rates may lag market developments and can be subjective. Libor is also restricted to the interbank money market, which has recently been a small part of the overall money market.[16] Finally, overnight Libor is not a commonly used benchmark rate, unlike longer maturity Libors (such as 3 month Libor which is used in our analysis of term rates below). SONIA and Bank Rate are confirmed as non-stationary and the presence of a single cointegrating vector was verified using a Johansen test.

Following Nautz and Schmidt (2009) and Papadamou (2013), the impact of changes in Bank Rate is allowed to vary depending on the extent to which they are expected (γ^E) or unexpected (γ^U).[17] The Haldane and Read (2000) approach is followed in calculating the unexpected component of Bank Rate

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[15] See "Investing in capital markets", speech by Chris Salmon in October 2015, available at http://www.bankofengland.co.uk/publications/Pages/speeches/2015/856.aspx.

[16] The BOE's Sterling Money Market Survey shows that interbank transactions have accounted for around 25-30% of banks' borrowing in the money market between 2011 and 2014. See http://www.bankofengland.co.uk/publications/Pages/other/mmlg/default.aspx.

[17] Note that this approach means that when there is no change, but a change has been expected, this counts as an unexpected change.

changes as the change in the implied 1-month Libor rate, 1 month forward on the day of the MPC decision. This is subtracted from the actual change in Bank Rate to obtain the expected component. From February 2006 onwards, rates implied by the overnight interest swap (OIS) referencing the next monetary policy maintenance period are used as measures of expected Bank Rate changes.

Dummy variables are included for calendar events (X_t) which include year-, quarter- and month-ends, public holidays, the day before a public holiday and the last day of each monetary policy maintenance period. The number of lags of changes in the dependent variable and the policy rate (J and K respectively) are chosen by starting with 6 lags of each and dropping those that are not significant. The Ljung-Box Q-statistic is checked to ensure there is no residual auto-correlation. The lag order of the cointegrating vector (l) in the mean equation is chosen using the Akaike Information Criterion (AIC).[18]

The conditional volatility of the overnight rate is estimated in a separate equation using a GARCH model. GARCH models have the advantage of estimating conditional volatility using a flexible, data-driven specification and capturing persistence in volatility consistent with the lumpiness often observed in financial market data. Most of the studies of money market rates cited earlier use the exponential GARCH (e-GARCH) model, which has the advantages that it implies that the conditional variance will always be positive and that it allows larger shocks to make a greater effect on volatility. But, as shown by Engle and Ng (1993), the exponential form can result in excess sensitivity to large shocks, resulting in implausible estimates of the conditional volatility which are well in excess of the squared residuals from the mean equation. This was found to be the case in some parts of the sample period.[19] A number of alternative GARCH models were considered based on their ability to absorb auto-correlation with a minimum of lags and their performance on the Akaike Information Criterion and the power GARCH (p-GARCH) was chosen, as follows:[20]

[18] In order to choose the specification of the mean equation (1), the variance of the errors σ_t^j is initially modelled as a GARCH(1,1). The presence of ARCH effects was confirmed using ARCH-LM tests and inspection of the auto-correlation of squared residuals.

[19] For example, during the RAF errors were generally consistently low but spiked up sharply due to isolated episodes of illiquidity from mid-2007 onwards. An exponential GARCH model for this period produces a peak estimated conditional volatility of 245, over a hundred times larger than the largest squared residual.

[20] We considered also the component GARCH (c-GARCH), integrated GARCH (i-GARCH) and threshold GARCH (t-GARCH).

$$\left(\sqrt{\sigma_t^2}\right)^{\tau} = c + \sum_{m=1}^{M} \lambda_m \left(\sqrt{\sigma_{t-m}^2}\right) + \sum_{n=1}^{N} \theta_n \left|\frac{\varepsilon_{t-n}}{\sigma_{t-n}}\right| + \sum_{o=1}^{O} \rho_o \frac{\varepsilon_{t-o}}{\sigma_{t-o}} + \eta Z_t \qquad (2)$$

Errors were found to be significantly non-normal and are assumed to follow the Generalised Error Distribution (GED). Additional lags of ARCH and GARCH terms (*M*, *N* and *O* in the p-GARCH specification (2)) are included in order to account for auto-correlation in the squared residuals.[21] Full specifications for the mean and volatility equations are reported in the results tables. The mean and volatility equations were jointly estimated by maximum likelihood.

In the second stage of the analysis, separate equations were estimated for longer-term rates at maturities of 1, 3 and 12 months. The dependent variables are spot interest rates for Overnight Interest Swaps (OIS) which are derivative contracts referencing the future level of SONIA. An additional model is estimated for 3 month Libor, given the importance of this benchmark in determining the price of corporate borrowing. Data limitations mean the sample begins in 2001.

Additional variables were added to those in Equations (1) and (2) which are likely to affect term rates. In the mean equation (3), OIS rates at the corresponding maturity in the US ($r_t^{US,i}$) and the euro area ($r_t^{EA,i}$) are added, both in changes and in the long-run (error correction) part of the model.[22] Dummy variables are also included in both mean and variance equations to capture monetary policy communications ($COMM_t$), measures of macroeconomic data surprises ($DATA_t$) and the conditional volatility of overnight rates in the relevant period ($\hat{\sigma}_t^{2,on}$) estimated by equation (2). Macroeconomic data surprises are calculated as the difference between the released figure and the mean expectation in Bloomberg polls of economists for CPI inflation, the unemployment rate and GDP growth. Monetary policy communications are MPC decisions, the release of minutes of the MPC's meetings and the quarterly Inflation Report (IR) which includes the MPC's forecasts for growth and inflation.[23] Dummy variables are included in the variance equation for the forward guidance policies adopted by

[21] The presence of remaining auto-correlation in the squared residuals is tested using ARCH-LM and Ljung-Box Q-tests.

[22] We alter the long-run part of the mean equation. While for equation (1) used the spread between overnight rate and Bank Rate is used, in equation (3) the long-run coefficient on each variable is determined in the model. For example, the long-run effect of Bank Rate is calculated as $-\frac{\delta^{2,i}}{\delta^{1,i}}$ and the standard error is calculated by the delta method.

[23] During the sample period, minutes were published 2 weeks after an MPC decision. An Inflation Report is published once a quarter, 1 week after the MPC decision. Note that following the Warsh Review published in December 2014, the MPC decision, minutes and IRs (where relevant) will be published on the same day.

the MPC from August 2013. In the first phase (forward guidance 1), the MPC stated its intention not to raise Bank Rate from 0.5% until after the unemployment rate had fallen to 7%, subject to certain conditions relating to financial and monetary stability. The threshold of unemployment was reached soon afterwards, in January 2014. The MPC then set out further forward guidance (forward guidance 2) in its February 2014 Inflation Report that increases in Bank Rate were likely to be gradual and Bank Rate would likely remain “materially below” its average level prior to the financial crisis. Such forward guidance policies may reduce the volatility of short-term interest rates by providing more clarity over the future actions of policymakers. For example, Ehrmann and Fratzcher (2007) and Nautz and Schmidt (2009) found that the introduction of a “balance of risks” statement by the FOMC in 2000, under which the FOMC set out whether it thought the risks for the economy suggested an easing bias or a tightening bias, reduced the volatility of the federal funds rate.

The reduced-form specification for the term rates equation is shown in (3a). The long-run cointegrating equation, which acts as an attractor for short-run changes in the interest rate, is given in (3b). Note that while for the overnight rate we imposed a unit coefficient on Bank Rate in the long-run equation (δ referred to the speed of catch-up), whereas for term rates we have adopted a more flexible specification in which the long-run coefficients on Bank Rate and US and EA rates are allowed to vary (δ^{BR}, δ^{US} and δ^{EA} refer to the long-run coefficients on these variables calculated as $-\frac{\delta^2}{\delta^1}$, $-\frac{\delta^3}{\delta^1}$ and $-\frac{\delta^4}{\delta^1}$ respectively).

$$\begin{aligned}\Delta r_t^i = \alpha^i &+ \sum_{j=1}^{J} \beta_j^i \Delta r_{t-j}^i + \sum_{k=0}^{K} \gamma_k^{U,i} \Delta o_{t-k}^U + \sum_{k=0}^{K} \gamma_k^{E,i} \Delta o_{t-k}^E + \sum_{p=0}^{P} \gamma_p^{US,i} \Delta r_{t-p}^{US,i} \\ &+ \sum_{q=0}^{Q} \gamma_q^{EA,i} \Delta r_{t-q}^{EA,i} + \delta^{1,i} r_{t-l}^i + \delta^{2,i} o_{t-l} + \delta^{3,i} r_{t-l}^{US,i} + \delta^{4,i} r_{t-l}^{EA,i} \\ &+ \varphi^i X_t + \iota^i COMM_t + \upsilon^i DATA_t + \omega^i \hat{\sigma}_t^{on} + \varepsilon_t^i\end{aligned} \tag{3a}$$

$$r_t = \delta^{BR,i} o_t + \delta^{US,i} r_t^{US,i} + \delta^{EA,i} r_t^{EA,i} \tag{3b}$$

The variance equation for term rates is shown in equation (4) below and is specified as GARCH(M,N). This departs from the p-GARCH used for overnight rates because part of the focus is the transmission of overnight volatility to longer-term volatility, and it is more straightforward to make inferences about this using the level of volatility rather than the power (or other) transformation of volatility. Short-run and long-run elasticities of the transmission of overnight volatility to term volatility are reported, or in other words the percentage increase in term volatility resulting from a 100% increase in overnight volatility, immediately and in equilibrium (see Colarossi and Zaghini, 2009). The appropriate lag lengths for the mean equation (J, K, P, Q) and the variance equation (M, N) were chosen as described above for the overnight equations. These equations were then jointly estimated using maximum likelihood.

$$\sigma_t^{i2} = c^i + \sum_{m=1}^{M} \lambda_m^i \sigma_{t-m}^{i2} + \sum_{n=1}^{N} \theta_n^i \varepsilon_{t-n}^i + \eta^i Z_t + \kappa^i COMM_t + \psi^i DATA_t + \mu^i \hat{\sigma}_t^{on} \tag{4}$$

4. Results

4.1 Overnight rates

Results of estimating equations (1) and (2), describing the behaviour of overnight rates, are shown in Table 1. Rates were found to be strongly (negatively) auto-correlated in all three periods. In both the pre-RAF period and the RAF period, there was rapid pass-through of changes in Bank Rate into the overnight rate (there have been no changes in Bank Rate during the floor period). When changes had been expected, pass through of Bank Rate changes was faster and the coefficient is greater than one. This may reflect some overshooting, for example if pricing for an expected announcement becomes a crowded trade or if banks were less willing to trade on the last day of the previous maintenance period. There was also subsequent equilibrium correction of rates towards the level of Bank Rate as indicated by the significant negative δ coefficients. Calendar effects were found to be significant in all three periods and the last day of a maintenance period was found to be associated with slightly lower rates under the reserves averaging period and the floor period.

Turning to the variance equations, strong ARCH and GARCH effects were found to be present in all three periods (θ and λ are significant and positive) suggesting that shocks were associated with larger and persistent volatility. For the floor period there were significant asymmetric ARCH effects (ρ), suggesting that positive shocks to market rates have a greater effect on volatility than negative shocks.

It is possible that this reflects the fact that Bank Rate was close to the effective lower bound during this period, so there was a limit to how much rates could fall. Consistent with the structural break tests reported earlier, there are very large differences in the mean estimated conditional volatility (i.e. the mean of $\hat{\sigma}_t$) across the three regimes operated during the sample period. Estimated volatility was around 10% prior to the introduction of reforms in 2006 and fell by about 10 times to 1% in the post-reform RAF period. Following the introduction of the floor regime in 2009 estimated volatility fell a further 100 times to 0.01%.

Calendar effects were found to be of mixed significance in both mean and variance equations. Rates tend to be lower at year-end and on the last day of a maintenance period. In the pre-RAF and RAF periods, rates tended to rise at month- and quarter-ends.

Table 1: Monetary policy implementation and the behaviour of overnight unsecured interest rates

Mean equation	**Pre-RAF**	**RAF**	**Floor**	***Variance equation***	**Pre-RAF**	**RAF**	**Floor**
α	-0.005	0.001***	0.002	c	0.001*	0.004	0.0001
	(0.004)	(0.0003)	(0.001)		(0.001)	(0.004)	(0.0002)
β	-0.64***	-0.127***	-0.685***	λ	0.91***	0.451***	0.079**
	(0.054)	(0.026)	(0.045)		(0.011)	(0.069)	(0.04)
γ^U	1.005***	1.001***	-	θ	0.098***	0.69***	0.405***
	(0.344)	(0.031)	-		(0.013)	(0.156)	(0.062)
γ^E	1.26***	1.359***	-	ρ	-0.02	-0.107	0.126
	(0.156)	(0.03)	-		(0.027)	(0.106)	(0.079)
δ	-0.36***	-0.045***	-0.003	τ	1.33***	1.05***	1.633***
	(0.021)	(0.004)	(0.002)		(0.206)	(0.244)	(0.334)
Calendar dummies (ϕ):				*Calendar dummies (η):*			
Month-end	0.1***	0.017***	-0.0001	Month-end	0.014*	0.019	0.0006
	(0.025)	(0.001)	(0.001)		(0.008)	(0.015)	(0.0008)
Quarter-end	0.021	0.15***	-0.006	Quarter-end	0.013	0.167	0.002
	(0.042)	(0.003)	(0.005)		(0.011)	(0.107)	(0.003)
Year-end	-0.11	-0.048***	0	Year-end	0.01	-0.029	0.005
	(0.096)	(0.003)	(0.017)		(0.023)	(0.138)	(0.006)
Pre-bank holiday	-0.118***	-0.004***	0.003***	Pre-bank holiday	0.006	-0.003	0.0002
	(0.033)	(0)	(0.001)		(0.014)	(0.004)	(0.0003)
Bank holiday	-0.026	0.002***	0.0003**	Bank holiday	-0.018*	-0.005	-0.0001
	(0.037)	(0.0001)	(0.0001)		(0.011)	(0.004)	(0.0002)
End maintenance period	-0.015	-0.022***	-0.0009*	End maintenance period	-0.014*	0.024	0.000001
	(0.019)	(0.002)	(0.0005)		(0.008)	(0.019)	(0.00003)
Mean est. conditional variance	0.108	0.013	0.0001				
Number of observations	2440	730	1390				
R-squared	0.22	0.32	0.04				
ARCH LM test (5), p-value	0.27	1.00	0.91				

Notes to Table 1:

Pre-RAF period is 9th January 1997 to 17th May 2006, RAF period is from 18th May 2006 to 4th March 2009,and floor period is from 6th March 2009 to 3rd July 2014. r_t is the Sterling Overnight Index Average (SONIA), a measure of overnight unsecured lending rates. o_t is Bank Rate set by the Monetary Policy Committee of the BOE. Changes in Bank Rate are separated into expected (Δo_t^E) and unexpected (Δo_t^U) components. Coefficients are summed over all lags of each variable (e.g. $\beta = \beta_1 + \beta_2$) with standard errors estimated using the delta method. Standard errors are given in parentheses; ***, ** and * denote statistical significance at 1%, 5% and 10% level respectively. Mean and variance equations are jointly estimated using maximum likelihood.

4.2 *Robustness test: Testing for structural breaks in overnight volatility*

The results in the previous section suggest that the introduction of the RAF in 2006 and the floor in 2009 were associated with reductions in the volatility of overnight rates. But it is possible that these may not coincide with the true breaks in volatility, or that there may be further structural breaks which have not been taken into account in the analysis. In order to test this, the models in equations (1) and (2) are estimated in such a way as to allow for multiple structural breaks in both mean and variance equations at *unknown* dates. In this approach, rather than impose break dates via dummy variables or by splitting the sample by regime, the breaks are estimated using the data itself.

For the mean equation (1), the Bai-Perron (2003) method is used to allow for an unknown number of structural breaks at unknown dates. In this method, the breaks are chosen so as to maximise the value of a test statistic. This method requires that the model (1) can be estimated for multiple sub-samples. But in the latter part of our sample, beginning 5th March 2009, model (1) cannot be estimated since there are no changes in Bank Rate. Hence, the sample is split into two parts, corresponding to the period before and after this date, and apply the Bai-Perron method separately to each of the two sub-samples (this is equivalent to imposing a structural break at this date).

The residuals are then taken from the estimated models and a GARCH (1,1) model is estimated which allows for multiple breaks at unknown dates.[24] The method developed by Rapach and Strauss (2008) is used to identify structural breaks in the unconditional variance of the residual. This uses the iterated cumulative sum of squares (ICSS) algorithm by Inclán and Tiao (1994), which allows for dependent processes. This method is appropriate when there is an unknown number of structural breaks in the unconditional variance at unknown dates. The estimated GARCH(1,1) model for the residual e_t is $e_t = h_t^{0.5}\varepsilon_t$, where $h_t = \omega + \alpha e_{t-1}^2 + \beta h_{t-1}$. The unconditional variance of e_t is given by $\omega/(1 - \alpha - \beta)$. Structural breaks are tested for at the 5% significance level. Note this is a simpler model than equation (2) since it is not a power GARCH and there are no other variables other than a constant (ω) and the GARCH terms.

The results are shown below. The full regression results for each sub-period are omitted but are available on request from the author. The structural breaks in the mean and variance equations are

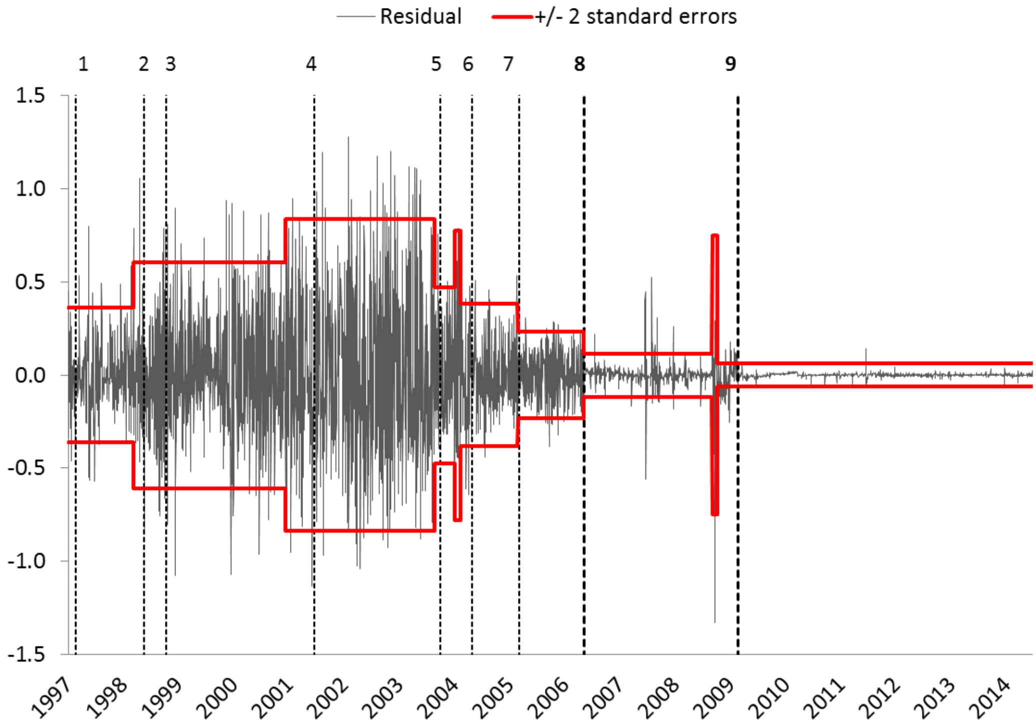
[24] The estimated GARCH(1,1) model for the residual e_t is $e_t = h_t^{0.5}\varepsilon_t$, where $h_t = \omega + \alpha e_{t-1}^2 + \beta h_{t-1}$. The unconditional variance of e_t is given by $\omega/(1 - \alpha - \beta)$. Structural breaks are tested for at the 5% significance level. Note this is a simpler model than equation (2) since there are no other variables other than a constant (ω) and the GARCH terms.

listed in Table 2. Figure 2 shows the estimated residual from the mean equation; this could be thought of as an estimate of the Sonia – Bank rate spread (shown in its raw form in Figure 1) after adjusting for changes in lags, Bank Rate and calendar effects included in Equation (1). Figure 2 also shows +/- two standard error bands corresponding to the estimated conditional variance from each sub-period. The results support the main findings that the introduction of the RAF and the floor in 2006 and 2009 respectively were associated with reduced volatility of the overnight rate, though in the case of the floor the structural break actually occurs a little earlier, in October 2008. The results also reveal a number of other structural breaks in the model. Volatility increased in 1998 and 2000, and there is no indication that the various reforms described in Section 2 acted to reduce volatility in this period. Volatility then fell in 2003, around the time of Governor King's speech announcing a review of the SMF, and again in 2005 which coincided with the implementation of a number of interim reforms described in Section 2. It is interesting that a large fall in volatility occurs at the time the review was announced, before any changes to the SMF had been made. This finding may suggest that signalling effects may have been just as important in reducing volatility as the reform package itself. In other words, the BOE's communication that its tolerance for volatility of the overnight rate had fallen may have caused the market to anticipate the effects of the reforms. Finally, there is a large increase in volatility in late 2008 when volatility returned to similar levels as those seen in the early 2000s. As noted in section 2, this corresponds to a period of liquidity problems described in Section 2.

Table 2: Structural breaks in models of the overnight rate

Structural breaks	
In mean equation (identified using Bai-Perron method)	In variance equation (identified using Inclan-Tiao method)
13 May 2009	20 March 1998
16 March 2001	20 December 2000
10 February 2003	01 September 2003
09 August 2005	12 January 2004
05 March 2009	23 February 2004
01 April 2010	04 March 2005
06 October 2011	18 May 2006
11 June 2013	12 September 2008
	17 October 2008
	04 July 2014

Figure 2: Structural breaks in the variance of the overnight rate



Key to events

1	Gilts obtained via reverse repo accepted in OMOs and access widened
2	Collateral eligibility further expanded
3	Access to borrowing facility extended to banks
4	Deposit facility introduced, completing corridor system
5	Governor announces review of Sterling Monetary Framework
6	First consultation paper on SMF review
7	Interim reforms including narrower corridor
8	Reserves averaging framework introduced
9	Start of large-scale asset purchases and floor framework introduced

Notes to Table 2 and Figure 2: The mean equation (1) is estimated using the Bai-Perron method allowing for multiple structural breaks at unknown dates. A break in the model is imposed at 05 March 2009 due to the lack of changes in Bank rate after that date. Figure 2 shows the residual from the mean equation. The conditional variance is estimated allowing for multiple structural breaks at unknown dates structural breaks identified using the method developed by Rapach and Strauss (2008) and Inclán and Tiao (1994). The red lines show +/- two standard error bands calculated using the estimated conditional variance.

4.3 Term rates

In the second stage of the analysis, longer-term rates are modelled by estimating equations (3) and (4). This is done for each maturity for the whole sample period and for each distinct operating framework.

The results are shown in Tables 3, 4, 5 and 6 for 1 month OIS, 3 month OIS, 12 month OIS and 3 month Libor rates respectively.

Table 3 shows the results for the 1 month OIS rate. Rates are negatively autocorrelated (β) in all periods except the floor period (indicating changes in rates tend to reverse themselves) and strongly correlated with changes in Bank Rate (γ^U, γ^E). Unexpected changes in Bank Rate have a much stronger effect than expected changes, which is likely to be because expected changes would already have been priced in to term rates before the change. Short-run co-movement with US rates (γ^{US}) and those in the EA (γ^{EA}) was positive for all periods though was only significant for the pre-RAF period. Bank Rate has a significant and positive long-run equilibrium effect (δ^{BR}). The long-run effect of the US (δ^{US}) is negative in the pre-RAF period but otherwise is either insignificant, whereas euro area rates (δ^{EA}) do not have significant long-run effects in any periods.

Rates tend to fall a little on MPC decision days during the pre-RAF period, suggesting that the MPC's communications were on average "dovish" relative to expectations in this period. Rates are generally positively correlated with data surprises as expected, though the effects are generally of only weak significance. Overnight volatility (ω) is associated with falls in rates in the pre-RAF and RAF periods. This may reflect investors sacrificing some yield in order to obtain a fixed term interest rate in the face of uncertainty regarding forward overnight interest rates – in other words, a negative term premium (Peacock 2004, Swanson 2007), or it may that volatility in overnight rates reflects deteriorating market conditions which are linked to a lower expected path of Bank Rate.

Turning to the variance equation, the 1 month OIS rate is found to be much less volatile than overnight rates during the pre-RAF and RAF periods, and of similar volatility in the floor period. GARCH and ARCH effects are found to be generally positive and significant. Overnight volatility (σ^{ON}) is positively correlated with term volatility, although none of the coefficients is statistically significant except the long-run elasticity of the effect in the pre-RAF period. Translating the estimated effect into a long-run elasticity produces a significant coefficient of 0.216, suggesting that, in equilibrium, a 100% increase in overnight maturity is associated with a 20% increase in volatility of the 1 month OIS rate. There is some evidence that volatility is lower around MPC communications and in particular minutes and *Inflation Reports*, and volatility was found to be lower during the periods corresponding to the MPC's forward guidance policies. Data surprises are generally not significantly associated with volatility of the 1 month OIS rate.

The models of 3 month OIS rates are shown in Table 4. Most of the results are similar to those for 1 month OIS rates and only the interesting differences in the results are discussed here. Short-run co-movement with the US and EA is much stronger for 3 month rates than for 1 month rates, perhaps reflecting the fact that while 1 month rates reflect short-term conditions which differ across the three economies, market participants expect rates to converge over longer maturities. Data surprises play a greater role for 3 month rates, in particular GDP and inflation releases which are significantly and positively associated with rates. There is greater evidence that overnight volatility affects 3 month rates than for 1 month rates. In the pre-RAF period, a coefficient of 0.002 is highly statistically significant and translates into an elasticity of 59%. Over the whole sample period, the relationship is smaller but still significant, implying an elasticity of 2% in the short-run and 5% in the long run.

Table 5 shows the models for 12 month OIS rates. Again only the interesting differences with the 3 month OIS model are discussed. Data surprises have an even greater impact than they did on 3 month OIS rates, with inflation and GDP releases having a positive and significant effect in almost all periods. MPC communications again appear to play a limited role at this maturity. *Inflation Reports* are associated with lower rates, consistent with communications that were more dovish than expected on average. On the days of MPC decisions and minutes rates are slightly less volatile, suggesting that these communications may act to calm markets. There is no evidence that volatility of the overnight rate affected the volatility of the 12 month OIS rate in any of the separate periods considered, although using the whole sample period there is a significant and positive effect which translates into elasticities of 1.5% in the short run and 3% in the long run.

Finally, Table 6 shows the results for 3 month Libor. As discussed above, this may be more relevant for transmission into the real economy than OIS given it is referenced in many corporate loan transactions. These rates generally have similar levels of volatility to the equivalent OIS maturity. Unlike the 3 month OIS rate, autocorrelation is positive. This may reflect the fact that Libor is based on banks' judgements about the rate they could borrow at, which may mean that banks maintain the same Libor submission over time if they have not accessed the market. Interestingly co-movement with US and EA rates is much weaker for 3 month Libor rates than for 3 month OIS rates, which may be because as a traded rate, OIS is more susceptible to short-term fluctuations caused by foreign news. There is no evidence that higher volatility in overnight rates increases the volatility of 3 month Libor; in fact, the only significant coefficient is negative, for the pre-RAF period.

Table 3: Model of 1 month OIS rates

Mean equations

	Pre-RAF	RAF	Floor	All
α	0.038***	-0.01	0.006	0.002
	(0.006)	(0.014)	(0.004)	(0.0024)
β	-0.167***	0.096	-0.15**	-0.089***
	(0.048)	(0.111)	(0.058)	(0.025)
γ^{U}	0.849***	0.666***		0.811***
	(0.101)	(0.021)		(0.134)
γ^{E}	0.342***	0.046*		0.107*
	(0.039)	(0.027)		(0.061)
γ^{US}	0.043**	0.005	0.009	0.126**
	(0.021)	(0.046)	(0.051)	(0.049)
γ^{EA}	0.11***	0.09	0.01	0.05
	(0.021)	(0.079)	(0.016)	(0.037)
δ^{BR}	0.864***	1.997**		1.01***
	(0.029)	(0.931)		(0.044)
δ^{US}	-0.028***	-0.335	-0.103	-0.027
	(0.009)	(0.325)	(0.485)	(0.031)
δ^{EA}	0.0003	-1.12	0.0842	0.036
	(0.025)	(1.148)	(0.07)	(0.06)
ω	-0.064***	-0.07*	0.731*	0.0002
	(0.01)	(0.036)	(0.383)	(0.0002)
Calendar dummies (φ):				
Month-end	0.003	-0.002	-0.001	-0.0012
	(0.002)	(0.01)	(0.001)	(0.004)
Quarter-end	-0.012**	0.004	0.003	-0.0016
	(0.005)	(0.014)	(0.002)	(0.005)
Year-end	0.015**	-0.013	-0.008***	-0.006
	(0.006)	(0.013)	(0.002)	(0.007)
Pre-bank holiday	-0.003	0.002	-0.001	-0.0019
	(0.002)	(0.009)	(0.002)	(0.002)
Bank holiday	-0.0016	-0.0044	0.0007	-0.001
	(0.001)	(0.007)	(0.001)	(0.0037)
End maintenance period	0.003***	-0.006	-0.001	-0.0015
	(0.001)	(0.009)	(0.001)	(0.0033)
Communications (τ):				
MPC decision	-0.005**	0.041***	0.003***	0.0038
	(0.002)	(0.008)	(0.001)	(0.002)
MPC minutes	-0.001	-0.004	0.001	-0.001
	(0.001)	(0.006)	(0.001)	(0.0027)
Inflation Report	-0.003	-0.013	-0.001	-0.006
	(0.002)	(0.01)	(0.002)	(0.0067)
Data surprises (υ):				
GDP	0.002	0.006	0.001	0.001
	(0.003)	(0.012)	(0.001)	(0.002)
Unemployment	-0.007***	0.002	0.00003	0.0003
	(0.001)	(0.011)	(0.0004)	(0.004)
Inflation	0.003***	0.003	0.001	0.0016
	(0.001)	(0.009)	(0.001)	(0.004)

Variance equations

	Pre-RAF	RAF	Floor	All
c	0.0007***	0.0006***	0.00002***	0.0005***
	(0.0003)	(0.0002)	(0.000004)	(0.0001)
λ	0.492***	0.535***	0.59***	0.198*
	(0.182)	(0.13)	(0.052)	(0.114)
θ	0.154	0.126**	0.148***	0.224***
	(0.103)	(0.059)	(0.037)	(0.042)
μ	0.002	0.0002	0.0001	0.0002
	(0.001)	(0.001)	(0.002)	(0.0002)
Pre-RAF dummy				-0.00001
				(0.00004)
RAF dummy				-0.00001
				(0.00004)
Communications (τ):				
MPC decision	0.0001	0.00003	0.000001	0.00002
	(0.001)	(0.0005)	(0.00001)	(0.0001)
MPC minutes	-0.001***	-0.001***	-0.00003***	-0.0002***
	(0.001)	(0.0005)	(0.00001)	(0.0001)
Inflation Report	-0.001***	-0.001*	-0.00004***	-0.0003**
	(0.0004)	(0.001)	(0.00001)	(0.0001)
Forward guidance 1			-0.00001**	-0.0002***
			(0.000003)	(0.000047)
Forward guidance 2			-0.00001***	-0.00023***
			(0.000002)	(0.000044)
Data surprises (υ):				
GDP	-0.0002	0.0001	0.000005	-0.00001
	(0.0004)	(0.0002)	(0.00001)	(0.00005)
Unemployment	0.00018	0.00031	-0.00001**	-0.00002
	(0.0001)	(0.0004)	(0.000004)	(0.0001)
Inflation	0.0003	-0.0001	-0.00001	0.000001
	(0.0005)	(0.0003)	(0.00001)	(0.0001)
Calendar dummies (η):				
Month-end	-0.0006	-0.0007**	-0.00001	-0.0002**
	(0.001)	(0.0003)	(0.00001)	(0.0001)
Quarter-end	-0.00003	-0.0002	-0.00001	-0.0001
	(0.001)	(0.001)	(0.00001)	(0.0001)
Year-end	-0.0002	-0.0001	-0.00001	-0.0001
	(0.001)	(0.0005)	(0.00002)	(0.0001)
Pre-bank holiday	-0.001	-0.001***	-0.00002***	-0.0004***
	(0.001)	(0.0002)	(0.00001)	(0.00004)
Bank holiday	-0.0005	-0.0005**	-0.00001***	-0.0002***
	(0.0004)	(0.0002)	(0.000005)	(0.00005)
End maintenance period	-0.001***	-0.00001	-0.00002	-0.00009
	(0.0003)	(0.0005)	(0.00001)	(0.0001)
Mean est. conditional variance	0.0017	0.0013	0.0001	0.0007
Number of observations	1160	730	1390	3278
R-squared	0.116	0.600	0.073	0.298
ARCH LM test (5)	0.006	0.394	0.1117	0.000
Elasticity of the transmission of overnight volatility				
Short-run	0.11	0.002	0.0002	0.019
	(0.077)	(0.014)	(0.006)	(0.017)
Long-run	0.216**	0.005	0.0004	0.023
	(0.106)	(0.03)	(0.014)	(0.021)

Table 4: Model of 3 month OIS rates

Mean equations

	Pre-RAF	RAF	Floor	All
α	0.022***	-0.003	0.007*	0.002
	(0.006)	(0.003)	(0.004)	(0.002)
β	-0.112**	-0.012	-0.272***	-0.048
	(0.049)	(0.033)	(0.088)	(0.051)
γ^{U}	0.666***	0.752***		0.719***
	(0.055)	(0.036)		(0.115)
γ^{E}	0.049	0.029		-0.006
	(0.038)	(0.021)		(0.054)
γ^{US}	0.184***	0.024	0.067	0.169***
	(0.026)	(0.015)	(0.077)	(0.029)
γ^{EA}	0.142***	0.514***	0.056***	0.205***
	(0.029)	(0.04)	(0.021)	(0.028)
δ^{BR}	1.649***	16.462		1.044***
	(0.381)	(42.479)		(0.035)
δ^{US}	0.083	-4.256	-0.084	-0.018
	(0.078)	(11.872)	(0.562)	(0.026)
δ^{EA}	-0.1156	-16.637	0.091	0.006
	(0.179)	(46.047)	(0.088)	(0.045)
ω	-0.013	-0.013**	1.221***	0.019***
	(0.01)	(0.006)	(0.446)	(0.006)
Calendar dummies (φ):				
Month-end	0.0002	0	-0.002	-0.0003
	(0.002)	(0.002)	(0.002)	(0.002)
Quarter-end	-0.011	-0.007***	0.001	-0.005*
	(0.007)	(0.002)	(0.005)	(0.003)
Year-end	0.002	0.005	-0.001	0.001
	(0.01)	(0.005)	(0.006)	(0.003)
Pre-bank holiday	-0.002	0.004*	-0.001	-0.002
	(0.003)	(0.002)	(0.001)	(0.002)
Bank holiday	0.0005	-0.004***	-0.001	0.0003
	(0.002)	(0.001)	(0.002)	(0.003)
End maintenance period	0.001	-0.005***	-0.001	-0.0006
	(0.002)	(0.001)	(0.002)	(0.002)
Communications (τ):				
MPC decision	-0.01***	0.028***	0.004***	0.0008
	(0.003)	(0.002)	(0.001)	(0.002)
MPC minutes	-0.002	-0.001	0.0005	-0.001
	(0.003)	(0.001)	(0.001)	(0.0016)
Inflation Report	-0.006	-0.017***	-0.0005	-0.007**
	(0.005)	(0.005)	(0.002)	(0.0035)
Data surprises (υ):				
GDP	0.007***	0.005**	0.001	0.002
	(0.002)	(0.002)	(0.001)	(0.002)
Unemployment	0.001	0.004	0.001	0.0032
	(0.002)	(0.003)	(0.001)	(0.0021)
Inflation	0.008***	0.014***	0.003**	0.007***
	(0.002)	(0.002)	(0.001)	(0.002)

Variance equations

	Pre-RAF	RAF	Floor	All
c	0.00004***	0.0005**	0.00005***	0.0003***
	(0.00001)	(0.0002)	(0.000009)	(0.00003)
λ	0.008	0.482**	0.575***	0.555***
	(0.043)	(0.194)	(0.075)	(0.05)
θ	0.119***	0.171	0.146***	0.129***
	(0.044)	(0.13)	(0.046)	(0.024)
μ	0.002***	0.004	-0.003	0.0002***
	(0.0002)	(0.004)	(0.003)	(0.0001)
Pre-RAF dummy				-0.0001***
				(0.00002)
RAF dummy				-0.00001
				(0.00002)
Communications (τ):				
MPC decision	0.0004***	0.0002	-0.00002*	0.00007**
	(0.0001)	(0.0004)	(0.00001)	(0.00003)
MPC minutes	0.0003***	-0.0003	-0.00006***	-0.0002***
	(0.0001)	(0.0004)	(0.00001)	(0.00003)
Inflation Report	0.0003*	0.001	-0.00007***	-0.0002***
	(0.0001)	(0.001)	(0.00001)	(0.0001)
Forward guidance 1			-0.00001*	-0.0001***
			(0.000005)	(0.00003)
Forward guidance 2			-0.00002***	-0.0001***
			(0.000005)	(0.00003)
Data surprises (υ):				
GDP	0.00003	0.0001	-0.00002	-0.00002
	(0.00003)	(0.0002)	(0.00002)	(0.00002)
Unemployment	-0.00005	0.0007	-0.00002***	-0.00006***
	(0.00005)	(0.0005)	(0.000005)	(0.00002)
Inflation	0.00004***	0.0005	0.000003	0.00008
	(0.00001)	(0.0006)	(0.00001)	(0.0001)
Calendar dummies (η):				
Month-end	-0.00003	-0.0007*	-0.00003	-0.0002***
	(0.00004)	(0.0004)	(0.00002)	(0.00003)
Quarter-end	0.00033	-0.0004	-0.00003	-0.0001***
	(0.0002)	(0.0005)	(0.00002)	(0.00004)
Year-end	-0.0001	0.001	-0.00002	-0.00001
	(0.001)	(0.002)	(0.00002)	(0.00003)
Pre-bank holiday	-0.00001	-0.001**	-0.00005***	-0.0002***
	(0.00005)	(0.0003)	(0.00001)	(0.00003)
Bank holiday	0.00004	-0.0005**	-0.00002*	-0.0001***
	(0.00005)	(0.0002)	(0.00001)	(0.00002)
End maintenance period	0.00003	-0.0006**	-0.00006***	-0.0002***
	(0.00005)	(0.0003)	(0.00001)	(0.00002)
Mean est. conditional variance	0.0003	0.001	0.0001	0.0006
Number of observations	1154	730	1391	3279
R-squared	0.222	0.585	0.097	0.432
ARCH LM test (5)	0.203	0.894	0.000	0.001
Elasticity of the transmission of overnight volatility				
Short-run	0.587***	0.045	-0.004	0.02***
	(0.069)	(0.042)	(0.004)	(0.005)
Long-run	0.592***	0.087	-0.011	0.045***
	(0.065)	(0.073)	(0.009)	(0.012)

Table 5: Model of 12 month OIS rates

Mean equations

	Pre-RAF	RAF	Floor	All
α	0.04***	-0.004	0.006	0.002
	(0.011)	(0.006)	(0.004)	(0.002)
β	-0.105***	-0.096***	-0.261***	-0.098***
	(0.03)	(0.025)	(0.06)	(0.034)
γ^{U}	1.222***	0.546***		0.561***
	(0.159)	(0.044)		(0.095)
γ^{E}	0.03	0.016		-0.005
	(0.091)	(0.032)		(0.058)
γ^{US}	0.22***	0.224***	0.541***	0.319***
	(0.021)	(0.019)	(0.053)	(0.03)
γ^{EA}	0.605***	0.555***	0.239***	0.503***
	(0.028)	(0.027)	(0.026)	(0.038)
δ^{BR}	3.601	-2.907		1.442***
	(2.335)	(5.483)		(0.353)
δ^{US}	-0.203	1.222	0.618	-0.433
	(0.285)	(1.599)	(0.46)	(0.309)
δ^{EA}	1.002	4.121	0.051	0.118
	(0.683)	(5.546)	(0.166)	(0.284)
ω	0.004	0.015	1.365	0.019*
	(0.013)	(0.017)	(1.056)	(0.01)
Calendar dummies (φ):				
Month-end	0.009***	-0.004	-0.002	0.0004
	(0.003)	(0.003)	(0.005)	(0.003)
Quarter-end	-0.036***	-0.013*	0.003	-0.017***
	(0.007)	(0.007)	(0.008)	(0.004)
Year-end	0.035***	0.001	-0.005	0.011***
	(0.011)	(0.017)	(0.009)	(0.004)
Pre-bank holiday	0.0005	-0.003	-0.006	-0.001
	(0.002)	(0.005)	(0.004)	(0.003)
Bank holiday	-0.003	-0.002	-0.004	-0.001
	(0.003)	(0.003)	(0.004)	(0.004)
End maintenance period	-0.0034	-0.012***	-0.001	-0.004**
	(0.003)	(0.004)	(0.002)	(0.002)
Communications (τ):				
MPC decision	-0.008**	0.024***	0.002	-0.001
	(0.004)	(0.004)	(0.002)	(0.003)
MPC minutes	0.001	-0.001	0.001	-0.001
	(0.005)	(0.004)	(0.003)	(0.003)
Inflation Report	-0.02*	-0.025**	-0.006	-0.014***
	(0.011)	(0.011)	(0.004)	(0.005)
Data surprises (υ):				
GDP	0.007**	-0.004	0.008***	0.005**
	(0.003)	(0.005)	(0.002)	(0.002)
Unemployment	0.007	0.008*	0.0004	0.005
	(0.005)	(0.004)	(0.003)	(0.003)
Inflation	0.031***	0.03***	0.008*	0.018***
	(0.004)	(0.001)	(0.004)	(0.002)

Variance equations

	Pre-RAF	RAF	Floor	All
c	0.0007***	0.001**	0.0003***	0.0008***
	(0.0001)	(0.001)	(0.00005)	(0.0001)
λ	-0.098	0.464**	0.551***	0.451
	(0.071)	(0.236)	(0.076)	(0.099)
θ	0.097***	0.106	0.107***	0.118
	(0.034)	(0.083)	(0.033)	(0.025)
μ	0.0004	0.004	-0.005	0.0006***
	(0.0004)	(0.005)	(0.022)	(0.0002)
Pre-RAF dummy				-0.0002***
				(0.0001)
RAF dummy				-0.0001**
				(0.0001)
Communications (τ):				
MPC decision	0.0004	-0.0002	-0.0002***	0.0001
	(0.0003)	(0.001)	(0.00004)	(0.0002)
MPC minutes	0.002**	-0.0002	-0.0003***	-0.0003***
	(0.0003)	(0.001)	(0.00004)	(0.0002)
Inflation Report	0.002	0.001	-0.00002	0.0002
	(0.002)	(0.002)	(0.0001)	(0.0003)
Forward guidance 1			-0.0001***	-0.0002*
			(0.00002)	(0.0001)
Forward guidance 2			-0.00008***	-0.0003***
			(0.00002)	(0.004)
Data surprises (υ):				
GDP	0.0002***	-0.0004	-0.0001*	-0.0001
	(0.00002)	(0.001)	(0.00007)	(0.00008)
Unemployment	-0.0003	-0.0005	0.00003	-0.0002
	(0.0003)	(0.002)	(0.0001)	(0.0001)
Inflation	0.0001	0.001**	0.00002	0.0004***
	(0.0002)	(0.0005)	(0.0001)	(0.0001)
Calendar dummies (η):				
Month-end	-0.0001	-0.001**	-0.0001	-0.0004***
	(0.0001)	(0.0007)	(0.0001)	(0.0001)
Quarter-end	0.0003	-0.0004	-0.0001	-0.0004***
	(0.0005)	(0.0021)	(0.0002)	(0.0001)
Year-end	-0.0001	0.0001	-0.0002	-0.0003***
	(0.001)	(0.003)	(0.0001)	(0.0001)
Pre-bank holiday	-0.001***	-0.001	-0.0002*	-0.001***
	(0.0001)	(0.001)	(0.0001)	(0.0001)
Bank holiday	-0.0002	-0.001	-0.0001	-0.0002
	(0.0001)	(0.0007)	(0.0001)	(0.0001)
End maintenance period	0.0001	-0.0007	-0.0004***	-0.0008***
	(0.0003)	(0.001)	(0.00003)	(0.0001)
Mean est. conditional variance	0.0009	0.0023	0.0005	0.0013
Number of observations	1160	730	1390	3280
R-squared	0.458	0.488	0.458	0.430
ARCH LM test (5)	0.255	0.080	0.327	0.000
Elasticity of the transmission of overnight volatility				
Short-run	0.056	0.022	-0.001	0.015***
	(0.053)	(0.027)	(0.006)	(0.005)
Long-run	0.051	0.04	-0.003	0.029**
	(0.049)	(0.045)	(0.013)	(0.012)

Table 6: Model of 3 month Libor rates

Mean equations

	Pre-RAF	RAF	Floor	All
α	0.019*	0.003**	0.002**	0.001
	(0.011)	(0.001)	(0.001)	(0.003)
β	0.084*	0.517***	0.759***	0.509***
	(0.045)	(0.012)	(0.052)	(0.052)
γ^{U}	0.698***	0.477***		0.538***
	(0.018)	(0.031)		(0.072)
γ^{E}	0.064***	0.161***		0.223***
	(0.02)	(0.023)		(0.054)
γ^{US}	0.043	-0.007	0.021	0.034
	(0.041)	(0.011)	(0.036)	(0.027)
γ^{EA}	0.074*	-0.004	0.008	-0.034
	(0.039)	(0.021)	(0.011)	(0.026)
δ^{BR}	1.336***	0.237***		0.875***
	(0.27)	(0.069)		(0.186)
δ^{US}	0.005	0.077***	-2.75	-0.015
	(0.08)	(0.018)	(2.84)	(0.119)
δ^{EA}	0.1138	1.035***	0.483	0.338
	(0.123)	(0.081)	(0.363)	(0.23)
ω	-0.001	-0.013***	-0.008	-0.012
	(0.009)	(0.002)	(0.311)	(0.011)
Calendar dummies (φ):				
Month-end	0.0016	-0.0001	0.00002	0.0005
	(0.002)	(0.001)	(0.001)	(0.004)
Quarter-end	-0.009**	-0.003**	-0.000001	-0.002
	(0.004)	(0.001)	(0.001)	(0.006)
Year-end	0.006	0.008**	0.0003	0.002
	(0.018)	(0.004)	(0.005)	(0.009)
Pre-bank holiday	-0.002	0.004**	0.001	0.001
	(0.004)	(0.002)	(0.001)	(0.005)
Bank holiday	-0.0003	-0.005***	-0.0003	0.0007
	(0.002)	(0)	(0.001)	(0.005)
End maintenance period	-0.004	-0.006***	0.0001	0.0003
	(0.003)	(0.001)	(0.001)	(0.005)
Communications (τ):				
MPC decision	-0.005***	0.025***	0.0001	-0.002
	(0.002)	(0.002)	(0.001)	(0.003)
MPC minutes	0.003	-0.002*	0.0001	-0.002
	(0.002)	(0.001)	(0.001)	(0.003)
Inflation Report	-0.0022	0.008**	0.0002	-0.002
	(0.003)	(0.003)	(0.001)	(0.002)
Data surprises (υ):				
GDP	0.001	0.005***	0.0002	0.001
	(0.002)	(0.001)	(0.001)	(0.004)
Unemployment	-0.0015	-0.005***	0.0002	0.0004
	(0.004)	(0.002)	(0.0006)	(0.004)
Inflation	-0.0004	-0.004***	0.0001	0.004
	(0.004)	(0.001)	(0.001)	(0.003)

Variance equations

	Pre-RAF	RAF	Floor	All
c	0.0001***	0.0006**	0.00001***	0.0002***
	(0.00002)	(0.0002)	(0.000002)	(0.00003)
λ	0.557***	0.5405**	0.599***	0.586***
	(0.101)	(0.2671)	(0.107)	(0.058)
θ	0.098***	-0.0198***	0.15**	0.151***
	(0.037)	(0.0037)	(0.061)	(0.029)
μ	-0.0001*	0.0004	-0.0004	-0.00005
	(0.00003)	(0.001)	(0.0005)	(0.0001)
Pre-RAF dummy				-0.00004***
				(0.00001)
RAF dummy				0.000001
				(0.00002)
Communications (τ):				
MPC decision	0.00001	0.0003	-0.000002	0.000002
	(0.00003)	(0.0003)	(0.000003)	(0.00006)
MPC minutes	-0.00011***	-0.0006**	-0.00001***	-0.0001*
	(0.00003)	(0.0003)	(0.000003)	(0.00006)
Inflation Report	-0.0002***	-0.0002	-0.00001**	-0.0003***
	(0.00003)	(0.0009)	(0.000004)	(0.00003)
Forward guidance 1			-0.000002*	-0.0001***
			(0.000001)	(0.00002)
Forward guidance 2			-0.000001	-0.0001***
			(0.000001)	(0.00002)
Data surprises (υ):				
GDP	0.001	0.00008	-0.0000002	-0.000003
	(0.002)	(0.0001)	(0.000002)	(0.00003)
Unemployment	-0.0015	0.0002	-0.000001	-0.000004
	(0.004)	(0.0004)	(0.000002)	(0.00005)
Inflation	-0.0004	-0.0002	-0.0000003	-0.00001
	(0.004)	(0.0004)	(0.000003)	(0.0001)
Calendar dummies (η):				
Month-end	-0.00006**	-0.0008**	-0.000004	-0.0002***
	(0.00003)	(0.0004)	(0.000003)	(0.00005)
Quarter-end	-0.00004	-0.0004	-0.000003	-0.0001*
	(0.00003)	(0.0004)	(0.000005)	(0.00005)
Year-end	-0.00001	0.0004	-0.000004	-0.00004
	(0.00006)	(0.0011)	(0.000003)	(0.00005)
Pre-bank holiday	-0.00014***	-0.001***	-0.000004	-0.0002***
	(0.00002)	(0.0001)	(0.000005)	(0.00005)
Bank holiday	-0.00003	-0.0003	-0.000002	-0.0001**
	(0.00002)	(0.0003)	(0.000002)	(0.00003)
End maintenance period	0.00001	-0.0005*	-0.000004	-0.00003
	(0.00003)	(0.0003)	(0.000003)	(0.00007)
Mean est. conditional variance	0.0002	0.001	0.00002	0.0005
Number of observations	1159	730	1390	3280
R-squared	0.352	0.708	0.657	0.650
ARCH LM test (5)	0.677	0.000	0.941	0.008
Elasticity of the transmission of overnight volatility				
Short-run	-0.028*	0.005	-0.003	-0.005
	(0.015)	(0.018)	(0.004)	(0.007)
Long-run	-0.063**	0.012	-0.008	-0.013
	(0.03)	(0.038)	(0.011)	(0.016)

Notes to Table 3, 4, 5 and 6:

r_t is the 1 month OIS rate (Table 3), the 3 month OIS rate (Table 4), the 12 month OIS rate (Table 5) and the 3 month Libor rate (Table 6). o_t is Bank Rate set by the Monetary Policy Committee of the BOE. Changes in Bank Rate are separated into expected (Δo_t^E) and unexpected (Δo_t^U) components. Coefficients are summed over all lags of each variable (e.g. $\beta = \beta_1 + \beta_2$) with standard errors estimated using the delta method. Long-run effects are shown where relevant (e.g. $\delta^{BR,i} = -\delta^{2,i}/\delta^{1,i}$) and standard errors estimated using the delta method. Standard errors are given in parentheses; ***, ** and * denote statistical significance at 1%, 5% and 10% level respectively. Mean and variance equations are jointly estimated using maximum likelihood.

5. Conclusion

This paper has found some evidence that a central bank's choices regarding the operational framework and the monetary policy communications contribute to changes in money market interest rates, though the effects on term rates are generally quite small. These results are relevant to central banks' choices as they seek to normalise monetary policy following the unconventional measures adopted as a result of the financial crisis. The implementation of floor systems by the BOE in the UK and the Federal Reserve Board in the US, in the context of their QE programs, has reduced money market volatility to historically low levels. But if these unconventional QE policies are unwound in time, it is possible that higher money market volatility may return, and central banks will then face a decision as to what level of money market volatility they will tolerate.

With regard to the effects of the implementation framework, the paper found that the volatility of overnight rates was highest under the zero-reserves corridor system operated by the BOE prior to 2006. It was significantly lower under the reserves averaging framework introduced in 2006, consistent with the aims of that reform. Indeed, volatility had reduced even before the RAF was introduced, following communications surrounding the launch of the BOE's review of its framework in 2003 and a set of interim reforms in 2005. But in late 2008, while the RAF framework was still in place, overnight volatility rose substantially amid turbulent liquidity conditions in the banking sector, largely reversing the earlier falls in volatility associated with the 2006 framework. This was caused by elevated counterparty credit risk concerns and large and rapid swings in reserves demand, which were difficult to fully accommodate within the operating framework given banks were required to pre-commit to a voluntary reserves target over each maintenance period. The subsequent implementation of a floor framework in 2009, in the context of the BOE's QE purchases, was associated with a very large fall in overnight volatility.

While the operational framework matters for the volatility of overnight rates, the effects on term rates are smaller. The results show that volatility of overnight rates transmitted up the curve to the volatility of longer-term rates in the zero reserves framework, but not under the reserves averaging or floor frameworks. There is no evidence that overnight volatility transmits into 3 month Libor rates, which are the key benchmark a large volume of derivatives and bank loans. This suggests that the potential for volatility in overnight rates to spill over into that of term rates and hence to disrupt the monetary policy transmission mechanism is limited. This finding is likely to be relevant to central banks as they consider their tolerance for money market volatility as exceptional monetary policy measures adopted during the financial crisis are unwound.

The second contribution is to quantify the effect of other factors on money market interest rates including monetary policy communications, macroeconomic data releases and changes in rates in other major economies. With regard to the effect of monetary policy communications, the results are mixed. The paper found that when changes in Bank Rate are expected, they have smaller effects on term rates relative to unexpected changes. This is consistent with the idea that monetary policy surprises increase the volatility of forward rates. The publication of MPC minutes and *Inflation Reports*, which contain information on the MPC's views on the path of inflation over the forecast horizon (18-24 months), do affect the level of short-term rates but were generally not associated with higher volatility of rates. Finally, the introduction of explicit forward guidance policies by the MPC in 2013 and 2014 coincided with lower volatility of short-term interest rates. Overall, these results suggest that if monetary policymakers are able to provide greater guidance on upcoming decisions, then this may reduce volatility in short-term interest rates.

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