The impact of reserves averaging on banks' liquidity management*

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Abstract

Using data on the timing of trading in the sterling overnight unsecured interbank market during the period January 2003-February 2008 we test the impact on banks' liquidity management of recent reforms to the Bank of England's sterling money market operations. We find that the introduction of reserves averaging in May 2006 is associated with trading shifting later in the day, as was the widening of the target ranges on reserve accounts in October 2007. We also show that the magnitude of this timing shift is greatest in the early days of a maintenance period.

Our results support the hypothesis that the introduction of reserves averaging enhanced banks' ability to manage their daily liquidity requirements, by enabling them to trade in the interbank market with better information about their liquidity needs.

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1 INTRODUCTION

Banks' management of the daily liquidity requirements arising from their net payment flows is a crucial process underpinning the stability of the financial system. These liquidity demands arise because the daily payment flows to and from each bank, driven by, *inter alia*, requirements to settle financial market transactions, make and receive transfers on behalf of customers, and extend or drawdown loan commitments, are rarely perfectly offsetting.[1] The net redemption that arises from a days payment activity must therefore be managed by lending and borrowing in the interbank market from other banks or from the central bank. Any disruption to this process can potentially have very severe reputational implications for a bank, therefore its smooth functioning is of benefit for the wider financial system.

In developed economies, the vast majority of payment flows by value are made in central bank money across accounts held at the central bank of issue for a specific currency. Therefore the terms under which banks can hold funds on such accounts are a key influence determining their ability to efficiently manage their daily liquidity requirements.

On 18 May 2006 the Bank of England implemented wide-ranging reforms to its sterling money market operations.[2] The primary objective of the changes was to reduce volatility in overnight market rates and bring them more in line with the official Bank Rate. However, an important secondary aim was to provide an efficient, safe and flexible framework for banking system liquidity management. These reforms had a significant impact on the terms under which the Bank of England provides the accounts which are used, *inter alia*, by banks when settling their sterling payment flows. The intention of this paper is to quantify the impact of these reforms on the way banks conduct their daily liquidity management processes in sterling. In addition, our approach enables us to analyse the impact of recent turbulence in the sterling overnight market on these processes.

The reform that is of most relevance to our study is the introduction of reserves averaging. This entailed the Bank of England introducing a policy of paying interest, at Bank rate, on banks' overnight holdings of cash on their Bank of England accounts. Banks were given the option to hold reserves overnight at the Bank of England, and permitted to actively manage their reserves holdings, provided they satisfy the condition that over the averaging period (defined as the period between 2 regular policy rate decisions) their mean daily reserve position falls within a pre-defined target

[1] Indeed as turnover in financial markets has grown rapidly over recent decades, reaching a situation where the daily value of payments flowing across a typical large-value payment system in a developed economy is a significant fraction of annual GDP in that economy, then these net liquidity demands can be very sizeable.

[2] For more information on the reforms, see Clews (2005)

range around the target balance they set prior to the start of the maintenance period.

The intention of reserves averaging is to encourage banks to respond to any deviations in overnight rates away from the target rate by substituting reserves holdings across days, lending out reserves when rates are above target, and borrowing in funds and holding them as additional reserves when rates are below target. In the absence of major frictions inhibiting this process, it should lead to significant deviations in overnight rates from the policy rate being arbitraged away.

In the UK prior to the May 2006 reforms, no arrangements for remunerating reserves were in place. Banks making payments across accounts at the Bank of England had very strong incentives to square-off their balances on these accounts to zero at the end of each day, because any excess balances retained would receive a zero rate of interest overnight, and any residual overdraft incurred a severe penal interest charge. We expect the introduction of reserves averaging to have significantly enhanced banks' ability to manage their daily net sterling liquidity position, because, in addition to recourse to the interbank market, they now have the ability to absorb unexpected fluctuations in their liquidity needs on their reserve account.

We test our hypothesis by examining how the timing of overnight loan transactions has altered across our sample. This approach is based upon an insight in Angelini (2000) that the timing of overnight loan flows conveys information about the constraints faced by banks' liquidity managers. Specifically we expect to see banks transacting in this market later in the day, taking advantage of the additional flexibility offered by reserves averaging. By delaying their final decision on the funding trades they wish to make in the interbank market banks are able to act at a point when they have greater certainty about their net liquidity needs on the day. We also expect a reduction in intraday rate volatility to have a similar impact on banks' timing decisions.

Our empirical results lend support to this hypothesis. We analyse the timing impact of two significant changes to the Bank of England's implementation framework: (i) the introduction of reserves averaging in May 2006; and (ii) widening of the target ranges around banks' target balances in October 2007. On both occasions loan activity shifts later in the day following the reform, supporting our hypothesis. We further demonstrate that towards the end of a maintenance period when the flexibility offered by reserves averaging is diminished, the timing impact is lessened and trading is seen to shift earlier in the day when compared to trading at the start of a maintenance period.

We identify two points in our sample where a significant shift in intraday rate volatility occurred. The first, in May 2004, was associated with a significant decline in rate volatility, and is anecdotally attributed to major players ending their practice of games playing in the overnight market. The second, in August 2007, was an increase (not of the same magnitude as the 2004 fall) in intraday rate volatility associated with the global market turbulence. Timing evidence around these shifts supports the hypothesis in Angelini (2000) that banks respond to a reduction in intraday rate volatility by trading later in the day, as the market risk implications of doing so are reduced.

The empirical analysis in this paper is performed on a transaction-level dataset on unsecured overnight transactions in the sterling interbank market. The data are obtained from payments data using a method that follows Furfine (1999). We estimate timing shifts using non-parametric methods tailored to irregular spacing of data. A GARCH model is used to quantify how intraday rate volatility has evolved over time, we perform a Bai and Perron test to identify structural breaks in the volatility series. Difference in difference estimation is used to quantify changes in timing caused by the introduction of reforms, or significant changes in intraday rate volatility.

The impact of reserves averaging as a tool for controlling the behaviour of the overnight rate has been examined in detail in the academic literature, see for example Poole (1968), Bartolini, Bertola and Prati (2001, 2002), Clouse and Dow (2002) and Whitesell (2003). In addition MacGorain (2005) has examined the implications of the precise form of reserves averaging adopted by the Bank of England. However, to our knowledge there has not been a published study specifically examining the impact of reserve averaging arrangements on banks' daily liquidity management. Demonstrating this effect will be of benefit for policymakers when they consider the optimal design of monetary policy implementation arrangements.

The remainder of this paper is structured as follows: the following section describes in more detail the recent reforms to the Bank of England's monetary policy implementation framework; Section 3 outlines the hypothesis that will be examined in this paper; Section 4 describes our dataset and how it was obtained; Section 5 presents our key empirical findings; Section 6 concludes.

2 STERLING MONEY MARKET REFORM

The aim of this paper is to analyse the impact of recent changes to the sterling monetary policy implementation framework, on banks' ability to manage their sterling liquidity. Therefore it is necessary to outline the key changes of the money market reform programme. The Bank of England's framework for its operations in the sterling money markets is designed to implement the Monetary Policy Committee (MPC)'s interest rate decisions while meeting the liquidity needs, and so contributing to the stability of, the banking system as a whole.[3] In order to reduce volatility in

[3] See www.bankofengland.co.uk/markets/money/publications/redbookjan08.pdf for a full description of the Bank of England's framework for its operations in the sterling money markets.

overnight rates and thereby bring them more in line with Bank rate, the Bank of England embarked on a reform of its sterling money market operations. The Bank's review began in 2003, and following a full consultation of all interested parties, the new framework was launched by the Bank on 18 May 2006.[4]

The first pillar of the framework, which will be our focus in this paper, consists of a system of voluntary remunerated reserve accounts with a period average maintenance requirement. Reserve accounts are current accounts held with the Bank of England that are remunerated at the official Bank rate. At least 2 days prior to the start of a maintenance period (the period between the MPC's monthly interest rate decisions, MPC decision day is the first day of each maintenance period) banks set a target balance that they intend to hold on their reserve account during that maintenance period.[5]Provided that a bank's average overnight balance on its reserve account over the maintenance period is within the pre-advised target range (which was set at $\pm 1\%$ when the framework was introduced) around the target the bank set at the start of the period, then these balances are fully remunerated at Bank Rate. Failure to remain within the target range is penalised through interest penalties; any excess reserves above the top of the range or shortfall of reserves below the bottom of the range are charged at Bank Rate and deducted from the interest paid. Overdrafts on reserve accounts on individual days during the maintenance period are charged at twice the official Bank Rate.

The reserves averaging mechanism is intended to allow banks to run their reserve balances up or down in response to changes in market interest rates. Arbitrage should smooth overnight market interest rates so that they do not deviate materially from the rate expected to prevail on the final day of the monthly maintenance period. Averaging is also intended to prevent banks from needing to immediately access the interbank market to offset a shock to their net payment flows. One implication of the averaging approach is that the flexibility available to banks to adjust reserve holdings to absorb a liquidity shock declines as the maintenance period progresses, because fewer days remain to offset any deviation away from target.

The second pillar of the reform, standing facilities, allow banks unlimited on demand access to standard deposit and (collateralised) borrowing facilities throughout the banking day, thus increasing

[4] The Bank of England implemented some relatively minor technical changes to its sterling operations on 14 March 2005 (see www.bankofengland.co.uk/publications/news/2005/014.htm for full details). Our data suggests that no significant change in behaviour in overnight markets occurred as a result of these changes therefore we do not attempt to study them in detail.

[5] The Bank has set reserves target ceilings for each scheme member as the higher of £1 billion and 2% of its sterling eligible liabilities.

further banks' flexibility by providing liquidity insurance. Standing lending and deposit facilities are available to eligible UK banks and building societies but carry a penalty relative to the official Bank rate of ±100 basis points. On the final day of the maintenance period, this penalty is decreased to ±25 basis points, thereby facilitating a rate-setting function, setting a narrower corridor for market rates.

The third and final pillar of money market reform is the Bank's changed use of open market operations (OMOs). The purpose of OMOs is to provide to the banking system the amount of central bank money needed to ensure that the banking system can achieve its aggregate reserves target over the maintenance period. The Bank's earlier programme of daily OMOs offering two-week money was replaced by weekly repo operations (every Thursday) lending funds for one-week maturity. Additionally, a routine overnight fine-tuning operation is conducted on the final day of the maintenance period. On the days when the MPC makes scheduled interest rate decisions, the Bank undertakes its weekly OMO at 12.15 pm, in order to follow the MPC's noon announcement. On days when there are no scheduled interest rate announcements, the Bank undertakes its weekly OMO at 10 am.

Another important impact of the reforms was to significantly increase the number of institutions having access to an account at the Bank of England. Prior to the reforms, only settlement banks (who were direct members of payment systems settling across accounts at the Bank of England) were eligible to have such accounts. Following the reforms a significant number of non-settlement banks became reserve scheme members, and a further group became standing facilities participants without taking up the offer of a reserve account (at the launch of the reforms there were 41 reserve scheme members and 58 standing facilities participants).

In the second half of 2007 some further changes were made to the implementation framework as a result of turbulence in the sterling money markets. Following two well publicised incidents in late August 2007, where significant media interest was generated when daily data released by the Bank of England revealed that the standing deposit facilities had been utilised the previous day, banks became reluctant to use this facility. Prior to the turbulence banks had been comfortable using the standing deposit facility when required (typically due to an unexpected liquidity shock late in the day, e.g. a failed payment) giving them an extra degree of flexibility over their liquidity management.

On 13 September in its weekly OMO the Bank of England lent an additional £4.4Billion (25% of the aggregate reserves target for the current maintenance period) because overnight interest rates had remained higher than normal relative to Bank Rate for some time. As this additional lending took place during a maintenance period the target range was widened from ±1% to ±37.5% to enable banks to accommodate the additional funds on their reserves accounts without missing their targets.[6] The range was further widened to ±60% on 18 September to accommodate an injection of a further 25% of extra reserves. Prior to the start of the following maintenance period on 04 October the Bank of England announced that the target range would be ±30% for the period.[7] The target range remained at this level for the remainder of our data period.

3 CONCEPTUAL FRAMEWORK

A liquidity manager has an important role to play in ensuring that their bank is able to meet its payment obligations in a currency as they fall due. They start each business day with a forecast of what payments they expect to make and receive in that currency, and the net funding requirement arising. This forecast is subject to significant sources of uncertainty. During the course of the day trades will be agreed in other parts of the bank that require same day settlement, customers (including other banks who are using the bank as their correspondent) will notify them of payments they would like to make or expect to receive, intraday margin requests will arise and payments to and from other banks may fail to settle as expected. As the day progresses, the uncertainty around their forecast liquidity needs will diminish, although ultimately it is only at the end of day when the payment system closes that the final position can be known with certainty.[8]

At the same time, the liquidity manager faces another significant source of uncertainty, about the rate at which their net liquidity position can be squared-off in the overnight interbank market. If they wait until the end of the day to access this market, then they will have certainty about their payment flows on the day, and hence about the amount they need to lend or borrow. However they face the possibility that the overnight rate may have moved against them during the course of the day, and they also risk an adverse rate movement if they try to transact in large size at the end of the day. Therefore, volatility in the overnight rate encourages liquidity managers to attempt to manage down their expected net positions earlier in the day, despite this requiring them to trade at a time when they are still uncertain about their precise payment flows.

[6] See www.bankofengland.co.uk/markets/money/documentation/statement070913.pdf for full details.

[7] See www.bankofengland.co.uk/markets/money/documentation/statement071002.pdf

[8] Indirect evidence on the importance of this process of information gathering to predict liquidity needs can be found in Arnold et al (2008). This examination of payment flows in the FedWire system finds that a significant proportion of daily flows are made late in the day once the closure of other important payment systems (CHIPS and DTCC) provides greater certainty about liquidity needs. This suggests payment flows are being delayed until liquidity managers are confident of their ability to fund them.

The interplay of these two sources of uncertainty is explored in Angelini (2000). The author uses a comprehensive dataset of trades in the Italian unsecured overnight market to investigate how the timing of loan transactions changes on days where volatility is predictably higher than normal. The analysis exploits the well-founded observation in a number of markets (see for example Bartolini and Prati, 2004) that where reserves averaging arrangements are in place, rate volatility is significantly higher on settlement days (the final day of the averaging period) than on non-settlement days. By demonstrating empirically that trading in the Italian overnight market shifts earlier in the day on settlement days, Angelini finds support for the simple model developed in his paper, which predicts that the intraday timing of overnight loan activity will be influenced by the volatility of overnight rates.

The hypothesis that we wish to test in this paper, is that the introduction of reserves averaging will have enhanced banks' ability to manage their daily sterling liquidity needs. Prior to the introduction of reserves averaging banks had strong incentives to square-off their balances on the Bank of England accounts to zero at the close of business every day because excess balances retained on these accounts were unremunerated, while any residual overdraft incurred a severe penal rate of interest. Provided a bank has targeted a positive balance on their reserve account at the start of the maintenance period, the introduction of reserves averaging gives them more flexibility in managing their daily liquidity needs because in addition to recourse to the interbank market, they now have the ability to absorb unexpected fluctuations in their liquidity needs on their reserve account.

We expect this increased flexibility to manifest itself through a shift in the timing of banks' interbank activity in the overnight unsecured market. Specifically we expect to see banks transacting in this market later in the day, taking advantage of their additional flexibility by delaying their final decision on the quantity of funds they wish to lend or borrow in the market to manage their reserve account position. We expect this delay to be most significant on days near the beginning of the maintenance period when banks have maximum flexibility to absorb shocks on their reserves balances.[9] By delaying trading banks are able to act with greater certainty about their net payment flows on the day. The remainder of this paper documents how we have tested this hypothesis using data on the timing of overnight loan flows in the sterling interbank market.

[9] In principle the possibility exists that the introduction of reserves averaging could manifest itself in a significant reduction in the frequency with which banks have recourse to the interbank market to manage net end of day liquidity needs. However, discussion with market participants indicates that in practice recourse to the interbank market has not significantly fallen in frequency, rather banks prefer to square-off their holdings (albeit less precisely) each day, preserving flexibility in case it is required in a subsequent day in the maintenance period.

4 DATA

4.1 Overnight Loans

We obtain a dataset of sterling overnight loan payments observed flowing through the CHAPS large-value payment system during the period January 2003 to February 2008. Our dataset contains transaction-by-transaction data on the values, rates and timings of loans transacted across CHAPS, and the identities of the banks sending and receiving payments. This information has been extracted from data on CHAPS payment flows using a method developed in Furfine (1999) which identifies pairs of payments made in CHAPS on consecutive days associated with the advancement and repayment of unsecured overnight loans. An algorithm is used which looks for payments from bank A to bank B on day t that are slightly larger than round valued payments from B to A on day $t-1$. The intuition is that loans are made in round value amounts and the slight difference in payment value accounts for the interest repayment on the loan. The implied interest rate can be calculated by comparing such pairs of payments. Following Demilrap et al. (2004) we adopt a refinement to the Furfine methodology by designing our algorithm to examine whether the implied interest rate could have plausibly been a quoted market rate, that is, whether it is in units of basis points or half basis points. A fuller description of the algorithm used can be found in the Appendix.

Our resultant data set forms the basis of our analysis for the remainder of this paper, allowing us to observe values, volumes, timings and interest rates of overnight loans made between banks across CHAPS. Table 1 displays some basic summary statistics for this dataset.

Observing loans settling in CHAPS means that timing observations will usually be limited to the times in the day when CHAPS is open (from 06:00 – 16:20 on a normal day). This period corresponds to the time during which the vast majority of trades in the overnight unsecured market are transacted. On occasions where a CHAPS bank, or the central system itself, has suffered from operational problems during the day, it is possible for this to delay payment flows in the system and for CHAPS operating hours to be extended. In practice however, disruptions due to operational outages do not have a significant impact on the timing of payments in the system, for example the aggregate length of all operational outages suffered by CHAPS members in 2007 was equivalent to an average of 22 minutes per member per month.[10] We exclude from our dataset loan flows occurring after the scheduled close of the CHAPS system.

We are not able to observe directly the time at which overnight loans are agreed. Rather our data indicates the time at which each loan trade is settled across CHAPS. There will inevitably be a

[10] See Bank of England (2008) page 10.

time lag between trade and settlement; in general we expect that this time lag would be of the order of seconds rather than hours, as banks' internal payment systems are generally highly automated, meaning the processing required to go from trade capture to generation of payment instructions and submission of those instructions to the central system can take place without delays due to the need for human intervention.

The key exception to this assumption would be if banks' submission of loan payments in CHAPS were subject to deliberate delay. Where intraday liquidity is costly to obtain, this provides incentives for participants in real-time payment systems to delay outgoing payments in an attempt to fund their payment activity using incoming payments as a source of intraday liquidity. Theoretical papers examining the incentives to delay payments include Kahn and Roberds (2001), Bech and Garratt (2003) and Buckle and Campbell (2003). Empirical studies by McAndrews and Rajan (2000) and Arnold et al. (2008) found evidence of significant payment delay in Fedwire, with a very high proportion of total payment flows occurring in a short period of time towards the end of the day. Therefore it is unsurprising that a recent analysis of the timing of overnight loan flows in Fedwire (Bartolini et al, 2008) finds evidence that banks systematically delay loan payments.

Studies have found little evidence of significant payment delay in the CHAPS system, see for example Becher et al (2008). This is thought to be a consequence of banks facing very low opportunity costs of obtaining intraday liquidity in sterling due to, *inter alia*, the Bank of England's policy of providing free (but collateralised) intraday liquidity, and the design of prudential liquidity regulation in the UK which makes the effective opportunity cost of pledging collateral intraday low for most CHAPS banks. Therefore we assume that delay does not have a significant impact on our timing data. In any case, as this study examines changes in the timing of payment flows across our sample, the presence of delay would only introduce bias if the level of delay had changed significantly during the period under investigation.

CHAPS currently only has 16 direct members, including the Bank of England and CLS bank, with a much larger number (several hundred) of banks being indirect participants making CHAPS payments via a correspondent bank who is a direct member of the system (this arrangement is known as tiering).[11] Where an indirect participant transacts an overnight loan with their correspondent bank, or with another customer of that correspondent, this transaction would settle across the books of a settlement bank (internalised settlement) without being submitted to the CHAPS system and therefore would not be captured in our dataset. The tiered nature of CHAPS membership means

[11] It should be noted however, that a lot of the larger banks who access CHAPS through a correspondent do hold reserve accounts at the Bank of England and therefore can still benefit from reserve averaging in enabling them to square-off their end of day position with their correspondent bank.

that missing data due to internalisation could comprise a significant fraction of all trade in the overnight market.[12] However there is no reason to believe that the composition of internalised flows will have altered systematically across our sample.

As a robustness test on our method of obtaining our sample of overnight loans, we compare the aggregate daily trading volumes and interest rates in our data against Sterling Overnight Index Average (SONIA) data collected by the Wholesale Market Brokers Association (WMBA).[13] SONIA is the weighted average rate to four decimal places of all unsecured sterling overnight cash transactions brokered in London by WMBA member firms between midnight and 4.15pm with all counterparties in a minimum deal size of £25 Million. The WMBA also publishes daily aggregate trading volumes reported by their members. The composition of this dataset might be expected to differ from the CHAPS dataset for two reasons. It is not affected by internalised settlement, but unlike CHAPS data it does not capture activity in the non-brokered market.

The top panel of Figure 1 shows that aggregate trading volumes in the CHAPS dataset are similar to those in the brokered data, although CHAPS volumes are slightly higher in the later part of the data period. This suggests that the portion of the market omitted from the CHAPS data due to internalisation, is slightly smaller than the portion omitted from the broker data due to it not capturing the non-brokered segment of the market. The bottom panel of Figure 1 demonstrates that the average value-weighted daily interest rate calculated from CHAPS data, tracks the same figure calculated from the WMBA data very closely (indeed the two lines are so close it is difficult to separate them in this figure). The almost perfect correlation of daily rates in the two samples, and the similarity of daily volume figures, indicates that our dataset is representative of the sterling unsecured overnight market.

4.2 Reserves Holdings

We examine daily data on banks' reserves holdings to examine the extent to which they are allowing their reserve holdings to fluctuate significantly away from their target balance. Let denote the target

[12] Precise figures are not available, but we understand that perhaps 20-30% of all CHAPS payment flows are internalised on the accounts of correspondent banks. Therefore it might be expected that the proportion of overnight loans being internalised and therefore missing from our dataset is of the same order of magnitude.

[13] This data can be found at www.wmba.org.uk/indices.php

set by bank k in period j, and the reserves balance held by bank k on day i.

$$D_{nj}^{k} = \frac{\frac{\sum_{i=1}^{n} B_{ij}^{k}}{n} - T_j}{T_j} \tag{1}$$

denotes the deviation of bank k from their target balance as a proportion of their target on maintenance period day n in maintenance period j.

Figure 2 shows how the daily standard deviation of this measure has evolved over the period since the introduction of reserves averaging. At the start of each maintenance period there is a significant deviation from target, demonstrating that banks do indeed take advantage of the additional flexibility offered by reserves averaging. Deviations decline sharply as the period progresses, as would be expected due to the cumulative approach used to calculate this measure. The intra-period decline is clearly less marked following the broadening of the target ranges in September 2007, suggesting that banks took advantage of the loosening of constraints by deviating further from target.

4.3 Intraday Timing of Overnight Loans

Since loan data arrives at irregularly spaced time intervals, the time lag between transactions carries vital information about banks timing decisions when agreeing loans. Applying standard econometric methods, which tend to focus on regularly spaced data, to analyse loans data would ignore the fundamental information contained in their time spacing. We therefore use techniques directly tailored to analysing irregularly spaced data, following Engel and Russell (1997).

The time between transactions is the reciprocal of the transaction rate, which is itself a proxy for volume. We are, however, interested in loan values, as funding costs are proportional to the value of a loan. Following Gourieroux et al (1998) value-weighted loan durations are calculated as follows. Assume that we observe on every day a sequence of payments, which are indexed by $n; n = 1, \ldots, N_m$ and the associated payment times $d_n(m)$: The duration between the successive ticks $n-1$ and n is simply the time that expires between two loan observations,

$$\tau_n\left(m\right) = d_n(m) - d_{n-1}\left(m\right) \tag{2}$$

The weighted durations instead represent the time required by a bank to make a fixed value v of payments. Let $v_n(m)$ denote the value paid at time $d_n(m)$. By summing up values of individual payments for a count of $N_t(m)$ payments, the cumulated payments value is obtained

$$V_t(m) = \sum_{n=1}^{N_t(m)} \upsilon_n(m) \tag{3}$$

i.e. the volume paid on day m by t. The value duration $\tau_{val}(t)$ is defined as the time necessary to observe an increment υ of cumulated value.

$$\tau_{val}(t, \upsilon) = \inf .(\tau : V_{t+\tau}(m) \geq V_t(m) + \upsilon) \tag{4}$$

υ is set to £500 Million, therefore our duration measure indicates the time taken for £500 Million to be traded in the overnight market.

Figure 3 plots expected duration conditioned on the time of day that the duration began, using all durations in our dataset. It demonstrates clearly that durations fall (trading intensity increases) steadily throughout the day, with durations being as long at 10,000 seconds at the start of the day, and falling below 300 seconds at the end of the CHAPS day.

Difference in difference estimation is used to quantify changes in the intraday duration profile between different sub periods of our sample. Formally, the duration variation V at time t between a treatment period T and a control period C reads

$$V_{t_i}^{TC} = E_T(D(t_i)) - E_C(D(t_i)) \tag{5}$$

The expected duration at time t is derived from the following specification

$$D_i = f_1(t_i) + error \tag{6}$$

where t_i is the time of day at which the duration at transaction i starts.

4.4 Intraday Rate Volatility

The other key variable required for our analysis is a measure of intraday rate volatility, as theory predicts this will be a key determinant of timing choice. Let R_i be the intra-duration value-weighted interest rate and $\overline{r}_i$ the rate per square root of time i.e. $\overline{r}_i = \frac{R_i}{\sqrt{d_i}}$. A simple model for$\overline{r}_i$ reads:

$$\overline{r}_i = \mu_i + e_i = \mu_i + \sigma_i \nu_i \tag{7}$$

where μ_i stands for the mean, e_i is the mean-corrected return and σ_i^2 is the conditional variance per unit of time.

One may model the mean as a martingale

$$\mu_i = \overline{r}_{i-1} \tag{8}$$

The conditional variance is given by a GARCH(1,1) specification where τ is a constant and e^2_{i-1} the unconditional variance.

$$\sigma^2_i = \iota + \phi e^2_{i-1} + \eta\sigma^2_{i-1} \tag{9}$$

Figure 4 shows how intraday rate volatility varies across the sample.[14] In 2003 and the first part of 2004 intraday volatility is relatively high. It falls significantly around May 2004, and remains generally low until 2007, when a significant increase is seen in the second half of the year. To quantify more precisely what significant shifts in intraday rate volatility are seen in our dataset, we perform a Bai-Perron structural break test on our sample.

The Bai and Perron (henceforth BP) (1998) procedure allows to estimate the timing of (lasting) level shifts in a series. This strategy, which ties the researcher's hands by "letting the data" identify the dates of interest, has the potential to reduce bias associated with choosing "important" events.

This method applies an algorithm that searches all possible sets of breaks and determines for each number of breaks the set that produces the maximum goodness-of-fit. Statistical tests then determine whether the improved fit produced by allowing an additional break is sufficiently large given what would be expected by chance (due to the error process), according to some asymptotic distributions. The WD max is used to investigate if at least one break is present. If there is evidence for one break the method continues to add breaks until the $supLRT(l + 1/l)$ test fails to reject the hypothesis of no additional structural changes at the 5% level or there is no room for more breaks. We allow for heterogeneous and autocorrelated errors as outlined in Bai and Perron (2003). The trimming parameter is set to 15%. This implies a minimal window length of about 6 months.

This identifies that, at the 95% confidence interval, three distinct structural breaks in the volatility series are seen in our sample (see Table 2). The first, and largest, structural break occurred in the period 10-14 May 2004, when volatility fell sharply. Our understanding is that high intraday rate volatilities prior to May 2004 were largely driven by games playing in the overnight market. Banks would attempt to become the dominant lender or borrower of overnight funds on a particular day and then move market rates in their favour. Anecdotal evidence suggests the publication on 07 May 2004 of a consultation paper on the reform of the Bank's operations in the sterling money markets[15],

[14] Summary statistics for both duration and intraday rate volatility can be found in Table 1.

[15] www.bankofengland.co.uk/publications/news/2004/059.htm

combined with bilateral discussions between the Bank and market participants, encouraged banks to move to a more cooperative equilibrium meaning that attempts to corner the market in overnight funds became a less significant source of rate volatility.

The second, and smallest, structural break occurred in the first half of 2005. Intraday rate volatility fell further. The precise timing of the break is not as clear from the test, but we believe the most likely explanation is that the break is due to the interim reforms implemented on 14 March 2005. As discussed in Section 2 some minor technical changes were made to the implementation framework. We do not treat this shift as a move to a distinct behavioural regime in the overnight market as the volatility change is not as significant as the earlier fall in 2004. A final structural break is observed centred on May 2007. The test does not pin down the timing of this break with much precision (indicating it took place within a range of October 2006 – November 2007), therefore we have chosen to assume the break took place on 9 August 2007 when general market conditions worsened in a number of financial markets.

It can be seen that no significant shift in intraday rate volatility is seen at the introduction of reforms in May 2006. This is in contrast to the pattern seen in daily data on the spread between Bank rate and the overnight unsecured rate (shown in Figure 5) which shows a significant reduction following the reforms. This suggests that while the reforms had a significant impact in bringing market rates closer to Bank rate, intraday volatility was largely unaffected. This seems at least in part to be due to the fact that intraday rate volatility had already reduced significantly in 2004.

5 ANALYSIS

The central hypothesis being tested in this paper implies that changes to sterling money market operations and structural shifts in intraday rate volatility would both affect banks' decisions about when to transact funding trades in the overnight market. We identify 4 distinct points within our sample where a significant shift has taken place in either the Bank of England's policy framework, or in the intraday rate volatility observed in the overnight market. We run four experiments, each comparing the impact of one of these shifts on bank's timing decisions. Taken together these results provide a test of our hypothesis that reserves averaging improves banks' ability to do their liquidity management, and that this manifests itself through later trading in the overnight market.

5.1 A significant fall in intraday rate volatility

Our first experiment tests how the significant fall in intraday rate volatility observed in May 2004 affects the timing of activity in the overnight loan market. We compare the intraday profile of durations in the high volatility control period, 10 January 2003 to 11 May 2004, with the profile seen in the lower volatility treatment period prior to the introduction of reserves averaging, 12 May 2004 to 17 May 2006.

The top left panel of Figure 6 displays the duration variations between the control and treatment periods at all points in the day. Recall that a fall in the duration measure at a specific point in the day means that the time taken to trade £500 Million of loans has reduced, implying that trading intensity has increased at this time. The reduction in volatility in May 2004 is associated with trading intensity shifting later in the day, durations are broadly unchanged prior to 10:00, but at least 25% shorter between 11:00 and 16:00, with the greatest shift being seen between 13:00 and 14:00. The evidence implies that banks have taken advantage of the reduction in market risk to shift trading later in the day, to allow them to trade with better information. This supports the Angelini (2000) hypothesis about the impact of rate volatility on the timing of trading in the overnight market.

In interpreting the timing pattern in this and subsequent charts it is important to note that no attempt has been made to control for the trend increase in trading volumes in the overnight market over our sample. It is clear from the results of this experiment that there has been a general increase in trading intensity between the two periods, as for the majority of the day intensity is significantly lower in the treatment period. Our focus here is solely on how intraday timing patterns have shifted across periods. We have not attempted to accurately quantify the magnitude of the timing shift, to do this would require some allowance to be made for the general trend of rising trading volumes seen in the overnight market.

5.2 Introduction of reserves averaging

Our second experiment tests how the introduction of reserves averaging in May 2006 affects the timing of activity in the overnight loan market. We compare the intraday profile of durations in the low volatility pre-reform control period, 12 May 2004 to 17 May 2006, with the profile seen in the low volatility post-reform treatment period, 18 May 2006 to 8 August 2007. The top right panel of Figure 6 shows that the introduction of reforms is associated with trading intensity shifting later in the day. Durations are 10-15% shorter prior to 10:00, largely unchanged in the middle of the day, and then sharply shorter towards the end of the day, being at least 20% shorter from 14:00 onwards. This observation supports our hypothesis that the introduction of reserve averaging allows banks to shift their trading later in the day.

Further support for our hypothesis can be drawn from Figure 7 which is constructed using data from the low volatility post-reform period 18 May 2006 to 8 August 2007. Here the control period aggregates duration data from the last days of each maintenance period (the last 5 days of each period, excluding the final day of the period where timing may be distorted by the fine-tuning OMO operation), while the treatment period aggregates duration data from the early days of each maintenance period (the first 5 days excluding the first day of the period, where timing may be distorted by the announcement of the MPC rate decision at 12:00).[16] A sharp increase in trading intensity is seen after 3pm in the early days of the maintenance periods, with durations being 20% shorter at 4pm. Less variation in durations is seen for the remainder of the day, although it can be seen that in general trading intensity is somewhat higher in the treatment period.

The additional flexibility offered by reserves averaging is greater at the start of a maintenance period, because more days remain to offset a large deviation from target. Therefore the timing impact of reserves averaging would be expected to be greatest in the early days of a maintenance period. The significantly higher intensity of late trading at the start of the maintenance period is supportive of our hypothesis that reserves averaging has the beneficial effect of allowing banks to shift the timing of the funding trades to later in the day, when they have better information about their funding requirements.

5.3 A rise in intraday rate volatility due to a deterioration in credit market conditions

Our third experiment tests how the rise in intraday rate volatility observed around the time of the start of the market turbulence in August 2007, affected banks' timing decisions. Our control period is 18 May 2006 to 08 August 2007 and the treatment period is 09 August 2007 to 03 October 2007. We end our treatment period on 03 October because after this date the Bank of England altered its implementation framework by widening target ranges from ±1% to ±30%. Our decision to include the period 13 September to 03 October in this sample, despite target ranges being wider than ±1% (they were widened to ±37.5% on 13 September and ±60% on 18 September) is due to the fact that these changes were specifically to accommodate an unexpected increase in reserve balances intra-period, and this increase will have reduced banks' flexibility to use the wider ranges to absorb payment shocks on their reserve accounts.

[16] By using a sample of 5 consecutive days at the start and end of each period we avoid any potential bias from day of the week effects.

The bottom left panel of Figure 6 shows that during the turbulence durations are 10-20% shorter throughout the morning and early afternoon, then dramatically shorter around 2-3 pm (almost halving in length), but by contrast are significantly longer in the last half hour or so of the day, when trading is typically at its most intense. This suggests that the rise in volatility caused banks to take a more cautious approach and shift their final overnight funding trades to earlier in the trading day. This shift is likely to be due to a number of factors acting in concert. The direct effect of an increase in intraday volatility would be to incentivise earlier trading to reduce market risk, an increase in banks' aversion to using standing facilities for reputational reasons would have a similar effect, as would a desire to avoid being seen bidding up rates in the overnight market (again for reputational reasons).

5.4 Widening of the target range

Our final experiment tests the timing implications of the Bank of England's decision that in the maintenance period starting on 04 October 2007 target ranges would be widened from $\pm 1\%$ to $\pm 30\%$, this wider target range has applied for the remainder of our sample. Our control period is 09 August 2007 to 03 October 2007 and the treatment period in 04 October 2007 to 06 February 2008. Our data suggests that intraday rate volatility is broadly unchanged across the two periods.

The bottom right panel of Figure 6 indicates that durations are generally longer throughout the day following the widening of target ranges, with the exception of the final hour of the day when durations are somewhat shorter. This implies that a shift of trading until later in the day occurred, consistent with the hypothesis that the widening of target ranges had a similar impact to the introduction of reserves averaging, that is, it gave banks greater flexibility in their liquidity management.

6 CONCLUSIONS

We have examined the impact of structural changes to the sterling monetary policy implementation framework on banking system liquidity management. Our results support the hypothesis that the introduction of reserves averaging in the UK in May 2006 has given banks greater freedom in their daily liquidity management, by enabling them to delay their funding trades in the overnight unsecured market until later in the day, when their requirements are known with greater certainty. The Bank of England's decision in October 2007 to significantly widen target ranges in response to turbulence in the sterling money markets, is also found to have impacted trading behaviour by allowing banks to shift trading later in the day.

We also find evidence that the timing of overnight loan flows varies within each maintenance period. Banks have greatest flexibility towards the start of the period, where more days remain to offset any deviation from target. Trading is shown to occur later on early days in the maintenance period, when compared to days towards the end of the period when the flexibility offered by reserves averaging is not as great.

We explore the impact of intraday rate volatility on the timing of trading in the overnight market. We show that a significant fall in rate volatility induces a similar response to the introduction of reserves averaging, namely a shift of trading activity to later in the day, while an increase in rate volatility has the reverse effect. This lends support to the hypothesis advanced in Angelini (2000), that the timing of overnight trading represents a trade-off between market risk and payment uncertainty. This strengthens the argument utilised in the interpretation of our results, that banks have a preference for conducting funding trades later in the day where conditions in interbank markets allow.

The logical next step to extend this analysis would be to explicitly model the incentives liquidity managers face under a reserves averaging arrangement and compare those to an arrangement where the central bank does not pay interest on overnight balances. This would enable a more rigorous and precise expression of the hypothesis being tested in this paper, and would also potentially allow the implications of different implementation arrangements for liquidity management to be compared. Ultimately this might provide a theoretical framework that allowed a welfare analysis of the impact of reserves averaging on liquidity management to be conducted, something that is not possible with our approach.

Although we are unable to perform a formal welfare analysis there is good reason to believe that greater flexibility in banks' liquidity management processes has a beneficial impact on the stability of the financial system. During times of heightened stress, banks' actions in the interbank market are subject to intense scrutiny. If a bank is perceived to be having difficulty in managing its end of day funding, for example if it is seen bidding up rates towards the end of the day, or approaching counterparties it would not normally trade with, this can cause severe reputational damage. While this is a rational reaction in cases where for credit reasons a bank is genuinely having difficulty finding willing counterparties in the interbank market, it is an unfortunate response if the funding difficulty had been caused by payment shock. Therefore a policy framework that enhances banks ability to absorb payment shocks can make an important contribution in promoting financial stability.

The key contribution of this paper is to highlight the potential importance of well-designed monetary policy implementation arrangements for the banking system's short-term liquidity management, particularly in periods where markets are under stress. We hope our findings will stimulate further work to investigate this issue in more depth. To date, attention has focused almost solely on the implications of the design of such arrangements for the behaviour of overnight rates. This is undoubtedly an important consideration, but the impact on liquidity management, and thus on financial stability, should also be considered by policymakers when they are designing the monetary policy implementation arrangements of the future.

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Appendix: Algorithm used to identify overnight loan transactions from payments data

This methodology follows Furfine (1999). The variables required to construct the dataset are date, time, value, payer and payee.

1. On day t, assume that all payments for round amounts (in increments of £100,000) and of value £1Million or above, are possible 'extensions' of overnight loans.

2. On day $t + 1$, assume that all non-round valued payments greater than £1Million are possible 'repayments' of overnight loans.

3. Calculate the incremental interest value, on day $t+1$ non-round valued payments by either rounding down to the nearest hundred thousand if value is less than £250Million (e.g. (i) 25,985,985 would become 25,900,000) or rounding down to the nearest million[17] if value is greater than £250mn (e.g. (ii) 344,052,400.2 would become 344,000,000), and then subtract these rounded values from the initial non rounded values (giving 25,985,985 - 25,900,000 = 85,985 and 344,052,400.2 - 344,000,000 = 52,400.2 respectively).

4. Calculate the implied interest rate using the incremental interest calculated in step 3 and the corresponding non-round value. In our examples this gives implied rates of (i) (85,985 / 25,900,000)*365*100 = 121.18 %, and (ii) (52,400.2 / 344,000,000)*365*100 = 5.5599%. We classify interest rates as plausible if they fall within a band ±200 basis points around Bank rate.

5. Following Demilrap et al (2004), a further test on the plausibility of interest rates is applied, to verify whether implied interest rates round to full basis point or half basis point amounts (as this is the price loans are usually extended). To allow for rounding error we accept interest rates within 0.01 basis point of our implied interest rate calculated in step 4, i.e. we accept rates of 5.5500, 5.5599 or 5.5501 but not 5.5598 or 5.5502.

6. Match payments day t to corresponding repayments on day $t + 1$ by:

a) matching values – day t values should correspond to day $t + 1$ rounded values calculated in step 3. The implied interest rate should fall within the ±200 bps band and be quoted to within 0.0001 of a whole or half basis point amount;

b) matching payer and payee – a loan extension from A to B on day t should correspond to a loan repayment from B to A on day $t + 1$; and

c) ensuring a payment has not already been matched with another repayment or vice versa

7. The payments which match are classed as loans and repayments.

[17] Rounding to the nearest £1 Million for loans of value >£250 Million is done to avoid errors arising due to one day's interest repayment being for value > £100,000.

Figure 1: Daily Aggregate Volume and interest Rate Series (comparing CHAPS and WMBA datasets)

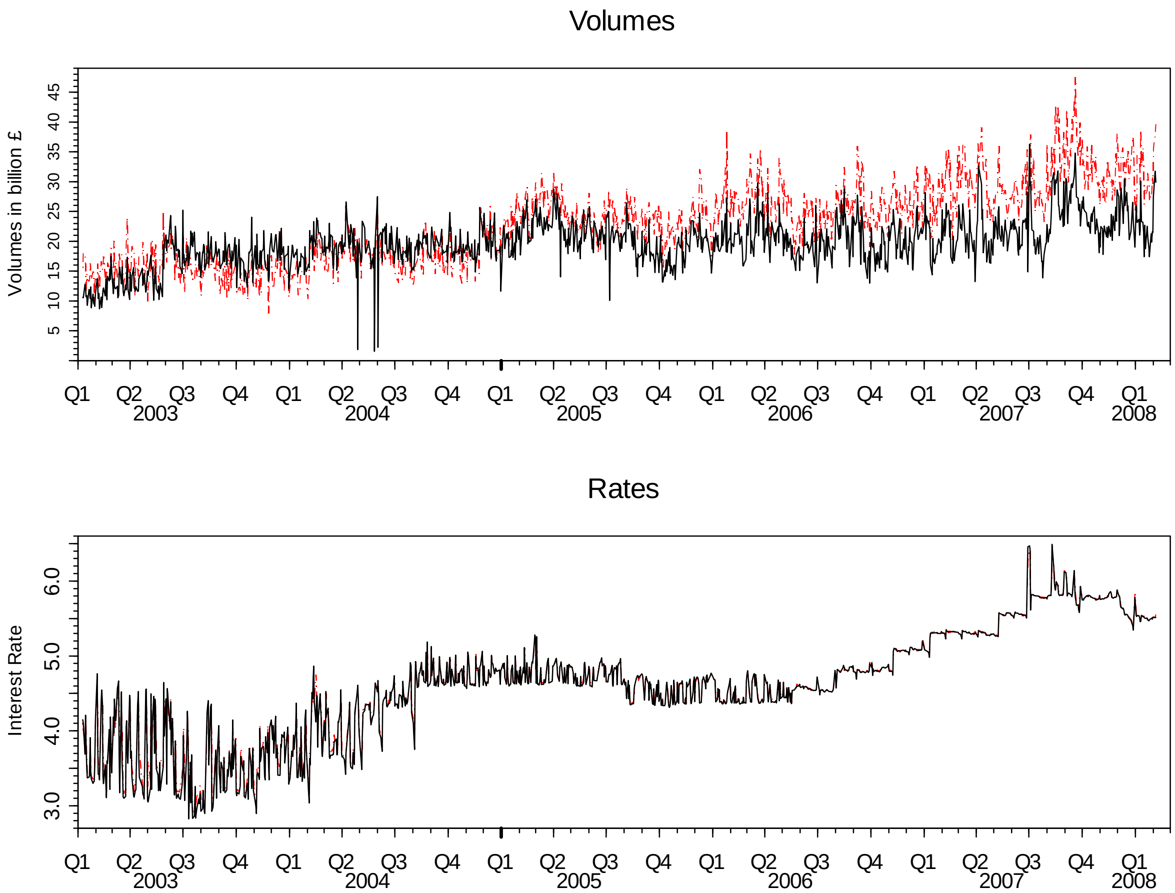

Figure 2: Daily Aggregate Deviations from Reserves Targets

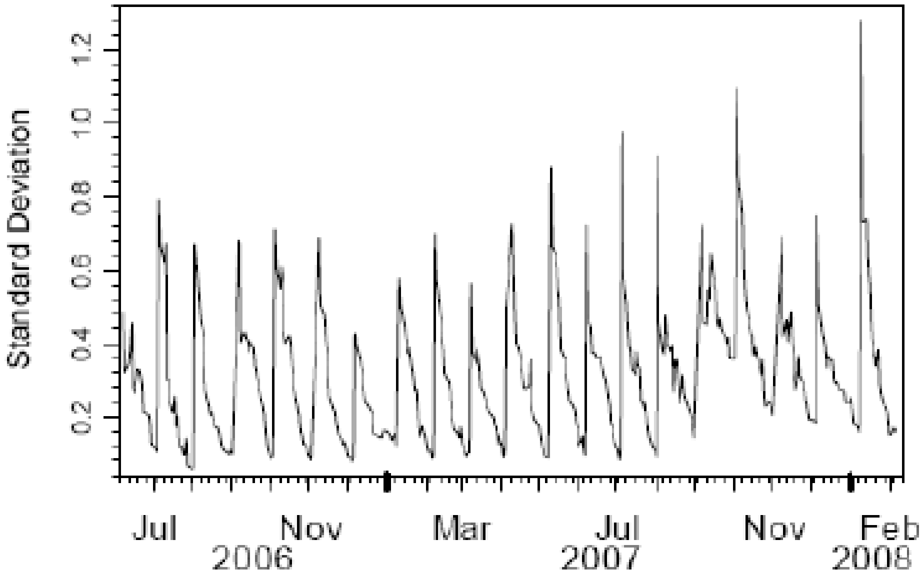

Figure 3: Intraday Duration Profile

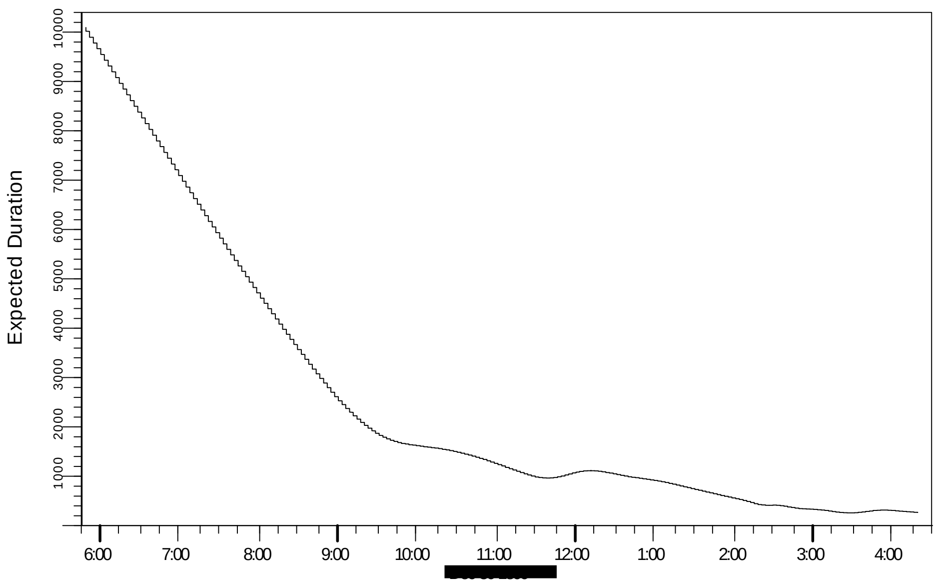

Figure 4: Intraday interest rate volatility

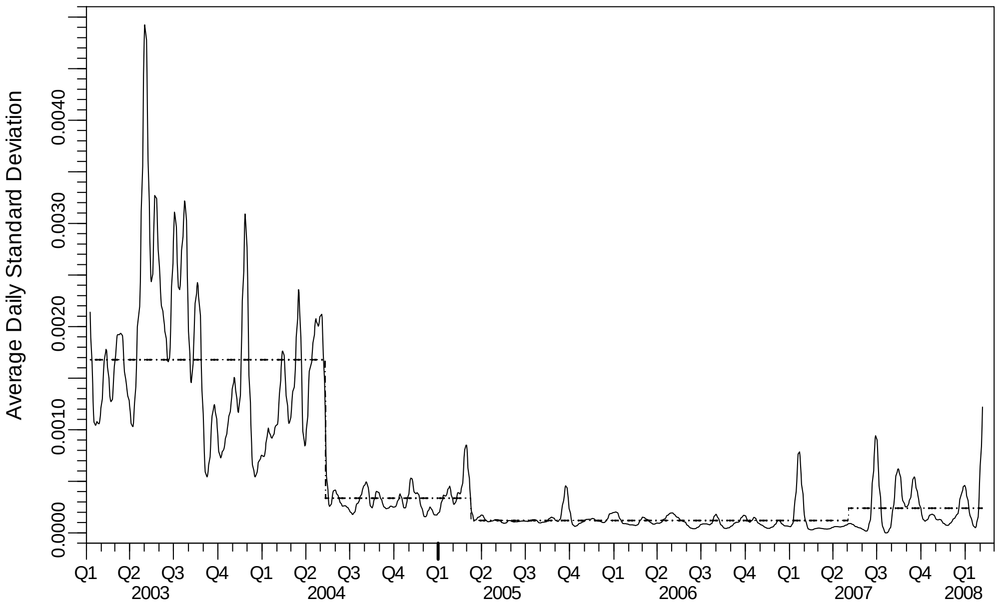

Figure 5: Overnight unsecured rate spread to Bank rate

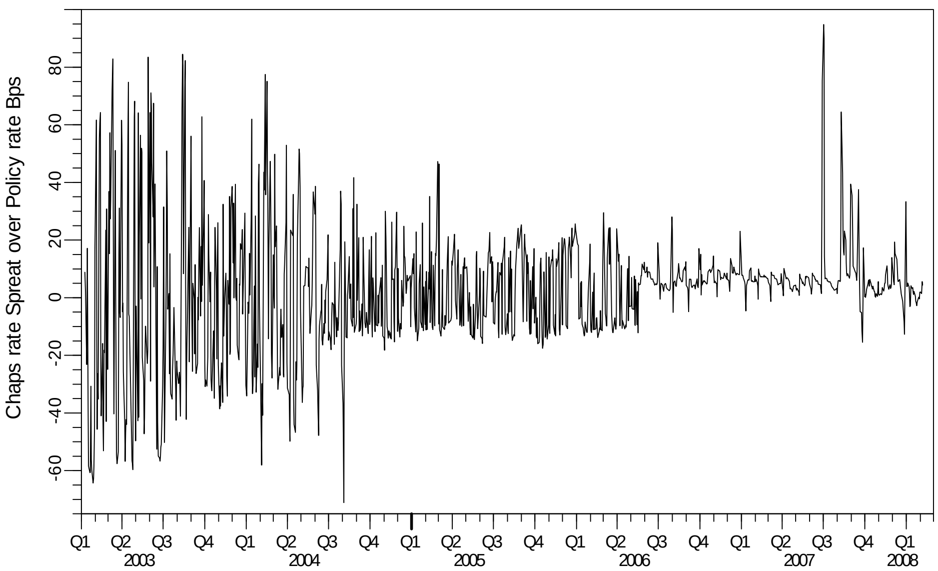

Figure 6: Impact of reforms and volatility shifts on timing of trading

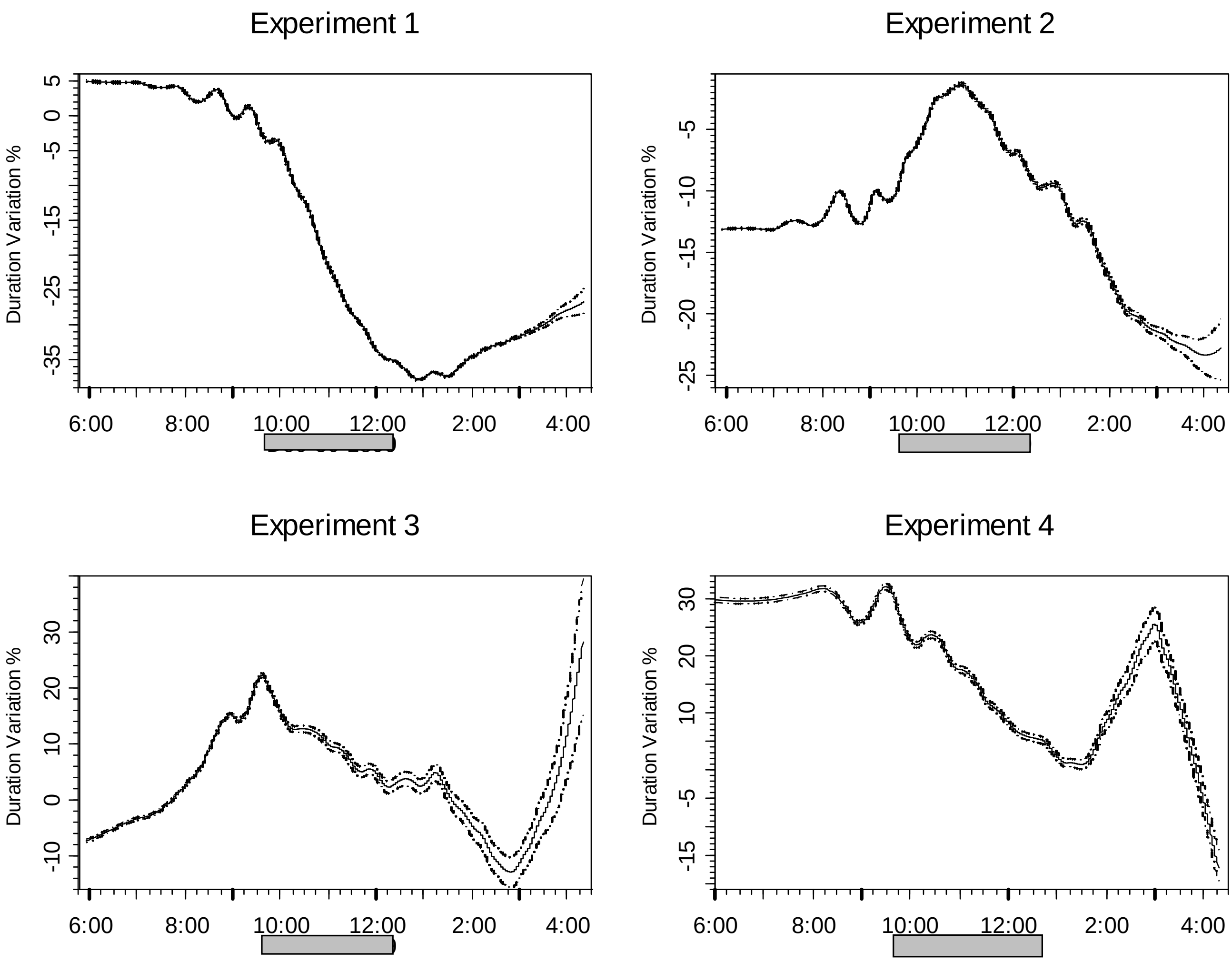

Figure 7: Timing variation within a maintenance period

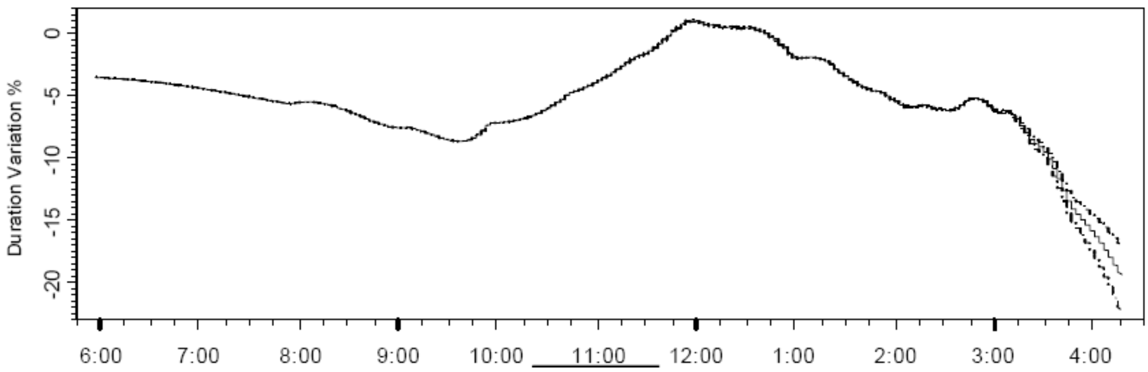

Table 1. Descriptive Statistics

	Nbr Obser.	Mean	Std. Dev.	Min	Max
Loans (£M)	534533	53.5	87.8	1	3000
Duration (seconds)	534533	1083	1637	0	32801
Intra-duration value-weighted interest rate	534533	4.7038	0.672	1.5	7.3
Intra-duration rate volatility	534533	0.0124	0.0185	0.0054	0.8595

Table 2. Bai-Perron Test

Break Date	Confidence Interval 95%	Estimates	Events
		0.0017***	Start Sample
		-0.000023	
12-May-04	[10/05/2004;14/05/2004]	0.0003***	Consultation paper published - 7 May 2004
		-0.00003	"Reform of the Bank of England's Operations in the Sterling Money Markets"
10-Mar-05	[07/01/2005;16/05/2005]	0.00012***	Interim reforms to the Bank's operations in Sterling money markets implemented 14 March
		-0.00002	2005.
04-May-07	[20/10/2006;14/11/2007]	0.0002***	Build up of stories in the news inferring pressure on UK banks from repercussions of American
		-0.00003	sub-prime mortgage crisis.
WDMAX test	SupF(2/1)	SupF(3/1)	
2922.31***	262.65***	108.98***	
	SupF(4/1)		
	11.39		

Note: (***) means significant at the 99% level. Coefficient standard errors in parentheses.