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ABSTRACT

The Overnight Interbank Market: Evidence from the G7 and the Euro Zone*

We study the interbank markets for overnight loans of the major industrial countries, linking the behaviour of short-term interest rates to the operating procedures of these countries' central banks. We find that many of the key behavioural features of US federal funds rates, on which previous studies have focused, are not robust to changes in institutional details, along both cross-sectional and time-series dimensions of the data. Our results indicate that central banks' operating procedures and intervention styles play a crucial role in shaping empirical features of short-term interest rates' day-to-day behaviour in industrial countries.

JEL Classification: E43, E52 and E58
Keywords: central bank operating procedures, interest rates and reserve requirements

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1 Introduction

The interbank market for unsecured overnight loans is the channel of implementation of monetary policy and the anchor for the term structure of interest rates in the world's largest financial markets. A considerable amount of research has focused on the behavior of this market, aiming to assess its efficiency in fostering banks' optimal liquidity management and the scope for monetary authorities to manipulate interest rates at high frequency. Empirical studies have focused on high-frequency patterns in the behavior of interbank interest rates, such as their tendency to be tight on reserve-settlement days and after holidays and week-ends, soft before week-ends, and increasingly volatile towards the end of reserve-holding periods (Campbell, 1987; Barren *et al.*, 1988; Lasser, 1992; Rudebusch, 1995; Roberds *et al.*, 1996; Hamilton, 1996; Balduzzi *et al.*, 1997).

These patterns are relevant for financial analysis because they deny empirical validity to the prediction that short-term interest rates should display no systematic pattern of change within each reserve-holding period. Since such a "martingale" property should be satisfied in a frictionless market with average reserve requirements, statistically significant periodic patterns suggests an important role for frictions such as fixed or transaction costs (Kopecky and Tucker, 1993; Hamilton, 1996; Clouse and Dow, 1999; Bartolini *et al.*, 2001), credit-line arrangements (Hamilton, 1996), bid-ask spreads (Spindt and Hoffmeister, 1988; Hamilton, 1996), or all-encompassing 'liquidity benefits' yielded by reserves (Campbell, 1987; Hayashi, 2000). From the policy viewpoint, the same patterns are relevant because they document scope for central banks to manipulate interest rates at high frequency by controlling the liquidity of the reserve market (Hamilton, 1997; Hayashi, 2000), and give insight on the relative effectiveness of the tools central banks use to keep rates close to target (including reserve requirements, various forms of open-market intervention, and standing facilities; see the studies in BIS, 1997, for extensive discussion).

Until now, however, empirical work on interbank markets has focused mainly on data from the United States. Evidence from other countries is scattered and hard to compare, due to cross-country differences in methodology and data. As a result, received wisdom on the behavior of interbank markets consists of facts and explanations which may or may not be robust to changes in sample and institutional regime. Aiming to fill part of this gap, in this paper we offer a comprehensive analysis of the empirical behavior of very-short-term interest rates in the main industrial countries.

Our goal is to provide a more solid basis for future work on interbank reserve markets by distilling a set of lessons on the general behavior of short-term interest rates.

The study documents that many of the empirical features emphasized by previous research are not robust to changes in institutional environment and/or style of central bank intervention. For financial market researchers, this finding implies that future research may benefit from focusing on the role of institutional details and central bank operating procedures in shaping the behavior of interbank markets. For policy-makers, the implication is that the behavioral features of interbank markets need not be taken as given, but can be expected to respond readily and predictably to changes in institutional arrangements.

The core of our study is a detailed analysis of the daily behavior of overnight interbank rates in the seven largest industrial countries over a period of about sixteen years, and in the Euro zone since its inception. This sample offers considerable variability in regimes originating, in time series, from the institutional reforms implemented in some of our sample countries and, in cross-section, from the coexistence of environments as diverse as those of Canada and the U.K.—which assign no role to periodic reserve requirements—and those of Italy, Germany, and the Euro zone—which have relied significantly on reserve requirements to manage liquidity and stabilize interest rates.

In order to draw lessons from such diversity, we insist on imposing a common econometric specification on all our samples, a feature that we view as the distinguishing trait of our work and its main contribution to the literature. This approach requires us to account in detail for many institutional features and to disentangle the interest rate effects of these features from those of factors such as time-persistent volatility and fat-tailed distributions of interest rates. The reward for this effort is that we can identify a number of interesting patterns in the high-frequency behavior of both levels and volatility of short-term interest rates, some of which were not previously known. Many of these patterns can be related to cross-country differences in the role of reserve requirements, standing facilities, and style of monetary intervention. Other features are less easily traceable to specific institutions or procedures and may motivate future research.

2 The interbank reserve market

The interbank reserve market plays a crucial role in the financial structure and in the implementation of monetary policy of most industrial countries. In this market, "banks" (or, more generally, institutions holding deposits at the central bank) lend unsecured claims on central bank deposits ("reserves") to each other. Most reserve lending has overnight maturity, and we study the behavior of daily transaction-weighted rates charged on such loans. These rates anchor the term structure of interest rates, which central banks aim to stabilize and steer by providing reserves through open market operations or standing facilities that banks may access at their discretion. (See Table 1 for a summary of institutional features in our sample countries.)

In most countries, banks access the reserve market both to clear customer-originated transactions and to satisfy reserve requirements. The latter are often defined on a period-average basis, whereby actual reserves (defined as averages of daily reserves over reserve "maintenance" periods) must at least equal required reserves (defined as a fraction of liabilities, averaged over prior reserve "computation" periods). These requirements play an important role in stabilizing interest rates through two interrelated channels. First, whenever banks hold reserves, they are better buffered against unanticipated liquidity shocks. Second, when the bulk of reserves is held to satisfy requirements defined on an average basis, market interest rates should exhibit a "martingale property:" banks have an incentive to trade reserves, bidding up low rates and bidding down high rates, until the expected opportunity cost of holding reserves—the expected overnight interest rate—remains constant within each maintenance period (aside from negligible discounting, and net of interest paid by the central bank on reserve accounts).

If the martingale property holds, predictable changes in quantities (reserves) should not cause predictable changes in prices (interest rates) within reserve maintenance periods. Interest rates should remain stable even when reserve flows display patterns, such as systematic Treasury payments, or Friday surges in cash withdrawals. Similarly, an anticipated monetary tightening in the middle of a maintenance period should not cause a gap between pre-tightening and post-tightening rates, all of which should rise by the same amount when the tightening is announced if banks can freely allocate reserve holdings over the period.

Empirically, the martingale hypothesis has not fared well. Studies of U.S. data have documented predictable patterns in mean federal funds rates (see Campbell, 1987, Rudebusch, 1995, Hamilton, 1996, and Balduzzi *et al.*, 1997), such as 'high' rates on reserve-settlement days, Mondays, and quarterly reporting dates, and 'low' rates on Fridays. These patterns have found two types of explanation in the literature. First, banks hold reserves not only to satisfy requirements, but also because of the liquidity services that reserves provide. Hence, banks may be reluctant to shift reserve holdings to take advantage of predictable changes in interest rates. Second, market frictions—such as transaction costs, interbank credit limits, window-dressing motives, and imperfect dealer/customer relationships—hinder arbitrage over predictable differences in daily costs of holding reserves. The evidence that we provide below (summarized as 'Lesson #1') documents widespread violations of the martingale property also in international data. Patterns of violation tend to be rather heterogeneous across countries, however. For instance we find ('Lesson #2') that evidence of high rates around settlement is not robust across countries, or even for recent U.S. data, suggesting an important role for central banks' inclination to provide liquidity as a determinant of short-term interest rate behavior, especially around reserve settlement days.

While the martingale hypothesis implies that interest rates *means* should be constant within maintenance periods, it has weaker predictions for the evolution of interest rate *volatilities*. High volatility on settlement days is empirically pervasive in countries with average reserve requirements ('Lesson #3'), and would be consistent with martingale behavior. More interestingly, interest rate volatility may cluster on settlement days or rise gradually over each maintenance period, depending on the market's confidence in the central bank's commitment to smooth interest rate behavior. In particular, if a central bank stands ready to offset all aggregate shocks to liquidity, volatility should be relatively low and constant through the last-but-one day of the maintenance period, spiking up only on settlement day. If instead the central bank is reluctant to offset liquidity shocks fully, then shocks occurring before end-period will exert pressure on current interest rates (upward or downward), causing high volatility to spread from settlement day to previous days (Bartolini *et al.*, 2002), a pattern prevailing in all of our samples with reserve averaging ('Lesson #4').

The behavior of interest rate volatility also reflects constraints imposed by alternative nominal anchors on central banks' ability to target interest rates in response to shocks. In particular, in countries where banks can confidently borrow from (or lend to) the central bank at posted rates in response to shocks, fluctuations in interest rates should be truncated—thus displaying lower volatility—as the target rate approaches rates posted on borrowing and lending facilities. Conversely, interest rate volatility may *rise* as target rates approach rates on marginal facilities when the latter do *not* represent a credible commitment by the central bank to control fluctuations of interest rates—e.g., because the facilities are rationed, or policy rates are 'realigned' in response to pressure on exchange rates and reserve outflows from the banking sector. We find that empirical tests of 'corridor credibility' highlight important features of monetary frameworks in the largest industrial countries ('Lesson #5'). Similarly, and intuitively, we show that short-term interest rate volatility was higher in countries involved in formal exchange rate targeting (Germany, France, Italy, and the United Kingdom in 1990-92) at times when these countries' subordination of 'interest rate smoothing' to 'exchange rate smoothing' was more binding.

Finally, our analysis allows us to focus on the effects of the ongoing international trend towards less stringent reserve requirements. This trend reflects not only central bank efforts to lower reserve ratios and narrow the set of liabilities subject to reserve requirements—so as to reduce the burden of these requirements on banks—but also the market's own evolution. Banks, especially in the United States, have begun to "sweep" balances overnight from liabilities subject to reserve requirement to liabilities free of any such requirement. By comparing regimes with different reliance on reserve requirements—both in cross-section and in time-series—our analysis allows us to focus on the impact that this important ongoing change may have on the behavior of interbank interest rates (see 'Lesson #6' for a summary).

3 Empirical analysis

3.1 The data

We assembled daily data on transaction-weighted rates charged on unsecured overnight interbank loans, as well as policy rates and information on central bank operating procedures, for the seven largest industrial countries and the integrated Euro zone (all rates are measured in percentage terms). The full sample starts in January 1985 and ends in December 2001, but the length of each country's series is limited by availability of homogeneously defined data. The Italian sample begins at end-1990, when the reserve regime with averaging was first implemented and banks' access to central bank credit was reformed. And while the samples for Italy and Germany end in December 1998 (when the Euro zone sample begins), the French sample is truncated in June 1994, when changes in data reporting and Banque de France procedures eliminated almost all volatility in recorded overnight rates. Sample periods, data sources, and other institutional details are summarized in Table 1 (see also Aspetsberger, 1996, and Borio, 1997, for institutional information). All the data are available upon request from the authors.

For each country, we assembled three series of policy rates, chosen on the basis of information drawn from BIS (1997) and from individual central banks. First, we collected the key operational rate used by monetary authorities to anchor short-term interest rates. For brevity, we refer to this rate for all countries as the "target," even though it corresponds to an explicit target rate only in the U.S., Japan and Canada. In our empirical specifications we set the "target" at the realized rate on repo open market auctions in Germany, Italy, and the U.K.; at the minimum accepted auction (bid) rate in the Euro zone; and at an implicit target in France.[1]

The other two rates are those applied on facilities designed to stabilize market rates around target rates. Of course, no bank would borrow or lend to other banks if it could obtain more favorable rates directly from the monetary authority. Hence, official facilities offering unrestricted overnight loans and accepting deposits at given rates should constrain market rates within a corridor.

While completely unrestricted standby facilities are rarely available, it is usually possible to

[1]Our target series for Japan begins in July 1995. While targets were not published until September 1998, they could be partly inferred from statements such as "(BOJ) expects that short-term market rates on average will decline slightly below the ODR (Official Discount Rate)." Accordingly, we set the target rate from July 1995 to September 1998 at the average interbank rate between announcements. (Such imputed targets averaged about five basis points below the discount rate.) The Banque de France never announced a formal target, but intervened since 1986 to steer the interbank rate inside a corridor (Pfister, 1997). Accordingly, we constructed a target series by assuming the target to remain constant at the median market rate of the last 5 days until the median changed by at least 5 basis points and sustained the change for at least 3 days. We use this imputed series, tracking the main discrete changes in the French overnight rate, only in our tests of corridor credibility, not as an explanatory variable of mean market rates. In the Euro zone we set the target to the rate on fixed-rate ECB repo auctions until June 2000 and to the minimum accepted auction rate after that date, when the ECB switched to flexible-rate auctions. For the United Kingdom, target rates are available since January 1985; for Canada, they are available since December 1992.

identify the boundaries of interest rate corridors. In our data, the corridor's *ceiling* is represented by central bank lending rates on standing facilities for Germany, France, United Kingdom, Italy, Canada, and the Euro zone; and by penalty rates on reserve deficiencies for the United States and Japan. We set the corridor's *floor* at rates paid on excess reserves in Italy, Canada, and the Euro zone; at the discount rate in Germany; and at the repurchase tender rate in France. For the United States, Japan, and the U.K., we set the corridor's floor at the natural lower bound of zero, as no more suitable series were available.[2] For some countries, corridor facilities were not in place throughout the whole estimation period; the corresponding series were dummied out when not operational.[3]

3.2 The empirical model

Our empirical model has the form:

$$r_t = \mu_t + \sigma_t \nu_t, \tag{1}$$

where ν_t is a mean-zero, unit variance, i.i.d. error term, and the mean μ_t and standard deviation σ_t of r_t evolve over time according to the models described below. Econometric implementation of (1) builds on the methodology of several recent studies of the U.S. funds market—including Rudebusch (1995), Hamilton (1996), and Balduzzi *et al.* (1997)—and improves on it in some technical respects. For instance, it allows for a different probability distribution for the error term, which lets us capture more easily empirical fat-tailed distributions of interest rates. It also includes a richer set of independent variables, which allows us to test hypotheses on the role of various

[2] Below-market rates on borrowing facilities (discount windows) limit downward movements of market rates only if such facilities are active, i.e., there is an outstanding stock of discount loans that banks can repay (or avoid rolling over, at term), instead of lending to other banks when the market rate falls below the discount rate. This is not the case in the United States, where discount lending has fallen almost to zero since the banking crisis of the mid-1980s, reflecting a stigma of financial weakness attached to banks borrowing from the window (Clouse, 1994; Peristiani, 1998). In Japan, discount borrowing was also too shallow to provide an effective lower bound for market rates.

[3] We did not include, among borrowing costs, non-pecuniary costs faced by banks when incurring a reserve deficiency or accessing a borrowing facility. These additional costs may include closer central bank scrutiny or adverse perception of financial strength by other banks. Because these costs are difficult to estimate, and are likely to be both bank-specific and time-varying, we included only statutory, out-of-pocket costs in our analysis.

institutional details in shaping the dynamics of short-term interest rates. The main novel feature of our analysis, however, is the application of a common econometric methodology to all the reserve markets of the main industrial countries. To ease comparison across countries, we first present a set of "benchmark" regressions, only allowing fixed-effect dummies to differ across countries to reflect different maintenance periods and holidays. We then examine more closely the effects of institutional arrangements on the behavior of short-term interest rates by presenting "extended" regressions, which include country-specific variables and structural breaks.

3.2.1 Mean interest rates

For all days of each maintenance period after the first, we model the conditional mean of r_t as the sum of the previous day's rate r_{t-1}, fixed maintenance-period, weekday, and other calendar effects, and country-specific variables. This format provides an easy test of the martingale hypothesis, which implies that no variable known at time $t-1$ other than r_{t-1} should help explain r_t. Formally, we model $\mu_t = E[r_t]$ as:

$$\mu_t = r_{t-1} + \delta_{m_t} + \delta_{w_t} + \delta_{c_t} + \alpha' h_t \ , \tag{2}$$

where $m_t = T, \ldots, 1, 0$, counts days until the end of the maintenance period at t;[4] $w_t = 1, \ldots, 5$, is the weekday at t; and c_t represents other special calendar days at t (holidays, days before and after holidays, and end of months, quarters, and years). Each of these calendar days is associated with a fixed effect with coefficient δ_{m_t}, δ_{w_t}, and δ_{c_t}, respectively.[5] In addition to these fixed effects, h_t includes country-specific policy rates and sample-splitting dummies, detailed in Section 3.2.3.

[4] We estimated no maintenance period effects for the U.K., where no reserve averaging was in place in our sample; we set these effects at zero in Canada after February 1999, when reserve averaging was abolished.

[5] In the United States maintenance periods always end on Wednesdays, so the coefficients δ_{w_t} and δ_{m_t} are not separately identified. Accordingly, in the charts below we plot the weekly coefficients implied by the estimated maintenance-period coefficients (which are fully identified). In Canada, we can identify the coefficients δ_{w_t} and δ_{m_t} separately from post-February 1999 data, when averaging was eliminated. In all countries other than the United States and the United Kingdom, the maintenance period is linked to calendar months. One linear restriction then suffices to identify both weekday and maintenance period effects (we use $\sum_{w_t=1}^{5} \delta_{w_t} = 0$). In Germany and Italy, end-months almost always fall on the same days of the maintenance period, preventing separate estimation of end-month coefficients, which were omitted from these countries' regressions.

Because of limits on banks' ability to carry reserve imbalances to future maintenance periods (some carryover is permitted only in France and in the United States), r_t need not follow a martingale *across* maintenance periods. Hence r_1 can, in principle, be determined by any variable known at $t-1$. The simplest way to model r_1 is to let its conditional mean follow an auto-regressive process, which we estimated as a function of the changes in r_t in the previous 5 days, in addition to the other variables in (2). Thus, for observations where $m_t = T$ we added $\sum_{i=1}^{5} \phi_i (r_{t-i} - r_{t-i-1})$ on the right-hand side of (2), and a constant term ψ_1 in (3).

3.2.2 Interest rate volatility

We model the variance of the federal funds rate, $\sigma_t^2 = E[(r_t - \mu_t)]^2$, for $m_t = T, \ldots, 1, 0$, as:

$$\log\left(\sigma_t^2\right) - \xi_{m_t} - \xi_{w_t} - \xi_{c_t} - \omega' h_t = \lambda \cdot [\log\left(\sigma_{t-1}^2\right) - \xi_{m_{t-1}} - \xi_{w_{t-1}} - \xi_{c_{t-1}} - \omega' h_{t-1}] + \varepsilon_{t-1}, \quad (3)$$

a specification that allows for fixed calendar effects,[6] denoted by ξ_{m_t}, ξ_{w_t}, and ξ_{c_t}, for maintenance period days, weekdays, and other special calendar days, respectively. As in equations (2)-(3), the vector h_t contains country-specific variables described in detail in Section 3.2.3.

Equation (3) allows for "Exponential GARCH" effects (Nelson, 1991) to capture persistent deviations of the (log) conditional variance from its unconditional expected value. Residuals' analysis led us to an EGARCH(1,1) model for all countries except the United Kingdom, where an EGARCH(2,2) was required. Finally, we modelled the regression error as $\varepsilon_{t-1} = \alpha |\nu_{t-1}| + \theta \nu_{t-1}$, allowing the effect of the variance of positive and negative shocks to differ when $\theta \neq 0$.

3.2.3 Benchmark vs. extended regressions

We perform two regressions for each country. In a first "benchmark" regression we include only the common fixed effects δ_{m_t}, δ_{w_t}, δ_{c_t} in (2), and ξ_{m_t}, ξ_{w_t}, and ξ_{c_t} in (3). In a second "extended" regression we also include country-specific variables h_t in (2) and (3), so as to examine more closely the link between interest rate dynamics and institutional factors.

Among the variables h_t, we first consider the role of policy rates. If policy changes are not fully anticipated at the beginning of the maintenance period in which they occur, or if the martingale

[6] Identifying restrictions on calendar effects are the same as in (2), except that $\xi_0 = 0$ replaces $\sum_{w_t=1}^{5} \delta_{w_t} = 0$. With variances estimated in logarithms, the variance in the last day of the period is then normalized to 1.

property does not hold for any reason, changes in policy rates should help explain changes in market rates. Accordingly, we included changes in target, ceiling, and floor rates—respectively $(r_t^T - r_{t-1}^T)$, $\left(r_t^C - r_{t-1}^C\right)$, and $\left(r_t^F - r_{t-1}^F\right)$, with rates measured in percent—in the mean equation (2), to capture level-shift effects of policy rates on market rates. To capture additional effects of the same policy shifts on volatility, we also include in (3) dummy variables valued at one for days in which either a target, a ceiling, or a floor rate changed.

Second, in all of our countries' variance equations, we included a variable measuring the position of the key operational ("target") rate in the fluctuation corridor for market rates, $z_t = \frac{r_t^T - r_t^F}{r_t^C - r_t^F}$. This specification allows us to test the link, discussed in Section 2, between interest rate volatility and position of target (and market) rates within the corridor. To test the link between interest volatility and exchange rate conditions, we included an index of exchange rate pressure (namely, the squared ERM divergence index) in the variance equation of countries participating in Europe's Exchange Rate Mechanism (ERM): Germany, France, Italy, and the United Kingdom.[7]

Next, we included in h_t a few country-specific dummies, to be interacted with other coefficients in tests of structural breaks. For the United States, we estimated the maintenance period coefficients δ_{m_t} and ξ_{m_t} separately over two subsamples: until July 1998, and after July 1998. We chose this date as a break-point because it corresponds to the Fed's shift to lagged reserve accounting,[8] and because it dominated—in terms of likelihood—alternative break-points we experimented with (such as January 1991, when reserve requirements for nontransaction deposits were eliminated). Fed commentary and our results below, however, suggest that this sample split may capture the effects of the diffusion of sweeps among U.S. banks in the late part of the 1990s, more than those of the shift to lagged reserve accounting. Similarly, in the U.S. volatility equation, we allowed the

[7] The index is defined as the ratio of *actual* to *maximum permitted* spread between a currency's market rate and its ECU central rate. Thus, the index varies between 1 (when the currency is maximally *ap*preciated relative to its central rate) and -1 (when the currency is maximally *de*preciated). The index is squared since the hypothesis is that interest rate volatility should rise when exchange rates diverge from their central parity in either direction. For Italy, the period of ERM participation includes all our sample, except from September 1992 to November 1996; for the United Kingdom, it includes only the period from October 1990 to September 1992.

[8] Effective July 30, 1998, the reserve maintenance period was lagged by 30 days (instead of only two) with respect to the computation period. This change aimed at reducing uncertainty over *required* reserves, although the major source of uncertainty for interest rates—Treasury flows affecting *actual* reserves—was not affected.

coefficient of the position of the target rate in the corridor to break in January 1991. While we chose this date because of the possible changes in volatility associated with the end-1990 reform of reserve requirements, we believe that the significant change we found for this coefficient is more likely to capture U.S. banks' greater reluctance to incur reserve deficiencies in the pre-1990 period than the institutional changes of December 1990. To correct for the extraordinary high variance in rates recorded after the December 1990 reform, we also included a constant dummy in the U.S. variance equation for the two maintenance periods from January 10 to February 6, 1991, in both the benchmark and extended U.S. regressions.

Canada provides the most drastic regime shift in our sample of countries. Effective June 1994, the maintenance period was lengthened and reserve requirements were lowered to zero; averaging was then fully eliminated in February 1999. The only sensible way to capture this comprehensive reform was to estimate the Canadian model separately over two samples, until June 1992 and after July 1994. We dropped completely the June 1992-July 1994 period, where operating procedures were a mixture of the positive-requirement and zero-requirement regimes.

Finally, we included a constant dummy in the United Kingdom variance equation, valued at one after March 1997 and zero otherwise, to capture the effects of changes in Bank of England procedures implemented around this time, aimed at streamlining the implementation of monetary policy and at limiting interbank rates' volatility.[9]

3.3 Estimation

We assumed the innovations ν_t to be distributed as a Student-t, with degrees of freedom estimated to match the fat tails and concentration of small rate changes found in the data. We used a twice-differentiable approximation to the absolute-value function $|\nu_t|$, as in Andersen and Lund (1997, p. 351), by setting $|\nu_t| = |\nu_t|$ for $|\nu_t| \geq \frac{\pi}{2K}$, and $|\nu_t| = \frac{\frac{\pi}{2} - \cos(K\nu_t)}{K}$ for $|\nu_t| < \frac{\pi}{2K}$. We set K=20, but any large K would ensure a very accurate and twice-differentiable approximation to $|\nu_t|$. We then obtained nonlinear maximum likelihood estimates of the parameters by numerical optimization.

[9] In March 1997, gilt repo was added to the instruments used in daily operations—soon becoming the predominant instrument—and banks and securities dealers were added to discount houses as eligible repo counterparties. In June 1998, late lending was significantly liberalized (e.g., previous quotas were essentially eliminated), in a move largely aimed at reducing interest rate volatility.

We did not pursue a general-to-specific model search, by sequentially omitting insignificant coefficients from individual country regressions. We felt that this paper's goal of presenting results as comparable as possible across countries was best served by keeping a variable in *all* country regressions if it was significant in *any* of them.

Clearly, our choice of a rather general empirical specification has drawbacks as well as advantages. In particular, we cannot claim to explain fully what we see in the data: many factors may influence differences in results across countries, and our model accounts for only some of them—mostly those that models of money markets and monetary policy execution have identified as important in shaping the *day-to-day* dynamics of short-term interest rates. For instance, we control for changes in policy rates, but we delegate explaining *why* these changes were implemented to more traditional (i.e., low frequency) models of monetary policy determination. Our empirical strategy, however, conveniently requires few prior restrictions on the estimation. One example of this flexibility is our treatment of maintenance period coefficients: we make no *a priori* assumption on how the length of maintenance periods may influence interest rate dynamics. Even though theory indicates that, after controlling for variables known at market opening, the last day of a four-week maintenance period should be similar to the last day of a two-week period (and to each day of a regime without averaging),[10] our empirical specification refrains from imposing any such restriction on maintenance-period coefficients in the mean and variance equations.

4 Six lessons from the G-7 and the Euro Zone

Complete results of our estimations are presented below, partly in tabulated form, partly in graphical form. Figures 1-4 and Tables 2-3 report results of country-by-country benchmark regression that exclude country-specific variables, h_t, from equations (2)-(3). (The electronic version of this paper, available on the authors' websites, includes Tables A1-A3, where we report the estimates

[10]This conjecture relies on the forward-looking nature of the reserve market (see Bartolini *et al.*, 2002, for a model), which causes banks' reserve-management decisions to depend on current interest rates, accumulated reserves, etc., *and* the number of days to elapse until period-end (which affects banks' uncertainty on end-period reserves and, hence, expected penalties), but not on days elapsed since the beginning of the period (which affect decisions only indirectly, through their cumulative impact on current state variables).

plotted in Figures 1-4.) Results of extended regressions that include country-specific variables are reported in full in Tables 4-8, and some key results are also displayed in Figure 5.

Because of the considerable volume of results generated by our analysis, we organize the discussion around specific hypotheses whose tests yield six main 'lessons.' Additional technical results are summarized as a set of 'other lessons.'

#1. Liquidity effects at the daily frequency are widespread. Under the martingale hypothesis, no variable known at time $t-1$ other than r_{t-1} should help explain the behavior of r_t, a conjecture formally stated as:

$$\{H_0 : \delta_{m_t} = \ \delta_{w_t} = \ \delta_{c_t} = 0 \text{ in the benchmark regressions of Equation (2)}\}.$$

In fact, in our data we find widespread violations of this hypothesis: our samples feature a multitude of predictable patterns in mean interest rates at the daily frequency. These patterns are illustrated in Figures 1 and 2, which report estimates of mean rates by day of the maintenance period and by day of the week, respectively (the first day of the period and of the week are normalized to zero); and in Table 2 for other calendar effects on mean rates.

Specifically, U.S. and German rates display a clear tendency to fall through the maintenance period and rise back at end-period, while in France, Italy, and Canada, rates fall significantly from the first day of the period to the immediately-following days; in the Euro zone, interest rates are on a declining trend over the period, which is, however, statistically significant only in the day-before-last. Also, in the United States, Tuesdays and Fridays are usually soft; in Germany, Thursdays and Fridays are soft; in the United Kingdom, Fridays are soft; in Italy, Wednesdays and Thursdays are soft; in Canada, Tuesdays are soft and Thursdays are tight.[11] The only market displaying little pattern in mean rates over the week or the reserve period is Japan where, however, rates are significantly higher on end-month and end-quarter days than on other days (Table 2). Indeed, rates are systematically higher on such days in most of our countries, displaying a broad tendency to fall back on subsequent days. Rates also tend to fall before three-day holidays and rise afterwards.

[11] Figure 2 plots weekday effects for Canada in the post-February 1999 period when average requirements were abolished and weekday effects could be independently estimated. As Figure 1 shows, in 1994-1999 the weekday profile implied by the maintenance-period coefficients shows a much sharper increase on Thursdays and fall on Fridays.

Longer and shorter holidays also have generally predictable effects, although their signs vary across countries.[12]

Thus, the prediction that interest rates should display no systematic tendency to rise or fall between days in the same maintenance period is generally rejected.[13] This evidence indicates that banks do not arbitrage the opportunity cost of holding reserves across days of the same maintenance period.[14] Previous literature has attributed this unwillingness to market frictions such as transaction costs (Kopecky and Tucker, 1993; Hamilton, 1996; Bartolini *et al.*, 2001), credit rationing (Hamilton, 1996), bid-ask spreads (Spindt and Hoffmeister, 1988; Hamilton, 1996), and periodic window-dressing (Allen and Saunders, 1992). Other studies have emphasized frictions such as the cost of incurring end-of-day overdrafts, which make banks reluctant to open wide positions in the interbank market, for fear of being unable to unwind such positions before period-end (Griffiths and Winters, 1995; Pérez Quirós and Rodríguez Mendizábal, 2000).

Irrespective of its underlying cause, failure of the martingale hypothesis is important because it allows for 'liquidity effects' at daily frequency. Then: i) country-specific features of the payment system may result in predictable patterns in rates; and: ii) there is scope for central banks to manipulate rates at high-frequency, e.g., to smooth the behavior of interest rates, if they so desire.[15]

Given the scope for high-frequency liquidity effects, a natural next logical step would be to trace the source of 'high' or 'low' demand for liquidity on particular days to country-specific features. To

[12] In the case of the Euro zone, the short sample size does not allow us to estimate the effect of the end of the year separately from that of the end of the quarter and the effect of 4-day holidays separately from that of 3-day holidays.

[13] For the United States, our findings are qualitatively in line with those of previous studies, such as Hamilton (1996). Hamilton also estimated a tendency for rates to decline through much of the period, to rise sharply in proximity of settlement, to fall on Fridays, to rise back on Mondays, and to be abnormally high at end-quarters. Very similar patterns were documented by Balduzzi *et al.* (1998) and Rudebusch (1995).

[14] Evidence of systematic patterns in mean rates from the Euro zone must be interpreted with caution. Unlike in our other samples, Euro zone excess reserves are remunerated at a positive, variable rate, equal to the rate realized on the last repo auction. Since mean interest rates can display systematic patterns if the remuneration for reserves displays systematic patterns, then evidence of patterns in mean rates does not, on its own account, provide evidence of imperfect substitutability of reserves across days.

[15] See, for instance, Hamilton (1997, 1998), and Hayashi (2000), for estimates of daily liquidity effects in the United States and Japan, respectively.

our knowledge, explanations have been offered and discussed only in the case of the United States.[16] Cross-country extensions lie beyond the scope of the present paper, focused on characterizing high-frequency empirical interest rate patterns. Our results, of course, may provide a useful starting point for future research attempting to link such patterns to payday arrangements, periodic Treasury flows, and other institutional features specific to each country.

#2. Settlement-day tightness is a non-robust feature of reserve markets. A number of studies of the U.S. federal funds market, including Campbell (1987), Kopecky and Tucker (1993), Griffith and Winters (1995), Balduzzi *et al.* (1998), and Hamilton (1996), have fostered a view that reserve markets are naturally tight on reserve settlement days, when interbank rates appear to be systematically higher than on other days. Evidence of strong demand for reserves at settlement also in other countries (see BIS, 1997) seems to buttress this view.

We tested the hypothesis of no settlement-day tightness, which can be formally stated as:

$$\{H_0 : \delta_0 \leq (\delta_1 + ... + \delta_{T-1})/T\}.$$

International evidence provides very limited support to the above view. We found a pattern of high settlement-day rates, similar to that historically displayed by U.S. data, only in German data (see Figure 1). For these two markets, Wald tests reject the equality between settlement and average non-settlement rates with p-values of 0.000 and 0.015, respectively. In no other country do we find settlement rates to be significantly higher than average non-settlement rates.

In principle, even if banks demand more reserves at settlement than at other times, settlement-day rates need not exceed non-settlement-day rates: the central bank can supply more reserves to match higher reserve demand, and keep settlement rates in line with non-settlement rates, even when the martingale property fails. Indeed, as documented in Bartolini *et al.* (2001) and discussed below, the Fed supplies the market with the bulk of its reserves in the last few days of each maintenance period.

In practice, central banks rarely stand ready to inject or drain reserves perfectly elastically, in response to aggregate liquidity shocks, to maintain settlement-day rates in line with non-settlement-

[16] For instance, soft reserve demand on Fridays and the associated bounce-backs on Mondays have been attributed to the triple counting of reserves for U.S. banks on Fridays, while tightness around end-quarters has been attributed to banks' attempts to boost the cash component of their balance sheet for quarterly reports.

day rates. The Bundesbank's approach to liquidity management, for instance, allowed rates to rise on settlement days, presumably in order to induce banks to manage liquidity prudently before settlement. The Fed never explicitly pursued a similar strategy. Nonetheless, the evidence that we present is that, historically, it only partially accommodated banks' high demand for reserves on settlement days, letting the funds rate rise somewhat, systematically, on these days.

We believe that this evidence points convincingly to central banks' 'style' of intervention—e.g., their inclination to provide (or not) liquidity around reserve settlement days—as an important factor in explaining failures of the martingale hypothesis. While previous literature has pointed to the importance of trading costs and other market frictions in explaining these failures, one might expect such frictions to be quite similar across industrialized countries. Hence, they are unlikely to differ significantly between United States and Germany on the one hand, and the other countries on the other. They are also not likely to have changed significantly between our early and late U.S. samples which, as discussed below, display significantly different interest rate behavior. Conversely, central banks' operating procedures are quite heterogeneous across countries and over time (see Table 1). For this reason, we think future money-market research could fruitfully focus on such institutional features and on their interactions with market frictions, rather than on the latter in isolation.

#3. High settlement-day volatility is a robust feature of reserve markets. We examined the conjecture that in countries assigning a significant role to periodic reserve requirements (that is, in all our sample countries except post-1994 Canada and the United Kingdom) settlement-day rates should be more volatile than non-settlement-day rates. Formally, we tested:[17]

$$\{H_0 : \xi_0 \leq (\xi_1 + ... + \xi_T)/T\}.$$

We found that in all these countries, as well as in pre-1992 Canada, settlement-day rates were always more volatile than (average) non-settlement-day rates (see Figures 3 and 5), with Wald tests strongly rejecting the null of equality between the variance on settlement days and the average variance on non-settlement days (p-values were always smaller than 10^{-5}).

[17] Recall that in our notation the subscript m_t in ξ_{m_t} counts days between t and the end of the maintenance period. Thus, ξ_0 measures the effect of settlement day on volatility, ξ_1 measures the effect of the day before settlement, and ξ_T measures the effect of the first day of a maintenance period with $T+1$ days.

This is a fairly unambiguous empirical property of interest rate volatilities, consistent with the predictions of most models of liquidity management by banks subject to periodic reserve requirements (see, for instance, Spindt and Hoffmeister, 1988, and Bartolini *et al.*, 2002). In these models, banks unable to carry reserve imbalances over to future maintenance periods will scramble on settlement day, either to make up reserve deficiencies or unload excess reserves, and bid interbank rates up or down until the opportunity cost of holding reserves equals the expected penalty charged on reserve deficiencies. An interesting, though indirect, confirmation of this theoretical insights is that the weakest evidence of high settlement-day volatility is found in France, the country with the most generous carry-over provisions among those with periodic reserve requirements in our sample.

#4. Settlement-day volatility effects, when present, tend to spread to previous days. A related point confirms the role played by central banks' intervention style in shaping the high-frequency behavior of interest rates. If banks expect aggregate liquidity shocks to be less than fully offset by official injection (or drain) of reserves by end-period, then shocks occurring *before* end-period will correlate with same-sign imbalances *at* end-period, and hence exert pressure (upward or downward) on current interest rates. As a result, high volatility of interest rates will spread from settlement days to previous days. Conversely, if the central bank stands ready to offset all aggregate shocks to liquidity before end-period, interest rate volatility should be rather small and constant through the last-but-one day of the period, spiking up only on settlement day. Thus, the time profile of interest rate volatility provides information on the central bank's commitment to interest rate smoothing, as perceived by participants in the interbank market.[18]

To assess this view, we tested the hypothesis that the n^{th}-last maintenance period day's volatility parameter was no greater than the average volatility in previous days:

$$\{H_0 : \xi_n \leqslant (\xi_{n+1} + ... + \xi_T)/(T - n)\}.$$

We found that all countries displaying a significant rise in settlement-day volatility also display greater volatility on one or more immediately previous days than on average over the rest of the period (Figure 3 and Table 5). In particular, Wald tests show that in Germany each of the seven last days has a significantly greater variance than the average of previous days. This is the case for

[18] See Bartolini *et al.* (2002) for a model and application to the U.S. funds market.

the last five days in Italy and the Euro zone, and for the last two days in the United States, Japan, and pre-1992 Canada. In France, where we estimate a rather unstable pattern of volatilities, only the last day has a significantly greater variance than previous days, but there is a clear trend rise in volatility from mid- to end-period.

To interpret this evidence, it is useful to distinguish between central banks that have adopted procedures which make it difficult to provide liquidity on an ongoing basis, from central banks that—at least in principle—could intervene daily to prevent volatility from spreading to pre-settlement days. In the first group, the central banks of Germany and of the Euro zone *pre-committed* to infrequent intervention, normally at the weekly frequency; hence, they were often unable to offset late shocks to liquidity, simply because no intervention date was scheduled before end-period. By contrast, the U.S. Federal Reserve and the Bank of Canada have adopted a schedule of normal daily intervention; hence, only their unwillingness or inability to completely offset liquidity shocks can rationalize high volatility spreading to non-settlement days. The intermediate cases were those of Italy, where operations normally took place on a weekly basis but could be intensified in response to large, unforeseen shocks; and France where, during the sample period, operations were conducted according to a flexible once- or twice-weekly schedule.

#5. Patterns in interest rate volatility reflect the choice of intermediate policy target. In countries that subordinate domestic (interest rate) targets to external (exchange rate) targets, interest rates can be expected to display greater volatility during periods of exchange rate pressure. Policy interest rates are often raised to defend exchange rates, and standing facilities are rationed in times of exchange rate pressure, to dissuade banks from taking funds abroad; greater interest rate volatility may also reflect an unusually strong exchange rate, if the central bank finds it difficult to sterilize the effect of capital inflows on the money market. In our estimation, we studied this channel of volatility transmission by including in the variance equation an index of 'exchange rate pressure', measuring the divergence of the exchange rate from its central parity for ERM countries. (This measure is lagged one day to avoid simultaneity problems.) We conjecture that the coefficient β_1 for this variable should be positive, and formally test:

$$\{H_0 : \beta_1 \leq 0\}.$$

To test the hypothesis that the relative strength of the central bank's commitment to interest rate vs. exchange rate stability should affect the behavior of interest rate volatility as interest rates approach rates on marginal lending and borrowing facilities, we included an index of proximity of interest rates to their corridor's bounds in the variance equation of all our samples. In this case, we would expect a negative coefficient β_2 for this variable in countries where domestic objectives prevail (interest volatility falls as the 'target' rate approaches the interest rate corridor's bounds because the corridor is credible); and a positive coefficient in countries where commitment to interest rate stability conflicts with commitment to an alternative (exchange rate) target. Formally, we test:

$$\left\{ H_0 : \begin{array}{ll} \beta_2 \leq 0 & \text{in countries strongly committed to exchange rate stability,} \\ \beta_2 \geq 0 & \text{in countries where such committment is absent or weak.} \end{array} \right\}$$

As regards our first conjecture, we found strong evidence that countries linked in an exchange rate arrangement (Germany, France, Italy, and the United Kingdom from 1990 to 1992) displayed greater interest rate volatility during periods of exchange rate pressure. The coefficient of the squared ERM divergence index was always precisely estimated with the expected positive sign (Table 8), even in Germany, whose currency was mostly subject to upward pressure during this period.

As regards the second prediction (also documented in Table 8), we found volatility to *increase* with target rates approaching the limits of the fluctuation corridor in Italy and France, which historically have subordinated their interest-rate policies to exchange-rate policies, as well as in Canada: in these countries, smoother exchange rate behavior was achieved at the cost of more volatile interest rates. By contrast, we found volatility to *decline* when target rates approached the corridor's bounds in our sample's larger countries—the United States, Japan, and Germany—which have historically emphasized domestic over external anchors. The U.S. coefficient was estimated as greater in absolute value in our late sample, reflecting evidence of less frequent breaching of the interest rate corridor in this sample.[19]

#6. Lower required reserves are associated with weaker periodicity in interest rates, but no apparent effect on overall volatility. To examine the impact of recent institutional

[19] We could not estimate the coefficients for pre-1992 Canada, because of the absence of a target rate in this sample; nor could we for the United Kingdom and the Euro zone, where the spread between the penalty rates and the target rates was essentially constant.

and behavioral development in the U.S. reserve market, we tested for changes in the time profile of U.S. mean and volatility coefficients by allowing for separate profiles of these coefficients in the pre- and post-July 1998 samples. Formally, we tested:

$$\left\{H_0 : \delta_{m_t}^{pre-07/98} = \delta_{m_t}^{post-07/98}\right\} \text{ and } \left\{H_0 : \xi_{m_t}^{pre-07/98} = \xi_{m_t}^{post-07/98}\right\}.$$

These estimates exhibit two interesting patterns (see Figure 5). First, evidence of high settlement rates essentially disappears in post-July 1998 U.S. data: equality between settlement and average non-settlement rates can be rejected with a p-value $< 10^{-5}$ in the pre-July 1998 data, but is accepted in the post-July 1998 data (p-value $= 0.89$). Second, while settlement-day volatility is significantly greater than non-settlement-day volatility in each of the two samples (both p-values are smaller than 10^{-4}), the gap falls significantly in the later period (see Figure 5).

We see two possible reasons for such different behavior between the two samples. The first factor is weaker demand for reserves by U.S. banks in recent years. As documented by Bennett and Peristiani (2001), the recent spreading of sweep practices has considerably weakened reserve requirements for U.S. banks. Clearly, less binding requirements should imply less cyclical behavior of interest rates over the reserve period. (Extreme examples are, of course, Canada and the United Kingdom, where maintenance-related cyclical behavior is absent by definition.)

A different (and complementary) explanation emphasizes supply-side factors. The data indicate that in the pre-1998 sample the pattern of volatilities induced by the Fed's daily interventions was quite similar to that observed in the German and Euro zone samples (where intervention is infrequent and need not take place on the last day of the maintenance period). While this might reflect the central bank's unwillingness or inability to stabilize interest rates in that period, the Fed may more recently have become increasingly prompt in offsetting aggregate reserve imbalances arising during each period, and especially aggressive in providing liquidity on settlement days. Fed intervention data available to us lends support to this view. First, the Fed has increased significantly the frequency of its intervention, from an average of 6.9 days per (ten-day) period before July 1998, to an average of 8.8 days per period after July 1998 (the difference is significant with a p-value $< 10^{-6}$). Also, in recent times, the Fed has provided relatively more reserves in the last days of each maintenance period: in the pre-July 1998 sample, excess reserves rose from a median value of 1.4 percent of required reserves in the first 7 days of the maintenance period to a median value of

4.1 percent in the last three days of the period; the corresponding figures for the post-July 1998 period (1.2 and 7.8 percent) are significantly more skewed towards supply around settlement.

In addition to dampening the cyclical behavior of interest rates, falling required reserves have been seen as potentially raising the overall volatility of interest rates (Brunner and Lown, 1993; Bennett and Hilton, 1997; Clouse and Elmendorf, 1997). To evaluate this conjecture, we included required reserves as an additional regressor in the equation for the variance of interest rates for the United States, and tested:

$$\{H_0\colon\ \beta_2 \geqslant 0\}$$

for β_2 the coefficient of aggregate required reserves in the U.S. volatility equation (3). Although we experimented with several linear and nonlinear functional forms,[20] none of our specifications delivered a significant link between declining reserves and interest rate volatility. Results for the other countries where reserves data were available (Italy and France) were also not informative.

Other lessons. Finally, we summarize a number of minor results, mostly as reference for future analysis of industrial countries' interbank markets.

We found some weak calendar patterns in interest rate volatility (Figure 4 and Tables 3 and 7), such as greater volatility on Fridays (in most countries, except Italy and Canada), greater volatility around end-months (in Japan and the Euro zone) and around end-quarters and end-years (in most of our samples).

We found changes in target rates to have a significant effect on interest rates; less so for changes in ceiling and floor rates (Table 8). Smaller-than-one coefficients for target rates in the mean equation reflect both time-aggregation (changes are often announced during business days; *effective* rates then aggregate both pre- and post-change transactions), and rationally anticipated changes (which are partially built into rates prior to the policy change). Intuitively, we found days with changes in policy rates to display greater volatility.

Lagged variances and innovations—whose coefficient is denoted by λ in equation (3) and Tables 3 and 7—were everywhere strongly significant, pointing to considerable time persistence in the

[20] We also tried *actual* reserves, in place of *required* reserves as an independent variable, and experimented with lags and moving averages of both.

volatility of shocks to interest rates. Finally, we found the probability distributions of shocks to display generally thick tails (Tables 3 and 7), with the estimated number of degrees of freedom of the Student-t distribution falling mostly between 2 and 3; and evidence of asymmetric shocks in five of our eight samples (as documented by significant coefficients θ in (3)).

5 Concluding remarks

A comprehensive analysis of the high-frequency behavior of the world's main interbank markets reveals patterns in the time series behavior of short-term interest rates that may serve as useful ground for future theoretical work on the operation of these markets. Empirical regularities identified in U.S. markets have motivated most work on reserve markets in the past twenty years, but our results reveal that few of them can be retained as solid stylized facts, i.e., as 'natural' features of reserve markets, that central bankers may take as given and finance scholars may need to explain theoretically. Rather, the behavior of short-term interest rates appears to reflect (in often intuitive ways) cross-sectional and time-series differences in institutional details and style of central bank intervention. Our results suggest that these factors can go a long way towards explaining the sharp differences in the behavior of interbank markets that we document. They should figure prominently in future theoretical and empirical research on money markets.

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Table 1
Data, reserve requirements, and other central bank operating procedures in the G-7 Countries
(description applies to end-sample)

	United States	Japan	Germany	France	United Kingdom	Italy	Canada	Euro zone
Sample	01/01/86-03/02/01	08/16/85-03/15/01	01/01/85-12/30/98	05/16/87-06/30/94	01/01/85-03/15/01	11/15/90-12/14/98	01/01/85-03/21/01	01/29/99-12/11/01
Data sources	Federal Reserve Bank of NY	Datastream	Datastream	Datastream and Banque de France	Datastream	Datastream and Banca d'Italia	Datastream and Bank of Canada	European Central Bank
Reserve regime	Lagged average required reserves	Lagged average required reserves	Lagged average required reserves	Lagged average required reserves	Minimal required cash ratio (.15%)	Lagged average required reserves	Nonnegative daily balance	Lagged average required reserves
Institutions subject to reserve requirements	Commercial and savings banks, credit unions, branches/agencies of foreign banks, Edge Act corpor.	City, regional, trust, long-term, and shinkin banks, branches of foreign banks, Norinchukin Bank	Almost all, broadly-defined, banking institutions	All credit institutions except very small ones and the Caisse Française de Developpement	All authorized banks, except very small ones	All credit institutions except very small ones	All institutions participating in the Large Value Transfer System	Almost all credit institutions in member states
Liabilities with positive reserve ratios	Transaction deposits	All deposits	Savings deposits, sight and time liabilities with less than 4 years of maturity	Most liabilities against residents with less than 2 years of maturity	Most residents' gross sterling liabilities and positive currency liabilities	Deposits with less than 18 month maturity (incl. affiliated inter-bank deposits)	--	Deposit and debt liabilities with up to 2 years of maturity
Maintenance period	Two weeks, from 3rd Thursday after the start of the computation period, to the second following Wednesday	One month, from the 16th of each month to the 15th of the following month	One calendar month, starting two weeks after the start of the computation period	One month, from the 16th of each month (two weeks before the computation day) to the 15th of the following month	Daily, over the six months following the end of the computation period	One month, from the 15th of each month to the 14th of the following month	--	One month, from the 24th of each month to the 23rd of the following month
Reserve Assets	Deposits at central bank + vault cash	Deposits at central bank	Deposits at central bank	Deposits at central bank + vault cash	Deposits at central bank	Deposits at central bank	Deposits at central bank	Deposits at central bank

	United States	Japan	Germany	France	United Kingdom	Italy	Canada	Euro zone
Computation period	Two weeks, from Tuesday to the second following Monday	One month: the calendar month prior to the computation period	One month, from the 16th of each month, or average of 23rd and last day of the month, and the 7th and 25th of following month	Last day of each month	Six end-month days prior to October 1 and April 1	One month, from the 1st to the last day of the month prior to the beginning of the maintenance period	--	One month, from the 24th of each month to the 23rd of the following month
Computation/ maintenance lag	30 days	15 days	15 days	15 days	About 6 months	45 days	--	One month
Seigniorage/ 1996 GDP, % (Borio, 1997; excl. ECB)	0.01	0.00	0.04	0.01	0.01	0.12	0.00	0.00
Interest on reserves	--	--	--	--	--	5.5% on required reserves; 0.5% on excess reserves	Bank rate minus 0.5% on positive balances	Most recent repo rate on required reserves
Carry-over	Up to smaller of $50,000 or 4% of required reserves	--	--	90% of first 2% of excess reserves, 75% thereafter	--	--	--	--
Intermediate policy target	Range of indicators	Range of indicators	M3	Exchange rate and money aggregates	Inflation	Exchange rate and money aggregates	Inflation	Inflation + M3
Operating target	O/N rate	O/N rate	O/N rate	O/N rate	Short-term rate	O/N rate	O/N rate	O/N rate
Key policy rate	O/N target rate	O/N target rate	Repo rate	Repo (‘repurchase tender’) rate	Repo rate	Repo rate	O/N target rate	Minimum repo bid
Frequency of intervention	Almost daily	Once daily or more	Weekly	Once/twice weekly	Twice daily or more	Weekly	Twice daily	Weekly

	United States	Japan	Germany	France	United Kingdom	Italy	Canada	Euro zone
Frequency of policy changes	A few times a year	A few times a year	Once a month or more	A few times a year	A few times a year	Several times a year	Up to 8 times a year	Infrequent
Interest rate ceiling	Penalty rate on deficiencies: discount rate + 2%	Penalty rate on deficiencies: discount rate + 3.75%	Rate on fixed-term lombard loans	Rate on 5-to-10 day repurchases	Rate on O/N late lending, equal to repo rate + 1.5%	Rate on fixed-term advances	Bank Rate (equal to target + 0.25%) on O/N advances	Rate on marginal lending facility
Interest rate floor / active below-market facility	--	--	Discount rate	Repurchase tender rate	--	Rate on ordinary advances	Bank rate -0.5% on positive balances	Rate on marginal deposit facility
Major changes	12/90: reserve ratios for non-transaction liabil-ities reduced from 3% to 0%; 07/98: maintenance period lagged by 4 weeks	10/91: reserve ratios lowered; 03-07/95: discount rate raised above market rate, and target rate announced	03/93, 03/94, 08/95: reserve ratios lowered	10/90: cash as reserve; 1990-92: reserve ratios lowered; 07/94: reserve calculation and intervention altered to almost eliminate O/N rate volatility	10/90-09/92: exchange rate target; 06/98: liberalized late O/N lending; 05/97: gilt repos introduced and counterparties for repos broadened	10/90: reserve averaging introduced and clearing balances modified	06/92-06/94: reserve ratios phased out; 02/99: averaging eliminated	06/00: switch from fixed- rate to variable-rate repo auctions

Table 2

Benchmark Estimates: Other Mean Parameters

(standard errors in parentheses; * indicates significance at 5% level)

	United States	Japan	Germany	France	Italy	Canada	U.K.	Euro zone
d_{ct}								
Day before end of months 1,2,4,5,7,8,10,11	0.022 *	0.000		-0.002		0.001	-0.014	-0.004 *
	(0.007)	(0.002)		(0.012)		(0.003)	(0.012)	(0.006)
End of months 1,2,4,5,7,8,10,11	0.092*	0.004 *		-0.004		0.016 *	0.061 *	0.057 *
	(0.007)	(0.002)		(0.014)		(0.003)	(0.013)	(0.009)
Day after end of months 1,2,4,5,7,8,10,11	-0.009	0.000		-0.012		-0.003	-0.029 *	-0.057 *
	(0.007)	(0.002)		(0.012)		(0.004)	(0.015)	(0.010)
Day before end of quarter	0.049	0.000	0.034	-0.012	0.000	0.005	0.023	0.000
	(0.031)	(0.024)	(0.032)	(0.015)	(0.014)	(0.007)	(0.024)	(0.020)
End of quarter	0.183 *	0.004 *	0.219 *	0.014	0.024	0.009	0.151 *	0.093 *
	(0.026)	(0.002)	(0.069)	(0.017)	(0.014)	(0.008)	(0.024)	(0.023)
Day after end of quarter	-0.148 *	0.002	0.052 *	-0.028	-0.013	-0.004	-0.099 *	-0.111 *
	(0.031)	(0.004)	(0.024)	(0.016)	(0.016)	(0.008)	(0.022)	(0.014)
Day before end of year	0.051	0.000	0.090	-0.002	-0.026	-0.012	0.028	
	(0.098)	(0.006)	(0.110)	(0.034)	(0.110)	(0.023)	(0.067)	
End of year	-0.525 *	0.015	1.053 *	0.112 *	0.178 *	-0.009	0.131 *	
	(0.068)	(0.011)	(0.113)	(0.021)	(0.050)	(0.012)	(0.067)	
Day after end of year	0.631 *	0.006	0.042	-0.190 *	-0.257 *	0.012	-0.043	
	(0.090)	(0.014)	(0.033)	(0.021)	(0.095)	(0.009)	(0.059)	
Day before 1-day holiday	-0.010	0.000	0.003	-0.002	-0.013	0.004		
	(0.023)	(0.002)	(0.004)	(0.012)	(0.034)	(0.015)		
Day after 1-day holiday	0.033 *	0.000	0.004	-0.000	-0.060 *	0.014		
	(0.016)	(0.001)	(0.005)	(0.013)	(0.027)	(0.023)		
Day before 3-day holiday	-0.024 *	-0.013 *	0.012	0.015	0.017	0.002	-0.197 *	0.078
	(0.008)	(0.001)	(0.015)	(0.010)	(0.010)	(0.004)	(0.038)	(0.061)
Day after 3-day holiday	0.220 *	0.003 *	0.029 *	-0.005	0.017	0.002	0.174 *	0.071 *
	(0.011)	(0.002)	(0.012)	(0.010)	(0.012)	(0.005)	(0.032)	(0.022)
Day before 4-day holiday		0.014	-0.015	-0.002	-0.023		-0.106 *	
		(0.010)	(0.020)	(0.022)	(0.050)		(0.049)	
Day after 4-day holiday		-0.026 *	0.033 *	-0.111 *	0.032		0.115 *	
		(0.012)	(0.014)	(0.020)	(0.176)		(0.053)	
Day before 5-day holiday		-0.002						
		(0.007)						
Day after 5-day holiday		0.000						
		(0.004)						
(One minus) coefficient of change in day one on changes in previous period's (f_i's):								
last day	-0.824 *	-0.865 *	-0.956 *	-0.432 *	-0.911 *	-0.298		-0.815 *
	(0.018)	(0.044)	(0.018)	(0.089)	(0.031)	(0.195)		(0.045)
day before last	-0.702 *	-0.678 *	-0.950 *	-0.161	-0.814 *	-0.124		-1.051 *
	(0.025)	(0.063)	(0.042)	(0.139)	(0.079)	(0.177)		(0.088)
two days before last	-0.478 *	-0.523 *	-0.683 *	-0.241	-0.544 *	-0.161		-0.755 *
	(0.025)	(0.075)	(0.056)	(0.134)	(0.117)	(0.151)		(0.121)
three days before last	-0.280 *	-0.060	-0.785 *	-0.127	-0.679 *	-0.164		-0.742 *
	(0.024)	(0.075)	(0.097)	(0.150)	(0.119)	(0.121)		(0.092)
four days before last	-0.201 *	-0.026	-0.685 *	-0.294 *	-0.011	0.202		-1.338 *
	(0.028)	(0.064)	(0.090)	(0.146)	(0.155)	(0.150)		(0.162)

Table 3

Benchmark Estimates: Other Variance Parameters

(standard errors in parentheses; * indicates significance at 5% level)

	United States	Japan	Germany	France	Italy	Canada	U.K.	Euro zone
x_{ct}								
End of months 1,2,4,5,7,8,10,11, or the previous and following days	0.122	1.193 *		0.084		0.378	-0.121	2.032 *
	(0.122)	(0.232)		(0.326)		(0.226)	(0.107)	(0.460)
End of quarter, or the previous and following days	1.861 *	3.296 *	0.568 *	0.959 *	0.228	0.485	-0.106	3.407 *
	(0.155)	(0.261)	(0.224)	(0.393)	(0.298)	(0.368)	(0.162)	(0.641)
End of year, or the previous and following days	2.067 *	1.218 *	0.825 *	0.796	1.762 *	0.022	0.186	6.852 *
	(0.339)	(0.290)	(0.408)	(0.476)	(0.539)	(0.622)	(0.292)	(1.108)
Day before 1-day holiday	0.733 *	0.242 *	-0.171	-0.762	0.933 *	0.958		
	(0.275)	(0.204)	(0.278)	(0.502)	(0.460)	(0.898)		
Day after 1-day holiday	0.274	0.476	-0.185	-1.115 *	0.811	1.784		
	(0.267)	(0.253)	(0.332)	(0.488)	(0.561)	(1.337)		
Day before 3-day holiday	0.172	-0.418 *	1.025 *	0.000	-0.673	0.037	0.885 *	-0.790
	(0.201)	(0.178)	(0.357)	(0.368)	(0.374)	(0.405)	(0.311)	(0.734)
Day after 3-day holiday	0.910 *	0.063	1.018 *	-0.228	-0.454	0.244	0.924 *	-1.250
	(0.185)	(0.205)	(0.397)	(0.299)	(0.405)	(0.371)	(0.262)	(1.055)
Day before 4-day holiday		-0.024	1.582 *	0.501	-0.636		0.609	
		(0.640)	(0.498)	(0.839)	(1.666)		(0.334)	
Day after 4-day holiday		0.310	0.820	-0.053	0.928		0.839 *	
		(0.589)	(0.543)	(0.759)	(3.073)		(0.405)	
Day before 5-day holiday		0.198						
		(0.714)						
Day after 5-day holiday		0.478						
		(0.469)						
t is between 1/10/1991 and 2/6/1991	2.881 *							
	(0.617)							
y_1								
t is the first day of the maintenance period	1.133	0.498 *	2.317 *	1.447 *	1.331 *	0.142		2.542 *
	(0.613)	(0.194)	(0.243)	(0.353)	(0.316)	(0.506)		(0.492)
EGARCH parameters								
l	0.561 *	0.980 *	0.920 *	0.969 *	0.946 *	0.492 *	1.334 *	0.707 *
	(0.037)	(0.002)	(0.009)	(0.005)	(0.008)	(0.046)	(0.084)	(0.041)
a	0.878 *	0.464 *	0.602 *	0.483 *	0.764 *	2.115 *	0.632 *	2.132 *
	(0.091)	(0.027)	(0.082)	(0.048)	(0.086)	(0.195)	(0.041)	(0.861)
q	0.322 *	0.044 *	-0.037	0.172 *	-0.036	0.547 *	-0.013	0.259
	(0.047)	(0.016)	(0.029)	(0.030)	(0.040)	(0.138)	(0.028)	(0.169)
l (2)							-0.340 *	
							(0.083)	
a (2)							-0.494 *	
							(0.043)	
q (2)							0.008	
							(0.030)	
Degrees of freedom of *t*-distribution	2.629 *	2.579 *	2.285 *	2.565 *	2.497 *	2.059 *	3.979 *	2.184 *
	(0.157)	(0.076)	(0.086)	(0.124)	(0.130)	(0.010)	(0.231)	(0.169)

Table 4

Extended Estimates: Maintenance Period Mean Effects

(mean difference from first day of the period; standard errors in parentheses; * indicates significance at 5% level)

Days from end of maintenance period, d_{mt}	United States pre-07/98	United States post-07/98	Japan	Germany	France	Italy	Canada pre-1992	Canada post-1994	Euro zone
0	3.109	-1.559	-0.110	5.528	2.266	-10.918	-0.161	-10.668*	-5.414
	(2.226)	(2.700)	(0.430)	(4.668)	(4.097)	(6.208)	(3.293)	(4.962)	(5.008)
1	-10.791 *	-6.397 *	-0.117	-6.472 *	2.491	-7.558*	-2.621	-11.575*	-9.568*
	(1.413)	(2.409)	(0.409)	(2.318)	(3.995)	(3.928)	(2.942)	(4.898)	(3.084)
2	-4.448 *	1.283	-0.109	-10.034 *	2.457	-8.805*	1.328	-10.696*	-4.363
	(1.236)	(2.244)	(0.405)	(1.572)	(3.956)	(3.530)	(2.684)	(4.830)	(2.477)
3	-13.353 *	-5.464 *	-0.115	-10.718 *	2.245	-8.833*	2.301	-13.873*	-3.739
	(1.051)	(2.100)	(0.401)	(1.396)	(3.950)	(3.363)	(2.514)	(4.773)	(2.185)
4	-8.610 *	-1.531	-0.115	-10.477 *	2.368	-9.891*	2.065	-1.536	-2.809
	(0.955)	(1.919)	(0.400)	(1.331)	(3.896)	(3.236)	(2.318)	(4.487)	(1.956)
5	-9.732 *	-5.473 *	-0.106	-9.758 *	2.373	-9.033*	0.636	-13.780*	-2.894
	(0.853)	(1.726)	(0.398)	(1.231)	(3.822)	(3.167)	(2.180)	(4.365)	(1.931)
6	-6.589 *	-4.313 *	-0.116	-9.417 *	2.109	-8.922*	1.042	-13.263*	-2.775
	(0.766)	(1.430)	(0.387)	(1.192)	(3.782)	(3.069)	(0.766)	(4.345)	(1.923)
7	-1.079	0.150	-0.089	-9.011 *	2.012	-7.983*	1.839	-13.124*	-2.399
	(0.663)	(1.140)	(0.386)	(1.151)	(3.744)	(3.013)	(1.858)	(4.324)	(1.909)
8	-6.934 *	-7.397 *	-0.104	-8.598 *	1.899	-9.056*	3.291*	-14.934*	-2.361
	(0.454)	(0.698)	(0.384)	(1.124)	(3.682)	(2.963)	(1.674)	(4.307)	(1.863)
9	0	0	-0.093	-7.820 *	2.116	-11.281 *	4.790*	-1.968	-2.470
			(0.382)	(1.086)	(3.624)	(2.903)	(0.766)	(4.149)	(1.853)
10			-0.059	-6.979 *	2.091	-9.246*	4.974*	-13.021*	-2.411
			(0.377)	(1.062)	(3.270)	(2.807)	(1.043)	(4.030)	(1.849)
11			-0.040	-6.418 *	2.960	-8.593*	0	-9.646*	-1.993
			(0.265)	(1.041)	(2.764)	(2.671)		(3.984)	(1.839)
12			-0.019	-6.218 *	3.339	-7.720*		-7.548*	-2.018
			(0.175)	(1.017)	(2.294)	(2.575)		(3.781)	(1.826)
13			-0.011	-5.521 *	3.472	-5.961*		-8.897*	-1.436
			(0.100)	(0.985)	(2.160)	(2.464)		(3.665)	(1.818)
14			-0.011	-5.522 *	3.481	-8.128*		1.317	-0.973
			(0.100)	(0.962)	(2.095)	(2.287)		(3.313)	(1.817)
15			0.000	-4.873 *	3.565	-8.547*		-12.142*	-0.345
			(0.096)	(0.943)	(1.993)	(2.077)		(3.117)	(1.814)
16			-0.010	-4.655 *	3.564	-8.066*		-12.909*	0.477
			(0.094)	(0.911)	(1.914)	(1.980)		(3.082)	(1.737)
17			-0.002	-4.469 *	3.655*	-8.005*		-13.553*	0.424
			(0.091)	(0.884)	(1.795)	(1.852)		(3.041)	(1.226)
18			-0.011	-3.928 *	3.708*	-6.802*		-16.764*	0.437
			(0.076)	(0.855)	(1.538)	(1.743)		(3.003)	(0.982)
19			-0.007	-3.167 *	3.653*	-5.246*		-4.711	0.254
			(0.059)	(0.823)	(1.308)	(1.626)		(2.825)	(0.956)
20			-0.004	-1.626 *	3.614*	-4.036*		-11.752*	0.232
			(0.049)	(0.765)	(1.081)	(1.482)		(2.478)	(0.929)
21			-0.011	-0.349	3.579*	-3.596*		-11.965*	0.081
			(0.030)	(0.634)	(0.689)	(1.093)		(2.310)	(0.733)
22			0	0	0	0		-11.685*	0
								(2.057)	
23								-12.853*	
								(1.888)	
24								0	

Table 5

Extended Estimates: Maintenance Period Variance Effects

(ratio to standard deviation of last day; standard errors in parentheses; * indicates significance at 5% level)

Days from end of maintenance period, x_{mt}	United States pre-07/98	United States post-07/98	Japan	Germany	France	Italy	Canada pre-1992	Canada post-1994	Euro zone
0	1	1	1	1	1	1	1	1	1
1	0.362*	0.644*	0.734*	0.500*	0.563*	0.350*	0.772*	0.986*	0.550*
	(0.027)	(0.094)	(0.065)	(0.052)	(0.084)	(0.049)	(0.069)	(0.188)	(0.147)
2	0.335*	0.587*	0.522*	0.244*	0.740*	0.212*	0.673*	0.943*	0.247*
	(0.027)	(0.094)	(0.044)	(0.026)	(0.114)	(0.030)	(0.062)	(0.180)	(0.064)
3	0.216*	0.671*	0.546*	0.150*	0.471*	0.189*	0.693*	1.940*	0.213*
	(0.017)	(0.110)	(0.045)	(0.017)	(0.068)	(0.028)	(0.068)	(0.459)	(0.058)
4	0.221*	0.588*	0.486*	0.166*	0.550*	0.112*	0.635*	1.389*	0.106*
	(0.017)	(0.095)	(0.044)	(0.018)	(0.078)	(0.016)	(0.062)	(0.284)	(0.030)
5	0.198*	0.771*	0.684*	0.118*	0.697*	0.132*	0.608*	0.498*	0.039*
	(0.016)	(0.130)	(0.060)	(0.014)	(0.106)	(0.019)	(0.055)	(0.104)	(0.011)
6	0.195*	0.611*	0.556*	0.106*	0.524*	0.110*	0.604*	0.462*	0.070*
	(0.016)	(0.097)	(0.052)	(0.012)	(0.082)	(0.016)	(0.056)	(0.101)	(0.021)
7	0.246*	0.622*	0.618*	0.086*	0.542*	0.112*	0.612*	0.568*	0.073*
	(0.020)	(0.104)	(0.058)	(0.010)	(0.087)	(0.016)	(0.056)	(0.117)	(0.021)
8	0.258*	0.571*	0.719*	0.092*	0.695*	0.126*	0.658*	1.454*	0.052*
	(0.021)	(0.091)	(0.071)	(0.010)	(0.102)	(0.020)	(0.061)	(0.342)	(0.015)
9	0.168*	0.481*	0.713*	0.080*	0.539*	0.134*	0.587*	1.353*	0.043*
	(0.054)	(0.164)	(0.071)	(0.010)	(0.093)	(0.023)	(0.059)	(0.297)	(0.012)
10			0.609*	0.072*	0.345*	0.137*	0.574*	0.804*	0.061*
			(0.095)	(0.008)	(0.080)	(0.021)	(0.076)	(0.182)	(0.017)
11			0.542*	0.080*	0.414*	0.132*	0.589*	1.236*	0.036*
			(0.078)	(0.010)	(0.093)	(0.019)	(0.128)	(0.276)	(0.010)
12			0.535*	0.085*	0.426*	0.148*		0.869*	0.053*
			(0.068)	(0.010)	(0.078)	(0.022)		(0.197)	(0.016)
13			0.424*	0.075*	0.349*	0.183*		1.775*	0.041*
			(0.038)	(0.009)	(0.052)	(0.027)		(0.413)	(0.012)
14			0.491*	0.066*	0.480*	0.164*		1.251*	0.059*
			(0.047)	(0.007)	(0.068)	(0.024)		(0.270)	(0.018)
15			0.509*	0.082*	0.595*	0.128*		0.546*	0.059*
			(0.047)	(0.010)	(0.087)	(0.019)		(0.114)	(0.019)
16			0.515*	0.078*	0.453*	0.134*		0.569*	0.060*
			(0.049)	(0.009)	(0.066)	(0.020)		(0.125)	(0.024)
17			0.533*	0.071*	0.603*	0.117*		0.675*	0.056*
			(0.050)	(0.008)	(0.089)	(0.017)		(0.147)	(0.019)
18			0.627*	0.086*	0.557*	0.138*		1.539*	0.028*
			(0.055)	(0.010)	(0.081)	(0.019)		(0.329)	(0.009)
19			0.496*	0.089*	0.628*	0.134*		1.566*	0.049*
			(0.044)	(0.010)	(0.092)	(0.020)		(0.370)	(0.012)
20			0.513*	0.111*	0.497*	0.166*		0.648*	0.068*
			(0.047)	(0.013)	(0.076)	(0.027)		(0.208)	(0.019)
21			0.484*	0.123*	0.692*	0.112*		0.738*	0.093*
			(0.056)	(0.018)	(0.154)	(0.021)		(0.219)	(0.037)
22			0.702*	0.084*	0.245*	0.118*		0.564*	0.076
			(0.152)	(0.020)	(0.074)	(0.040)		(0.167)	(0.047)
23								1.316*	
								(0.345)	
24								1.800*	
								(0.735)	

Figure 1: Benchmark Mean Estimates: Maintenance Period Effects
(mean difference from first day of the period and 95 percent confidence band)

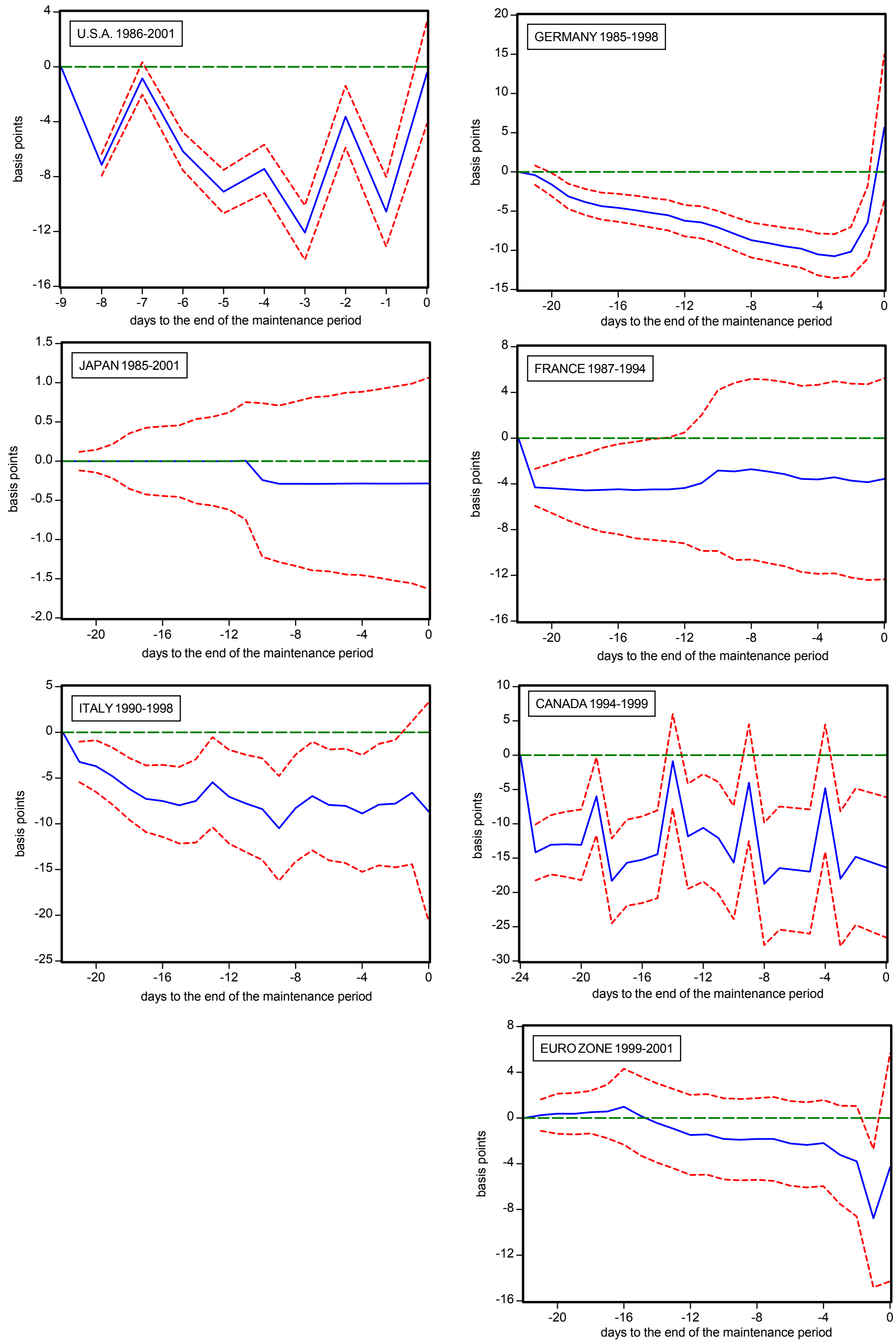

Figure 2: Benchmark Mean Estimates: Weekday Effects
(mean difference from Monday and 95 percent confidence band)

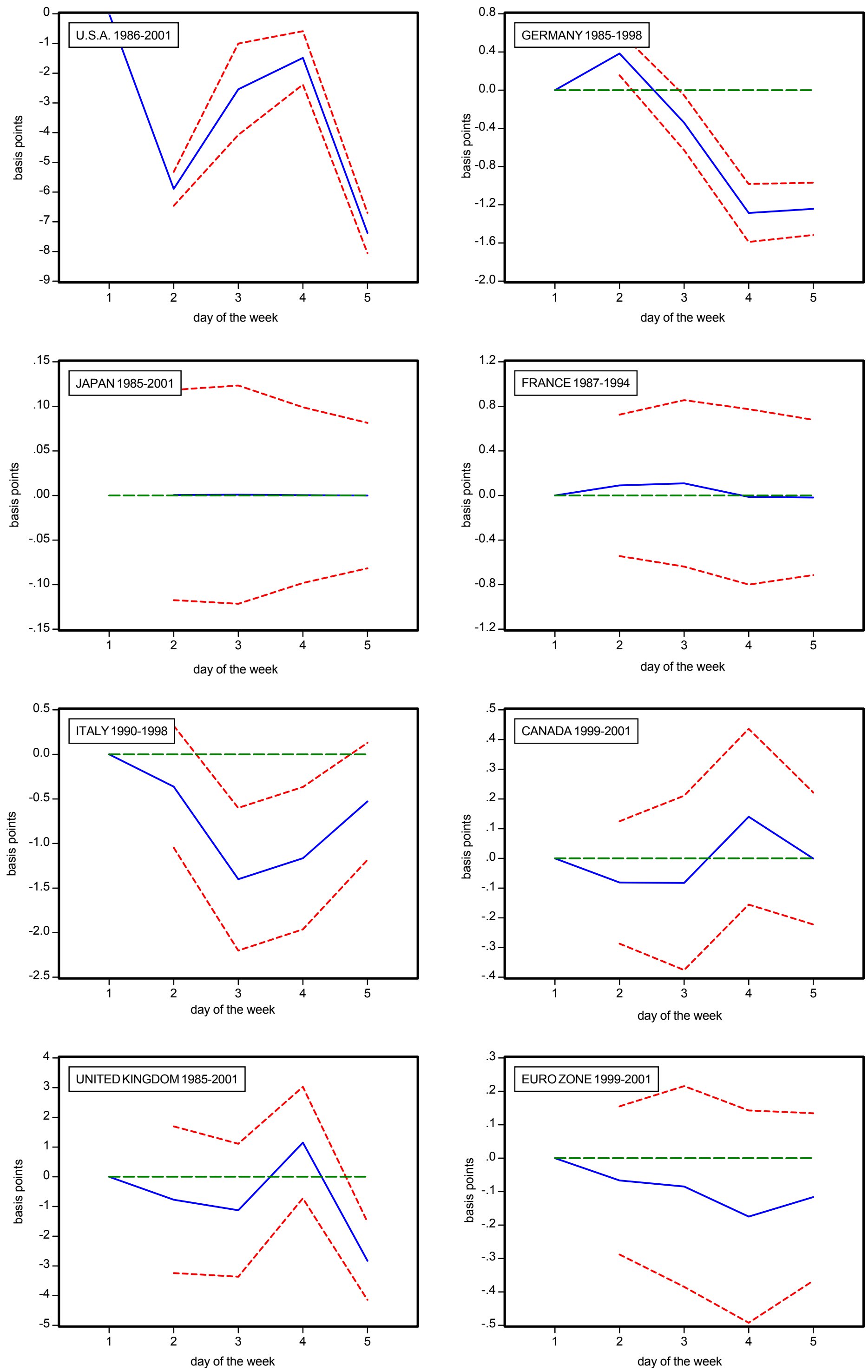

Figure 3: Benchmark Variance Estimates: Maintenance Period Effects
(ratio to standard deviation of the last day and 95 percent confidence band)

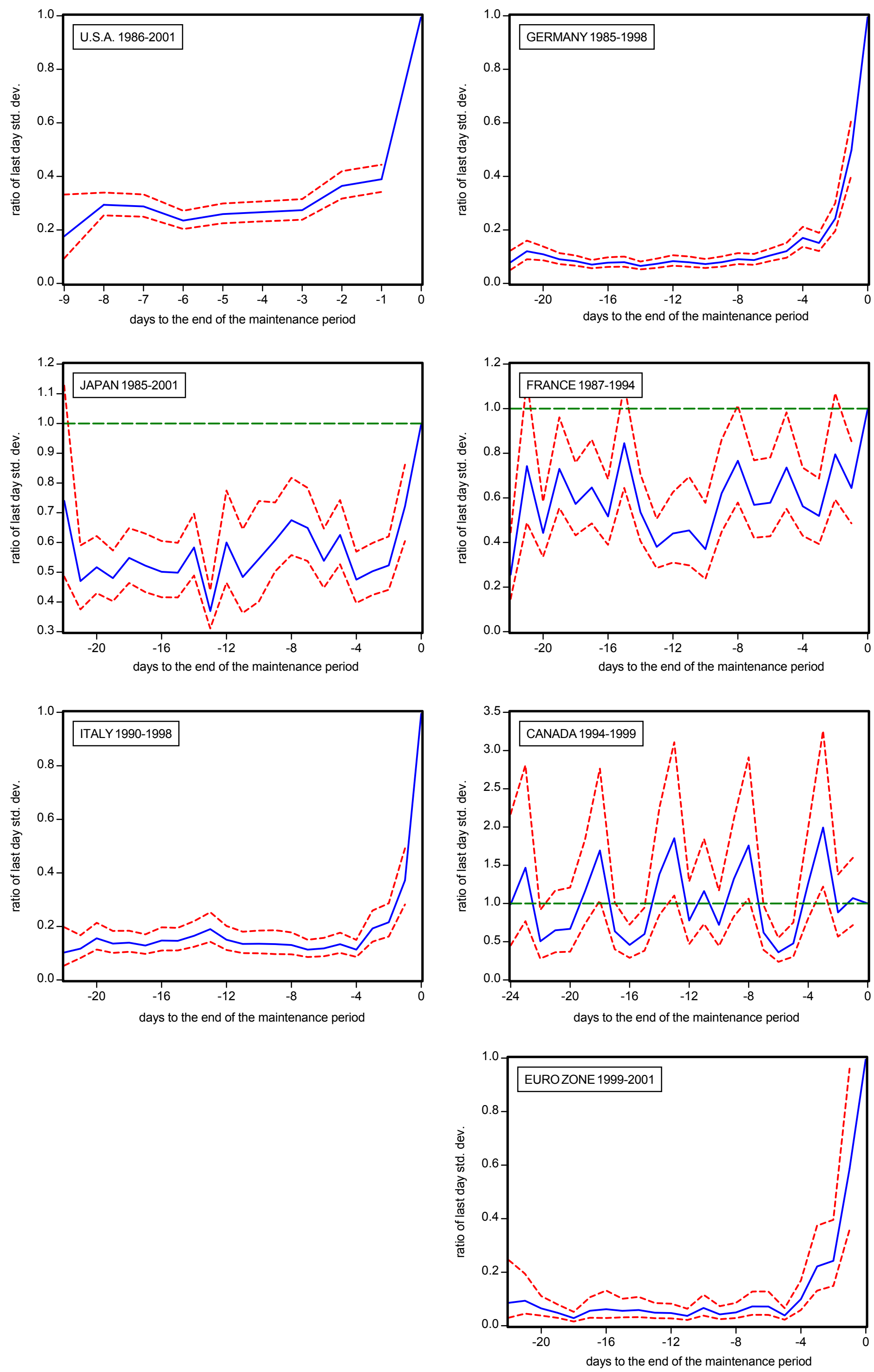

Figure 4: Benchmark Variance Estimates: Weekday Effects
(ratio to standard deviation of Monday and 95 percent confidence band)

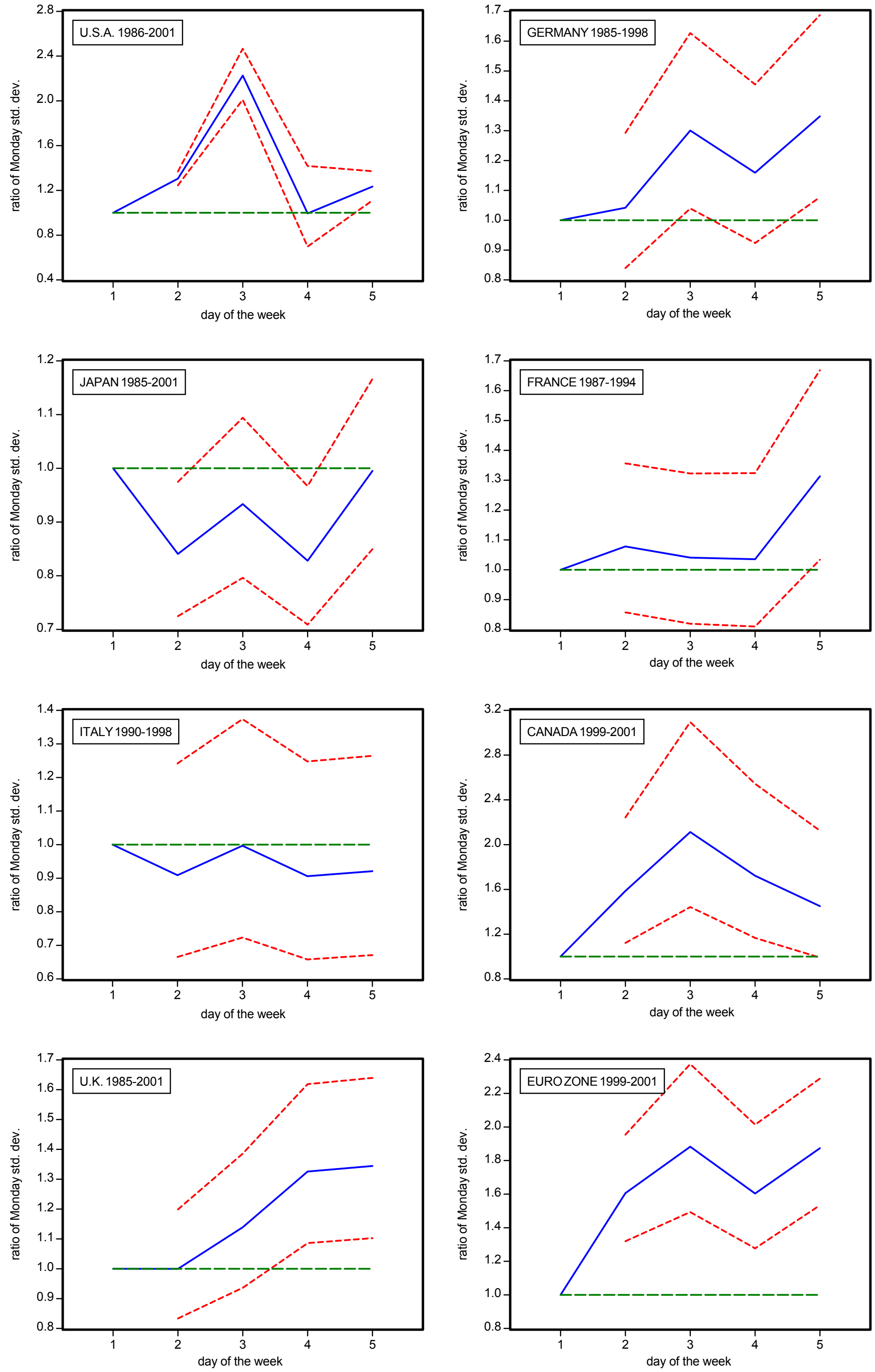

Figure 5: Extended Mean and Variance Estimates
(mean difference from first day of the period (left column), ratio to standard deviation of the last day (right column), and 95 percent confidence band)

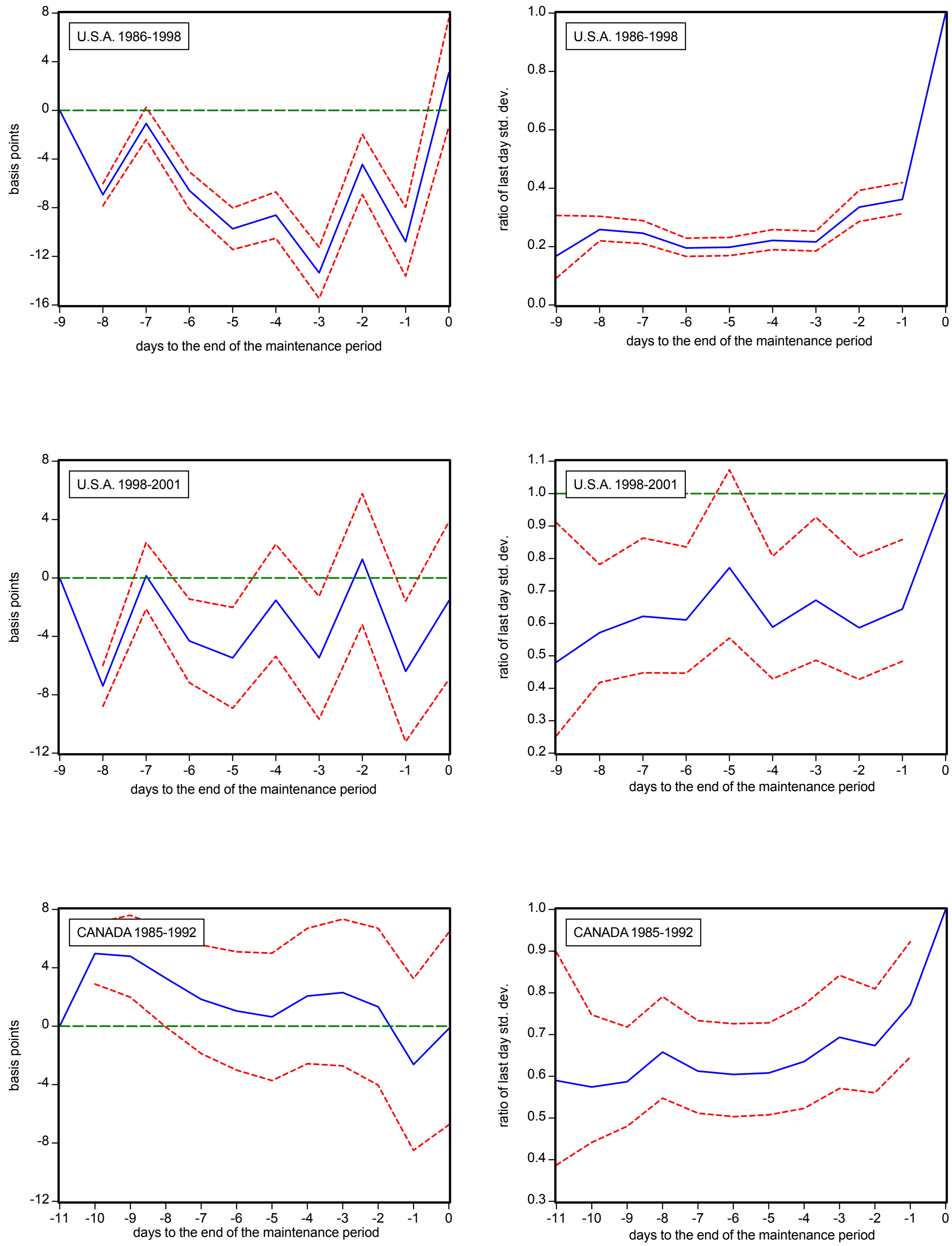

Table 6

Extended Estimates: Other Mean Parameters

(standard errors in parentheses; * indicates significance at 5% level)

	United States	Japan	Germany	France	Italy	Canada pre-1992	Canada post-1994	U.K.	Euro zone
d_{wt}									
Monday		0	0	0	0	0	0	0	0
Tuesday[1]		-0.010	0.389 *	0.064	-0.394	0.202	-0.024	-0.766	-0.083
		(0.018)	(0.114)	(0.314)	(0.347)	(0.533)	(0.102)	(1.210)	(0.113)
Wednesday[1]		0.001	-0.341 *	0.059	-1.306 *	-3.662 *	0.001	-1.104	-0.062
		(0.022)	(0.144)	(0.355)	(0.407)	(0.669)	(0.126)	(1.094)	(0.149)
Thursday[1]		-0.002	-1.321 *	-0.033	-1.107 *	-2.077 *	0.188	1.230	-0.134
		(0.020)	(0.151)	(0.371)	(0.404)	(0.722)	(0.133)	(0.917)	(0.159)
Friday[1]		-0.013	-1.254 *	-0.007	-0.402	0.256	0.012	-2.628 *	-0.083
		(0.018)	(0.134)	(0.318)	(0.333)	(0.620)	(0.109)	(0.641)	(0.122)
d_{ct}									
Day before end- month 1,2,4,5,7,8,10,11	0.022 *	0.000		-0.002			0.000	-0.016	-0.001
	(0.008)	(0.001)		(0.012)			(0.003)	(0.012)	(0.006)
End-month 1,2,4,5,7,8,10,11	0.089*	0.001		-0.004			0.012 *	0.062 *	0.060 *
	(0.007)	(0.000)		(0.013)			(0.003)	(0.013)	(0.009)
Day after end-month 1,2,4,5,7,8,10,11	-0.006	0.000		0.009			-0.002	-0.029 *	-0.054 *
	(0.007)	(0.001)		(0.011)			(0.003)	(0.015)	(0.011)
Day before end-quarter	0.043	0.000	0.037	-0.013	0.003	0.042	0.004	0.022	0.002
	(0.032)	(0.010)	(0.032)	(0.014)	(0.016)	(0.030)	(0.006)	(0.024)	(0.021)
End-quarter	0.170 *	0.000	0.202 *	0.010	0.026	0.033	0.017 *	0.151 *	0.095 *
	(0.026)	(0.003)	(0.069)	(0.015)	(0.017)	(0.046)	(0.007)	(0.024)	(0.023)
Day after end-quarter	-0.122 *	0.000	0.053 *	-0.027	-0.014	0.074 *	-0.012 *	-0.100 *	-0.104 *
	(0.031)	(0.003)	(0.025)	(0.015)	(0.017)	(0.031)	(0.006)	(0.021)	(0.015)
Day before end-year	0.065	-0.001	0.086	-0.002	-0.026	0.033	-0.012	0.028	
	(0.111)	(0.007)	(0.112)	(0.036)	(0.123)	(0.068)	(0.035)	(0.071)	
End-year	-0.534 *	0.026 *	1.057 *	0.114 *	0.188 *	-0.146	-0.011	0.130 *	
	(0.065)	(0.010)	(0.112)	(0.018)	(0.059)	(0.079)	(0.052)	(0.073)	
Day after end-year	0.715 *	0.003	0.043	-0.191 *	-0.255 *	0.020	0.016	-0.042	
	(0.101)	(0.011)	(0.033)	(0.018)	(0.107)	(0.048)	(0.013)	(0.058)	
Day before 1-day holiday	-0.012	0.000	0.003	-0.001	-0.009	0.082	-0.009		
	(0.022)	(0.001)	(0.004)	(0.011)	(0.037)	(0.083)	(0.021)		
Day after 1-day holiday	0.037 *	0.002	0.005	0.000	-0.059 *	0.048	0.021		
	(0.016)	(0.001)	(0.005)	(0.013)	(0.028)	(0.059)	(0.029)		
Day before 3-day holiday[1]	-0.023 *	-0.011 *	0.011	0.019	0.017	-0.003	0.002	-0.196 *	0.086
	(0.008)	(0.001)	(0.015)	(0.011)	(0.011)	(0.022)	(0.004)	(0.038)	(0.069)
Day after 3-day holiday[2]	0.219 *	0.002	0.030 *	-0.004	0.015	0.053 *	0.000	0.166 *	0.071 *
	(0.011)	(0.001)	(0.012)	(0.009)	(0.012)	(0.017)	(0.005)	(0.032)	(0.025)
Day before 4-day holiday		0.003	-0.013	0.003	-0.006			-0.113 *	
		(0.010)	(0.019)	(0.029)	(0.071)			(0.047)	
Day after 4-day holiday		-0.021 *	0.033 *	-0.089 *	0.032			0.119 *	
		(0.010)	(0.013)	(0.024)	(0.152)			(0.052)	
Day before 5-day holiday		0.000							
		(0.007)							
Day after 5-day holiday		0.000							
		(0.008)							
(One minus) coefficient of change in day one on changes in previous period's (ϕ_i's):									
last day	-0.835 *	-0.864 *	-0.956 *	-0.369 *	-0.928 *	-0.264 *	-0.272		-0.840 *
	(0.017)	(0.050)	(0.018)	(0.088)	(0.032)	(0.054)	(0.170)		(0.043)
day before last	-0.689 *	-0.666 *	-0.950 *	-0.171	-0.784 *	-0.286 *	-0.126		-1.033 *
	(0.026)	(0.066)	(0.042)	(0.137)	(0.076)	(0.065)	(0.179)		(0.090)
two days before last	-0.476 *	-0.636 *	-0.665 *	-0.183	-0.587 *	-0.331 *	-0.305 *		-0.794 *
	(0.025)	(0.079)	(0.057)	(0.135)	(0.118)	(0.095)	(0.156)		(0.128)
three days before last	-0.301 *	-0.018	-0.773 *	-0.092	-0.747 *	-0.106	-0.208		-0.797 *
	(0.026)	(0.077)	(0.095)	(0.150)	(0.112)	(0.084)	(0.128)		(0.106)
four days before last	-0.208 *	0.011	-0.673 *	-0.250	-0.105	0.052	0.208		-1.346 *
	(0.029)	(0.059)	(0.084)	(0.155)	(0.145)	(0.108)	(0.166)		(0.167)

[1]Mean difference from Monday.

Table 7

Extended Estimates: Other Variance Parameters

(standard errors in parentheses; * indicates significance at 5% level)

	United States	Japan	Germany	France	Italy	Canada pre-1992	Canada post-1994	U.K.	Euro zone
x $_{wt}$									
Monday		1	1	1	1	1	1	1	1
Tuesday[1]		0.790*	0.938*	1.159*	0.905*	1.030*	1.025*	0.806*	1.303*
		(0.037)	(0.050)	(0.083)	(0.061)	(0.071)	(0.115)	(0.033)	(0.153)
Wednesday[1]		0.873*	1.161*	1.132*	0.986*	1.172*	1.143*	0.913*	1.442*
		(0.043)	(0.066)	(0.082)	(0.070)	(0.079)	(0.135)	(0.040)	(1.80)
Thursday[1]		0.793*	1.049*	1.098*	0.911*	1.414*	1.398*	1.040*	1.099*
		(0.037)	(0.059)	(0.081)	(0.064)	(0.165)	(0.162)	(0.045)	(0.132)
Friday[1]		0.901*	1.160*	1.195*	0.923*	1.242*	1.187*	1.019*	1.275*
		(0.043)	(0.064)	(0.083)	(0.064)	(0.085)	(0.131)	(0.044)	(0.150)
x $_{ct}$									
End of months 1,2,4,5,7,8,10,11, or the previous and following days	0.142	0.862 *		0.083			0.434*	-0.085	2.018 *
	(0.123)	(0.236)		(0.336)			(0.182)	(0.106)	(0.464)
End of quarter, or the previous and following days	1.840 *	2.966 *	0.631 *	0.978 *	0.362	0.228	0.845*	-0.086	3.356 *
	(0.152)	(0.257)	(0.227)	(0.394)	(0.298)	(0.271)	(0.310)	(0.160)	(0.647)
End of year, or the previous and following days	2.243 *	1.283 *	0.851 *	1.253*	1.815 *	-0.017	0.167	0.238	6.611 *
	(0.346)	(0.299)	(0.415)	(0.531)	(0.533)	(0.612)	(0.526)	(0.292)	(1.082)
Day before 1-day holiday	0.733 *	0.421 *	-0.171	-0.896	0.933 *	0.226	0.958		
	(0.275)	(0.218)	(0.278)	(0.464)	(0.460)	(0.832)	(0.898)		
Day after 1-day holiday	0.274	0.156	-0.185	-1.085 *	0.811	-0.991	1.784		
	(0.267)	(0.248)	(0.332)	(0.556)	(0.561)	(0.863)	(1.337)		
Day before 3-day holiday	0.172	-0.290	1.025 *	0.489	-0.673	0.028	0.037	0.885 *	-0.790
	(0.201)	(0.180)	(0.357)	(0.423)	(0.374)	(0.286)	(0.405)	(0.311)	(0.734)
Day after 3-day holiday	0.910 *	0.070	1.018 *	-0.219	-0.454	-0.041	0.244	0.924 *	-1.250
	(0.185)	(0.203)	(0.397)	(0.302)	(0.405)	(0.255)	(0.371)	(0.262)	(1.055)
Day before 4-day holiday		-0.319	1.582 *	0.629	-0.636			0.609	
		(0.521)	(0.498)	(0.916)	(1.666)			(0.334)	
Day after 4-day holiday		0.299	0.820	-0.286	0.928			0.839 *	
		(0.576)	(0.543)	(0.850)	(3.073)			(0.405)	
Day before 5-day holiday		0.004							
		(0.726)							
Day after 5-day holiday		0.775							
		(0.452)							
t is between 1/10/1991 and 2/6/1991	2.825 *								
	(0.613)								
y $_1$									
t is the first day of the maintenance period	0.850	0.514 *	2.226 *	1.408 *	1.164 *	0.548*	-0.731		2.547 *
	(0.568)	(0.201)	(0.253)	(0.373)	(0.313)	(0.228)	(0.487)		(0.486)
EGARCH parameters									
l	0.572 *	0.954 *	0.899 *	0.979 *	0.940 *	0.985*	0.776*	1.315 *	0.768 *
	(0.037)	(0.004)	(0.011)	(0.004)	(0.009)	(0.006)	(0.030)	(0.087)	(0.037)
a	0.803 *	0.616 *	0.651 *	0.371 *	0.695 *	0.230*	0.716*	0.630 *	1.593 *
	(0.074)	(0.039)	(0.095)	(0.037)	(0.080)	(0.031)	(0.063)	(0.041)	(0.568)
q	0.325 *	-0.040 *	-0.040	0.194 *	-0.088 *	-0.014	0.135*	-0.010	0.227
	(0.043)	(0.020)	(0.031)	(0.028)	(0.040)	(0.020)	(0.045)	(0.028)	(0.135)
l (2)								-0.322 *	
								(0.085)	
a (2)								-0.486 *	
								(0.043)	
q (2)								0.004	
								(0.029)	
Degrees of freedom of *t*-distribution	2.765 *	2.694 *	2.298 *	2.596 *	2.621 *	5.890 *	3.588 *	4.300 *	2.231 *
	(0.166)	(0.113)	(0.099)	(0.127)	(0.172)	(0.875)	(0.322)	(0.273)	(0.193)

[1] Ratio to standard deviation of Monday.

Table 8

Extended Estimates: Country-Specific Mean and Variance Parameters

(standard errors in parentheses; * indicates significance at 5% level)

	United States	Japan	Germany	France	Italy	Canada pre-1992	Canada post-1994	U.K.	Euro zone
Mean parameters, $\boldsymbol{h_t}$:									
Day *t* change when target is changed by 1 on the same day	0.419 *	0.255 *	0.066 *				0.842 *	0.665 *	0.291 *
	(0.037)	(0.071)	(0.021)				(0.026)	(0.064)	(0.070)
Day *t* change when ceiling is changed by 1 on the same day	-0.031		0.262 *	0.010	0.178	0.095 *	0.101 *		
	(0.056)		(0.050)	(0.036)	(0.103)	(0.043)	(0.020)		
Day *t* change when floor is changed by 1 on the same day		0.343 *	-0.034	0.059 *	0.241 *				
		(0.086)	(0.033)	(0.024)	(0.092)				
Variance parameters, $\boldsymbol{h_t}$:									
ERM indicator			0.033 *	0.035 *	0.062 *			0.014 *	
			(0.000)	(0.000)	(0.015)			(0.000)	
Position of target in corridor	pre-91: -1.541* (0.734); post-91: -7.557* (1.815)	-19.159 *	-2.034 *	0.270 *	3.427 *		1.693 *		
		(1.390)	(0.938)	(0.054)	(1.333)		(0.787)		
t is the day of a target change	0.523 *	2.800 *	0.118				0.658 *	0.902 *	1.177 *
	(0.233)	(0.442)	(0.162)				(0.183)	(0.179)	(0.799)
t is the day of a ceiling change	0.562		2.021 *	1.425 *	1.061 *	-0.265	0.090		
	(0.339)		(0.463)	(0.295)	(0.332)	(0.208)	(0.226)		
t is the day of a floor change		2.710 *	-0.837	0.300	-0.448				
		(0.440)	(0.432)	(0.296)	(0.489)				
Gilt repo change dummy								-0.868 *	
								(0.381)	

Table A.1 (data plotted in charts)

Benchmark Estimates: Maintenance Period Mean Effects

(mean difference from first day of the period; standard errors in parentheses; * indicates significance at 5% level)

Days from end of maintenance period, d_{mt}	United States	Japan	Germany	France	Italy	Canada	Euro zone
0	0.454	-0.285	5.653	-3.561	-8.667	-16.352*	-4.312
	(1.854)	(0.674)	(4.675)	(4.400)	(5.979)	(5.115)	(4.984)
1	-10.557 *	-0.286	-6.435 *	-3.851	-6.608	-15.595*	-8.767*
	(1.266)	(0.637)	(2.314)	(4.280)	(3.906)	(5.053)	(3.024)
2	-3.630 *	-0.287	-10.172*	-3.713	-7.797*	-14.804*	-3.793
	(1.128)	(0.620)	(1.574)	(4.237)	(3.482)	(4.970)	(2.413)
3	-12.083 *	-0.287	-10.749*	-3.423	-7.904*	-18.009 *	-3.231
	(0.987)	(0.601)	(1.401)	(4.199)	(3.320)	(4.910)	(2.148)
4	-7.438 *	-0.286	-10.513*	-3.605	-8.872*	-4.820	-2.200
	(0.883)	(0.585)	(1.333)	(4.131)	(3.193)	(4.638)	(1.883)
5	-9.099 *	-0.287	-9.791*	-3.565	-8.047*	-16.971*	-2.355
	(0.789)	(0.579)	(1.224)	(4.070)	(3.126)	(4.525)	(1.861)
6	-6.158 *	-0.289	-9.485*	-3.149	-7.933*	-16.712*	-2.225
	(0.693)	(0.559)	(1.181)	(4.026)	(3.031)	(4.505)	(1.852)
7	-0.840	-0.290	-9.070*	-2.916	-6.966 *	-16.455 *	-1.838
	(0.590)	(0.552)	(1.140)	(4.007)	(2.970)	(4.491)	(1.834)
8	-7.143 *	-0.290	-8.701 *	-2.719	-8.287 *	-18.750*	-1.838
	(0.397)	(0.524)	(1.111)	(3.948)	(2.923)	(4.464)	(1.787)
9	0	-0.290	-7.909 *	-2.912	-10.493 *	-4.009	-1.904
		(0.499)	(1.072)	(3.874)	(2.863)	(4.253)	(1.779)
10		-0.241	-7.076 *	-2.836	-8.401*	-15.641 *	-1.835
		(0.490)	(1.046)	(3.517)	(2.781)	(4.125)	(1.775)
11		0.004	-6.440*	-3.935	-7.773*	-12.082*	-1.434
		(0.374)	(1.024)	(2.963)	(2.658)	(4.082)	(1.761)
12		-0.001	-6.228 *	-4.359	-7.050 *	-10.583*	-1.487
		(0.310)	(0.999)	(2.427)	(2.563)	(3.921)	(1.747)
13		-0.002	-5.527*	-4.486*	-5.457 *	-11.829 *	-0.952
		(0.283)	(0.967)	(2.266)	(2.460)	(3.829)	(1.735)
14		-0.002	-5.224*	-4.486*	-7.504*	-0.886	-0.448
		(0.269)	(0.942)	(2.202)	(2.278)	(3.438)	(1.730)
15		-0.001	-4.875*	-4.545*	-7.971*	-14.441*	0.180
		(0.228)	(0.922)	(2.107)	(2.091)	(3.203)	(1.727)
16		-0.001	-4.584*	-4.466*	-7.503*	-15.235*	0.979
		(0.222)	(0.891)	(1.972)	(1.969)	(3.160)	(1.661)
17		-0.001	-4.376 *	-4.531*	-7.271*	-15.674 *	0.570
		(0.213)	(0.862)	(1.830)	(1.818)	(3.134)	(1.171)
18		0.000	-3.838 *	-4.570*	-6.182 *	-18.320 *	0.503
		(0.176)	(0.834)	(1.587)	(1.687)	(3.094)	(0.933)
19		-0.001	-3.124 *	-4.480*	-4.816*	-5.993 *	0.367
		(0.109)	(0.802)	(1.365)	(1.560)	(2.833)	(0.905)
20		-0.001	-1.610 *	-4.387*	-3.702*	-13.074*	0.374
		(0.072)	(0.742)	(1.081)	(1.412)	(2.579)	(0.876)
21		-0.001	-0.425	-4.304 *	-3.232 *	-12.986*	0.246
		(0.059)	(0.616)	(0.808)	(1.108)	(2.375)	(0.688)
22		0	0	0	0	-13.063*	0
						(2.158)	
23						-14.173 *	
						(2.036)	
24						0	

Table A.2 (data plotted in charts)

Benchmark Estimates: Maintenance Period Variance Effects

(ratio to standard deviation of last day, standard errors in parentheses; * indicates significance at 5% level)

Days from end of maintenance period, x_{mt}:	United States	Japan	Germany	France	Italy	Canada	Euro zone
0	1	1	1	1	1	1	1
1	0.389 *	0.722 *	0.498 *	0.644 *	0.372 *	1.071 *	0.587 *
	(0.025)	(0.064)	(0.052)	(0.092)	(0.052)	(0.220)	(0.150)
2	0.364 *	0.523 *	0.242 *	0.795 *	0.216 *	0.883 *	0.243 *
	(0.026)	(0.045)	(0.026)	(0.119)	(0.031)	(0.202)	(0.062)
3	0.274 *	0.503 *	0.151 *	0.519 *	0.193 *	1.993 *	0.221 *
	(0.019)	(0.044)	(0.017)	(0.074)	(0.029)	(0.509)	(0.061)
4	0.267 *	0.475 *	0.170 *	0.562 *	0.113 *	1.266 *	0.100 *
	(0.019)	(0.043)	(0.019)	(0.076)	(0.016)	(0.296)	(0.027)
5	0.259 *	0.625 *	0.121 *	0.736 *	0.134 *	0.479 *	0.038 *
	(0.018)	(0.054)	(0.014)	(0.108)	(0.019)	(0.112)	(0.011)
6	0.235 *	0.538 *	0.105 *	0.578 *	0.118 *	0.361 *	0.072 *
	(0.017)	(0.050)	(0.012)	(0.088)	(0.017)	(0.079)	(0.022)
7	0.288 *	0.649 *	0.087 *	0.569 *	0.113 *	0.620 *	0.072 *
	(0.021)	(0.061)	(0.010)	(0.087)	(0.016)	(0.146)	(0.022)
8	0.294 *	0.675 *	0.091 *	0.766 *	0.131 *	1.759 *	0.050 *
	(0.021)	(0.065)	(0.010)	(0.109)	(0.020)	(0.462)	(0.014)
9	0.176 *	0.608 *	0.080 *	0.621 *	0.134 *	1.321 *	0.042 *
	(0.060)	(0.058)	(0.010)	(0.103)	(0.022)	(0.318)	(0.012)
10		0.545 *	0.072 *	0.370 *	0.135 *	0.720 *	0.066 *
		(0.084)	(0.008)	(0.085)	(0.021)	(0.181)	(0.019)
11		0.484 *	0.079 *	0.454 *	0.135 *	1.162 *	0.037 *
		(0.070)	(0.009)	(0.099)	(0.020)	(0.278)	(0.010)
12		0.600 *	0.083 *	0.440 *	0.150 *	0.777 *	0.048 *
		(0.078)	(0.010)	(0.079)	(0.022)	(0.205)	(0.014)
13		0.370 *	0.073 *	0.380 *	0.190 *	1.853 *	0.049 *
		(0.032)	(0.009)	(0.055)	(0.028)	(0.501)	(0.014)
14		0.583 *	0.065 *	0.535 *	0.165 *	1.382 *	0.059 *
		(0.052)	(0.007)	(0.075)	(0.024)	(0.349)	(0.019)
15		0.499 *	0.079 *	0.845 *	0.146 *	0.601 *	0.056 *
		(0.046)	(0.009)	(0.116)	(0.021)	(0.140)	(0.017)
16		0.501 *	0.078 *	0.517 *	0.147 *	0.458 *	0.062 *
		(0.047)	(0.009)	(0.074)	(0.022)	(0.109)	(0.026)
17		0.522 *	0.070 *	0.646 *	0.129 *	0.637 *	0.056 *
		(0.049)	(0.008)	(0.094)	(0.018)	(0.153)	(0.019)
18		0.548 *	0.083 *	0.572 *	0.139 *	1.693 *	0.029 *
		(0.046)	(0.009)	(0.082)	(0.020)	(0.431)	(0.009)
19		0.480 *	0.090 *	0.730 *	0.136 *	1.159 *	0.048 *
		(0.043)	(0.010)	(0.102)	(0.020)	(0.275)	(0.013)
20		0.517 *	0.109 *	0.443 *	0.156 *	0.669 *	0.065 *
		(0.048)	(0.013)	(0.062)	(0.025)	(0.210)	(0.018)
21		0.470 *	0.120 *	0.742 *	0.117 *	0.649 *	0.094 *
		(0.054)	(0.017)	(0.160)	(0.021)	(0.201)	(0.037)
22		0.740 *	0.079 *	0.256 *	0.103 *	0.506 *	0.086
		(0.161)	(0.018)	(0.074)	(0.036)	(0.159)	(0.054)
23						1.467 *	
						(0.510)	
24						0.990 *	
						(0.430)	

Table A.3 (data plotted in charts)

Benchmark Estimates: Weekday Mean and Variance Effects

(standard errors in parentheses; * indicates significance at 5% level)

	Japan	Germany	France	Italy	Canada	U.K.	Euro zone
$\boldsymbol{d}_{wt}$							
Monday	0	0	0	0	0	0	0
Tuesday[1]	0.000	0.384 *	0.091	-0.362	-0.081	-0.773	-0.067
	(0.059)	(0.114)	(0.317)	(0.342)	(0.103)	(1.234)	(0.111)
Wednesday[1]	0.001	-0.341 *	0.109	-1.401 *	-0.083	-1.128	-0.085
	(0.061)	(0.143)	(0.373)	(0.400)	(0.147)	(1.118)	(0.150)
Thursday[1]	0.000	-1.286 *	-0.013	-1.165 *	0.140	1.148	-0.175
	(0.049)	(0.152)	(0.393)	(0.399)	(0.148)	(0.938)	(0.159)
Friday[1]	0.000	-1.243 *	-0.018	-0.528	-0.001	-2.830 *	-0.116
	(0.041)	(0.137)	(0.348)	(0.329)	(0.111)	(0.656)	(0.125)
$\boldsymbol{x}_{wt}$							
Monday	1	1	1	1	1	1	1
Tuesday[2]	0.714 *	0.941 *	1.154 *	0.908 *	1.336 *	0.789 *	1.355 *
	(0.033)	(0.050)	(0.082)	(0.061)	(0.168)	(0.032)	(0.150)
Wednesday[2]	0.751 *	1.187 *	1.115 *	0.985 *	1.747 *	0.904 *	1.490 *
	(0.036)	(0.064)	(0.079)	(0.069)	(0.234)	(0.039)	(0.182)
Thursday[2]	0.696 *	1.037 *	1.101 *	0.903 *	1.405 *	1.047 *	1.048 *
	(0.031)	(0.058)	(0.080)	(0.062)	(0.191)	(0.046)	(0.123)
Friday[2]	0.813 *	1.206 *	1.379 *	0.929 *	1.169 *	1.027 *	1.368 *
	(0.039)	(0.065)	(0.093)	(0.063)	(0.152)	(0.045)	(0.152)

[1] Mean difference from Monday.
[2] Ratio to standard deviation of Monday.