The Overnight Interbank Market: Evidence from the G-7 and the Euro Zone

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Abstract

We study the interbank markets for overnight loans of the major industrial countries, linking the behavior of very-short-term interest rates to the operating procedures of these countries' central banks. Previous studies have focused on key features of U.S. federal funds rates' behavior. We find that many of these features are not robust to changes in institutional details and style of central bank intervention, along both cross-section and time-series dimensions of our data. Our results suggest that the empirical features of the day-to-day behavior of short-term interest rates are more strongly influenced by institutional arrangements than by extensively researched market frictions.

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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, increasingly volatile towards the end of reserve-holding periods, and others (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 in a frictionless market short-term interest rates should display no systematic pattern of change from one trading day to another. Empirical findings suggest 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' yield by reserves (Campbell, 1987; Hayashi, 2000). From the policy point of view, 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.

This paper offers a comprehensive analysis of the empirical behavior of very-short-term interest rates in the main industrial countries. Its 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. Since the market frictions that have played a major role in explaining these features are unlikely to be very different among the countries we analyze, our results suggest that future research may benefit from focusing on institutional details and central bank operating procedures as the main factors shaping the behavior of interbank markets. For policy-makers, the implication of this viewpoint 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 and the Euro zone, over a period of about sixteen years. This sample of international data offers considerable variability in institutional regimes. In time series, this variability originates from the reforms of money-market arrangements implemented in some of our sample countries. In cross-section, institutional variability reflects 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 sample countries, a feature that we view as the distinguishing trait of our work, and its main contribution to the literature. This effort requires us to account in detail for many institutional features of our sample markets, and to disentangle the effects of these features on interest rates from those of factors such as time-persistent volatility and fat-tailed distributions of interest rates. The reward for our effort to implement a coherent empirical strategy across countries and periods is that we can identify a number of interesting features 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 features can be related to cross-country differences in the role of reserve requirements, standing facilities, style of monetary intervention, and choice of nominal anchor. Other features are less easily traceable to specific institutions or procedures, and may motivate future research in this field.

2 The interbank reserve market

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

In most countries, banks access the reserve market both for the purpose of clearing customer-originated transactions and to satisfy reserve requirements. The latter are usually defined on a period-average basis: required reserves as a ratio of average liabilities over "reserve computation" periods; and actual reserves as averages of daily values over subsequent "reserve maintenance" periods.

Reserve requirements play an important role in stabilizing interest rates through two interrelated channels. First, if banks hold reserves then markets are of course better buffered against unanticipated liquidity shocks on any given day. Moreover, when requirements are defined on an average basis, market interest rates should exhibit a "martingale property:" if the bulk of reserves is held for the purpose of satisfying reserve requirements, 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 in the face of systematic patterns in reserve flows, such as Friday surges in cash withdrawals or Treasury payments, and should not respond to predictable central bank intervention. For instance, an anticipated monetary tightening in the middle of a maintenance period should not lead to 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.

While the martingale hypothesis implies that interest rates *means* should be constant within each maintenance period, it has weaker predictions for the daily evolution of interest rate *volatilities*. Spindt and Hoffmeister (1988) argue that increasing variance through each maintenance period is a necessary implication of average reserve accounting. Interest rate volatility, however, may cluster on settlement days or rise gradually over each maintenance period, depending on the confidence with which the market views the central bank's commitment to target interest rates. In particular, if a central bank is reluctant to offset fully aggregate reserve shocks experienced by banks, then shocks to reserves occurring before end-period will exert pressure on current interest rates (upward or downward), causing high interest rate volatility to spread from settlement day to previous days. Conversely, if the central bank stands ready to offset all aggregate shocks to liquidity before end-period, interest rate volatility will be relatively small through the last-but-one day of the maintenance period, spiking up only on settlement day (Bartolini *et al.*, 2002). Thus, the time profile of interest rate volatility over the maintenance period provides information on the central bank's commitment to interest rate smoothing, as perceived by participants in the interbank market.

Empirically, the martingale hypothesis has not fared well. Many studies have documented high-frequency, predictable patterns in mean U.S. federal funds rates (see, for instance, Campbell, 1987, Rudebusch, 1995, Hamilton, 1996, and Balduzzi *et al.*, 1997). For instance, federal funds rates tend to rise systematically on reserve-settlement days, on Mondays, and on quarterly reporting dates, and to fall systematically on Fridays. Such patterns have found two types of explanations in the literature. First, banks do not hold reserves merely to satisfy requirements, but also because of the liquidity services that reserves provide; hence, banks may be reluctant to substitute holdings of reserves over the maintenance period, so as to offset predictable changes in interest rates. Second, market frictions–such as transaction costs, interbank credit limits, window-dressing needs, and imperfect dealer/customer relationships–hinder the arbitrage over predictable differences in the cost of holding reserves across days.

Both of these mechanisms are realistic, and likely contribute to deviations of interest rates from a martingale empirical representation. Bid-ask spreads and transaction costs, however, play a similar qualitative role and are roughly comparable in magnitude in different countries; customer-broker relationships and credit line arrangements are also pervasive and qualitatively similar internationally. By contrast, differences in institutional details and style of central bank intervention are very plausible sources of the sharp differences in the behavior of short-term interest rates we identify below, both across countries and over time.

In this respect, an important source of institutional variation in our data is the ongoing international trend towards less stringent reserve requirements. This trend is occurring not only because of central banks' effort to lower reserve ratios and narrow the set of liabilities subject to reserve—so as to reduce the burden of reserve requirement on banks—but also because of the market's own evolution. Banks, especially in the United States, have begun to "sweep" balances overnight from liabilities subject to reserve 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 highlights the likely impact on interbank markets of this important ongoing change.

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. The overall sample starts in January 1985 and ends in June 2001, but the length of each country's series is limited by availability of homogeneously defined data. Hence, the Italian sample begins at end-1990, when the reserve requirement 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). The full data set is available upon request from the authors.

For each country, we assembled three series of policy rates on the basis of information from BIS (1997) and from individual central banks.

The first series is 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 interbank rate target only in the U.S., Japan and Canada, and to an implicit target in France.[1] In our empirical specifications, the "target" role is played by the realized rate on repo open market auctions in Germany, Italy, and the U.K., and by the minimum accepted auction rate in the Euro zone.

The other two interest rate series pertain to central bank 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, central bank facilities offering unrestricted overnight loans and accepting deposits at given rates would constrain market rates within a 'corridor.' While such completely unrestricted standby facilities are rarely available, it is usually possible to identify the boundaries of money market policy corridors. In our data set, the corridor's ceiling is represented by rates on standing lending facilities for Germany, France, United Kingdom, Italy, Canada, and the Euro zone; and by penalty rates on reserve deficiencies for United States and Japan. The corridor's floor is represented by rates of interest paid on excess reserves in Italy, Canada, and the Euro zone; by discount rates in Germany; and by repurchase tender rates in France. For the United States, Japan, and the U.K., we set the corridor's floor at the natural zero

[1] Target rates are available since January 1, 1985, for the United Kingdom and since December 1, 1992, for Canada. Our series for the Bank of Japan's target begins in July 1995. Until September 1998, however, targets were not published, but could be inferred to some extent from statements in the form "(BOJ) expects that short-term market rates on average will decline slightly below the ODR (Official Discount Rate)." Accordingly, we set the target for the July 1995-September 1998 period at the average interbank rate recorded between announcements (such imputed targets averaged about five basis points less than the discount rate). In France, the central bank never announced a formal target for the short-term rate, but it intervened since 1986 to steer the rate inside the policy corridor defined by its marginal facilities (Pfister, 1997). Accordingly, we constructed a "target" series assuming the target rate to remain constant at the median market rate of the last 5 days until this median changes by at least 5 basis points and the change is sustained for at least 3 days. This imputed series–which tracks the main discrete changes in the French overnight rate–is only used below in tests of corridor credibility, not as an explanatory variable for the level of the market rate.

lower bound of nominal interest rates, as no more suitable series are available.[2] For some countries, the corridor facilities were not in place throughout the whole estimation period; the corresponding series were dummied out when not operational.

Before proceeding with estimation, we examined the data to identify outliers and other factors requiring special attention. Quite generally, across countries and over time, both mean levels and volatilities of market rates displayed clear seasonal behavior, such as higher and more volatile rates at end-months, end-quarters, and end-years. Volatility persistence and many outliers were also apparent. The empirical specification that we outline next was designed to encompass these features.

3.2 The empirical model

Our basic empirical model has the form

$$r_t = \mu_t + \sigma_t \nu_t,$$

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 the interest rate r_t evolve over time according to the models described below. Econometric implementation 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, we allow for a different probability distribution for the error terms, so as to capture more easily empirical fat-tailed distributions of interest rates. We also consider a richer set of independent variables to test hypotheses on the role played by various institutional details in 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

[2] Rates on below-market borrowing facilities (discount windows) can provide lower bounds for market rates only if the facilities themselves are actively used, i.e., there is a significant outstanding stock of discount loans that banks can repay, instead of lending to other banks, when the market rate tends to fall 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). Discount borrowing was too limited in Japan to rely on discount rates as effective lower bounds to market rates.

markets of the main industrial countries. To ease comparisons across countries, we first present a set of benchmark regressions for all our sample markets, allowing only fixed-effect dummies to differ across countries to reflect different reserve-maintenance periods and holidays. In order to examine more closely the effects of different institutional arrangements on the behavior of short-term interest rates, we then present "extended" regressions that 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

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

where $m_t \in \{2, \ldots, T\}$ is the day of the maintenance period of length T associated with observation t, if any (no maintenance period effects are estimated for the U.K., which did not implement a reserve-averaging system at any time during our sample; Canada abolished reserve averaging in February 1999, hence maintenance period effects are identically zero after that date). Calendar and maintenance period effects are denoted as follows:[3]

δ_{m_t} is a constant specific to day m_t of the maintenance period,

δ_{w_t} is a constant specific to day w_t of the week, and

[3] These effects are not always easy to identify separately. Since the U.S. and post-1994-Canada maintenance periods always end on Wednesdays, high collinearity prevents separate identification of the δ_{w_t} and δ_{m_t} coefficients; in the charts below, the implied weekly coefficients are derived from the estimated maintenance period coefficients. In the other countries, where the maintenance period is linked to calendar months, one linear restriction suffices to identify both weekday and maintenance period effects (we restrict the sum of the weekday coefficients δ_{w_t} to zero). In Germany and Italy, however, end-months fall almost always on the same days of the maintenance period: high collinearity prevents separate estimation of end-month coefficients, which were omitted from these countries' mean and variance equations.

δ_{c_t} is a set of constants specific to calendar days c_t, which include holidays, days before and after holidays, and end of months, quarters, and years.

Finally, h_t is a vector of country-specific policy rates and sample-splitting dummies, described below.

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 included in (1). Thus, for $m_t = 1$:

$$\mu_t = r_{t-1} + \sum_{i=1}^{5} \phi_i (r_{t-i} - r_{t-i-1}) + \delta_{m_t=1} + \delta_{w_t} + \delta_{c_t} + \alpha' h_t \ . \qquad (2)$$

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 $m_t = 1, \ldots T$, as:

$$\log\left(\sigma_t^2\right) - \xi_{m_t} - \xi_{w_t} - \xi_{c_t} - \omega' h_t - \log(1 + \gamma N_t) = \alpha \left|\nu_{t-1}\right| + \theta \nu_{t-1} +$$
$$\lambda \cdot \left[\log\left(\sigma_{t-1}^2\right) - \xi_{m_{t-1}} - \xi_{w_{t-1}} - \xi_{c_{t-1}} - \omega' h_{t-1} - \log\left(1 + \gamma N_{t-1}\right)\right] \ , \qquad (3)$$

a specification that again allows for calendar and maintenance-period effects:[4]

ξ_{m_t} is a constant specific to day m_t of the maintenance period;

ξ_{w_t} is a constant specific to day w_t of the week;

ξ_{c_t} is a constant specific to calendar day c_t, including holidays, end-months, end-quarters, and end-years.

[4]As discussed above, for the U.S. we report the weekday coefficients implied by the estimated maintenance-period coefficients. For the other countries, we exclude the last-day-of-maintenance-period dummy. End-of-months effects could not be estimated in Germany and Italy, due to high collinearity with maintenance-period days.

The vector h_t again contains country-specific variables, and N_t denotes the number of nontrading days between trading days $t-1$ and t.[5]

Equation (3) allows for "Exponential GARCH" effects (Nelson, 1991) to capture persistent deviations of the (log of) the conditional variance from its unconditional expected value. Analysis of the correlogram of squared standardized residuals led us to an EGARCH(1,1) model for all countries except the United Kingdom, where an EGARCH(2,2) was required. Our specification also allows for the variance of positive and negative shocks to differ, as captured by a non-zero coefficient θ for ν_{t-1}.

3.2.3 Extended regressions

In our extended regressions we included a small set of country-specific variables and sample-split dummies, to examine more closely the link between interest rate dynamics and institutional factors. Among these, first we considered 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 property does not hold for any reason, changes in policy rates should be a significant explanatory variable for market rates. For this reason, we included changes in target, ceiling, and floor rates (i.e., respectively, the variables $\left(r_t^T - r_{t-1}^T\right)$, $\left(r_t^C - r_{t-1}^C\right)$, and $\left(r_t^F - r_{t-1}^F\right)$) in the equation for the mean, to capture level-shift effects of policy rates on market rates. To capture additional effects of policy shifts on volatility, we also included, in the equation for the variance, dummy variables valued at one for days in which either a target, a ceiling, or a floor rate changed.

Second, for all countries, we included a variable measuring the position of the key operational ("target") rate in the trading corridor for market rates, $z_t = \frac{r_t^T - r_t^F}{r_t^C - r_t^F}$, in the equation for the variance. This specification allows us to test the conjecture that interest rate volatility should reflect the commitment of the monetary authority to provide or drain liquidity to keep market rates within corridors around the target rate. If banks are confident of their ability to borrow from (or lend to) the central bank as markets rates approach the corridor's limits, fluctuations in interest rates should be truncated—thereby reducing volatility—as the target rate approaches either the corridor's

[5] Thus, for instance, if γ=0.1 and there are two nontrading days between trading day *t-1* and trading day t, then σ_t^2 is 20 percent higher than usual.

ceiling or its floor. Conversely, if marginal facilities do not represent a credible commitment by the central bank to control fluctuations of interest rates—e.g., because such facilities are rationed, or policy rates are 'realigned' in response to pressure on exchange rates and reserve outflows from the banking sector—then interest rate volatility may rise as target rates approach the corridor's bounds.

Third, similar considerations led us to include an index of exchange rate pressure (namely, the squared ERM divergence indicator)[6] in the equation for the variance of interest rates for countries participating in Europe's Exchange Rate Mechanism (ERM): Germany, France, Italy, and the United Kingdom.[7] This accounts for the fact that these countries' monetary authorities had to subordinate their stance in the interbank market to conditions in the currency market, by intervening in the reserve market and/or altering policy rates when their currencies were out of line with respect to other ERM currencies. We conjecture that subordinating domestic interest rate targets to exchange rate targets may cause (otherwise unexplained) volatility in interbank rates during periods of exchange rate pressure.

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 corresponded to the Fed's shift to a system of 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).

[6]The indicator is calculated as the ratio between the *actual* and *maximum permitted* spread between a currency's market rate and its ECU central rate. Thus, the indicator 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 indicator is squared since the hypothesis is that interest rate volatility should rise when exchange rates diverge from their central parity in either direction.

[7]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 reserve computation period. The goal of the change was to reduce uncertainty over *required* reserves, although the major source of uncertainty for interest rates—Treasury flows affecting *actual* reserves—was not affected by the change.

Fed commentary and our results below, however, suggest that this sample split may capture the effects of the diffusion of sweep practices among U.S. banks in the late part of the 1990s, rather than those of the shift to lagged reserve accounting. Similarly, in the volatility equation, we allowed the 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, bank-crisis period, than the statutory changes implemented in December 1990.[9]

Canada provides the most drastic regime shift in our whole sample: first, the length of the reserve maintenance period was changed and reserve requirements were lowered to zero by June 1994; then, averaging was completely 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 dummy in the United Kingdom volatility 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.[10]

3.3 Estimation

We assumed the innovations to interest rates, ν_t, to have a Student-t distribution, whose degrees of freedom we could estimate to match both the fat tails and the concentration of small interest rate changes found in the data. We then obtained nonlinear maximum likelihood estimates of the

[9] We also included a dummy in the U.S. variance equation for the two maintenance periods from 1/10/1991 to 2/6/1991, which immediately followed the December 1990 reform in reserve requirements, and during which volatility was extraordinarily high.

[10] 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), a move largely aimed at reducing interest rate volatility.

parameters by numerical optimization.

To circumvent convergence problems induced by the non-differentiability of the EGARCH variance at the origin, we used a twice-differentiable approximation to the absolute-value function $|\nu_t|$. We followed Andersen and Lund (1997, p. 351) in 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 value of K would ensure a very close and twice-differentiable approximation to $|\nu_t|$.

We did not pursue a general-to-specific specification 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.

Difficulties in achieving convergence of the extended model forced only two exceptions to this rule. For France, we set all maintenance-period and weekday coefficients to zero: these 27 coefficients were insignificant in our benchmark mean regressions, and attempts to estimate them in the extended maximum likelihood specification failed to converge. Almost the same was true for Japan: only two of 27 maintenance period coefficients were significant in the benchmark mean regression, and all others were set to zero in the extended regression for that country.

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

Complete results of our estimations are presented, partially in tabulated form, partially in graphical form, in Tables 2-7 and Figures 1-5.[11] We discuss them in the form of main lessons we draw from our analysis, plus a summary of more technical results.

1. ***Liquidity effects at the daily frequency are widespread.*** Under the martingale hypothesis, none of the calendar variables (δ_{m_t}, δ_{w_t}, and δ_{c_t}) should help explain the behavior of r_t in our benchmark regressions. In fact, we find widespread violations of this prediction: our samples feature a multitude of predictable changes in mean interest rates at the daily frequency. These effects are formally documented by the presence of statistically significant coefficients of vari-

[11] Tables A.1-A.3 of the electronic version posted on the authors' Web pages report the estimates plotted in the charts.

ables other than r_{t-1} in equation (1), beginning with the maintenance-period and weekday effects displayed in Figures 1-2.

In particular, the U.S. and German rates display a clear tendency to decline through the maintenance period and to rise back at end-period, while in France, Italy, and Canada, the rate falls significantly from the first day of the period to the immediately-following days. (Mean Euro zone rates also display a J-shaped pattern as in Germany but less marked.) Also, in the U.S., Tuesdays and Fridays are normally soft days; 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.[12] The only market displaying virtually no pattern in mean rates over the week or the reserve period is Japan where, however, end-month, end-quarter, and end-year rates are significantly higher than rates on other days (Table 2). Indeed, these rates are systematically higher in most of our samples, displaying a broad tendency to fall back in the following days. Rates also tend to fall before three-day holidays and to rise afterwards. Longer and shorter holidays also generally have predictable effects, although their sign varies across countries.

Thus, the prediction that interest rates should not display a systematic tendency to rise or fall between days in the same maintenance period is strongly and quite generally rejected. This indicates that banks are unwilling to shift their demand for reserves across days to take advantage of systematic differences in the opportunity cost of holding reserves.[13] 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 needs (Allen and Saunders, 1992). Other studies have emphasized frictions such as the cost of incurring end-of-day

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

[13] 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 repo rates display systematic patters, then evidence of patterns in mean rates does not, on its own account, provide evidence of imperfect substitutability of reserves across days.

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 (e.g., payday arrangements, periodic Treasury flows, etc.), or window-dressing effects linked to reporting dates, may result in predictable patterns in rates; 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.[14]

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 contributed to establishing the view of reserve markets as naturally 'tight' on reserve settlement days, with interbank rates 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. However, our analysis reveals that a pattern of relatively high settlement-day rates, similar to that historically displayed by U.S. data, is matched only by German and Euro-zone data. (See Figure 1.) For these three markets, Wald tests reject the equality between settlement and average non-settlement rates with p-values of 0.000, 0.049, and 0.000, respectively. In no other country we find settlement rates to be significantly higher than average non-settlement rates.

In principle, there is no theoretical need for settlement-day rates to exceed non-settlement day rates, even if banks demand more reserves at settlement then at other times: the central bank could 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.

However, central banks rarely stand ready to inject or drain reserves perfectly elastically, in

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

response to aggregate liquidity shocks, to maintain settlement-day rates in line with nonsettlement-day rates. The Bundesbank's approach to liquidity management, for instance, involved letting rates rise on settlement days, presumably to discipline banks to manage liquidity prudently before settlement. (A similar attitude may have been inherited by the ECB.) 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 this evidence points convincingly to central banks' 'style' of intervention—e.g., their inclination to provide (or not) liquidity around reserve settlement days—as a more important factor than features such as trading costs and market frictions, that were previously relied upon to explain failures of the martingale hypothesis (in particular, evidence of high settlement-day rates) in U.S. data. These frictions are unlikely to be so different between the United States, Germany, and the Euro zone on one side, and the other countries on the other. They are also unlikely to have changed significantly between our early and late U.S. sample, which, as discussed below, display different interest rate behavior.

3. *High settlement-day volatility is a robust feature of reserve markets.* In all countries assigning a significant role to periodic reserve requirements (that is, in all our sample countries except post-1994 Canada and the United Kingdom) we find settlement rates to be significantly more volatile than non-settlement rates (see Figure 3). For these countries, including pre-1992 Canada (Figure 5), Wald tests strongly reject (with p-values always smaller than 10^{-5}) the null of equality between the variance on settlement and the average variance on non-settlement 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 to either fill reserve deficiencies or unload excess reserves, thus bidding interbank rates up or down, until the opportunity cost of holding reserves equals the expected penalty charged on reserve deficiencies. An interesting confirmation of this view 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 shocks to liquidity not to be fully offset by official injection (or drain) of reserves before end-period, then shocks occurring *before* settlement will correlate with same-sign imbalances *at* settlement, 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 will be rather small through the last-but-one day of the period, spiking up only on settlement day. Thus, the time profile of interest rate volatility over the maintenance period provides information on the commitment of the central bank to interest rate smoothing, as perceived by participants in the interbank market.[15]

Indeed, in all countries displaying a significant rise in settlement-day volatility, the one or few days immediately prior to settlement display higher volatility than the rest of the period's average (Figure 3 and Table 5). Wald tests indicate that in Germany each of the seven last days has a significantly higher variance than the average of previous days. This is the case for 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 more unstable pattern of volatilities than elsewhere, only the last day has a significantly higher 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

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

intervention; accordingly, it has been either their unwillingness or their inability to completely offset liquidity shocks, the more likely reason for high interest volatility to spread 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 operations were conducted according to a more flexible once- or twice-weekly schedule.

5. *Lower required reserves are associated with weaker periodicity in interest rates, but no apparent effect on overall volatility.* Two interesting patterns are exhibited by our U.S. estimates that allow for separate profiles of interest rate means and volatilities in the pre- and post-July 1998 samples (see Figure 5). First, evidence of high settlement rates all but disappears in post-July 1998 data: the equality between settlement and average nonsettlement 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=0.87). Also, while settlement-day volatility is significantly higher than nonsettlement-day volatility in post-1998 data, as it was in pre-1998 data (both p-values are smaller than 10^{-4}), the gap falls significantly in the later period (see Figure 5).

We believe that two factors contribute to 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 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.)

An alternative compatible explanation emphasizes supply-side factors. Over time, the Fed may have become increasingly prompt in offsetting aggregate reserve imbalances as they arise during the periods, and especially aggressive in providing liquidity on settlement days. Fed intervention data 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 are 1.2 and 7.8 percent—significantly more skewed towards supply around settlement.

In addition to dampening the cyclical behavior of interest rates, falling required reserve have been seen as potentially raising the overall volatility of interest rates (Brunner and Lown, 1993, Bennett and Hilton, 1997, and 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, experimenting with several linear and nonlinear functional forms.[16] In none of our specifications, however, we found a significant link between declining reserves and interest rate volatility. Results for other two countries for which we had data on reserves (Italy and France) were also not informative.

6. *Patterns in interest rate volatility reflect the choice of intermediate policy target.* Interbank markets of countries that subordinate domestic (interbank interest rate) targets to external (exchange rate) targets can be expected to display greater volatility of interest rates during periods of exchange rate pressure: policy 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. Higher volatility of overnight rates may also be associated with an unusually strong exchange rate, if the central bank finds it difficult to sterilize the effect of capital inflows on the money market. We allowed for such a channel of volatility transmission by including in the variance equation an index of 'exchange rate pressure'–measuring the divergence of the exchange rate from the central parity–and an index of proximity of interest rates to their corridor's bounds. If the above conjecture is correct, the coefficient of the former variable should be positive: exchange rate pressure should raise the volatility of interest rates, as long as a monetary authority attaches *some* weight to the exchange rate in determining its stance in the reserve market. The coefficient of the latter variable should reflect the weight of the commitment to interest rate stabilization within the corridor, relative to that of the commitment to other objectives, such as an exchange rate target. Thus, we would expect a negative coefficient in countries where domestic objectives prevail (interest volatility falls as the 'target' rate approaches the interest rate corridor's bounds

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

because the corridor is credible); and a positive coefficient in countries where the commitment to interest rate stability conflicts with that to an alternative target (typically, the exchange rate).

As regards the first prediction, we found unambiguous evidence that countries linked in an exchange rate arrangement (Germany, France, Italy, and the United Kingdom) displayed greater interest rate volatility during periods of divergence of the exchange rate from its central parity: the coefficient for the squared ERM divergence index was always precisely estimated with the correct positive sign (Table 7), even in Germany, whose currency was mostly subject to upward pressure during this period.

As regards the second prediction (also see Table 7), we found volatility to *increase* as the interest rate approached the limits of its fluctuation corridor in Italy and France, which historically have subordinated their interest-rate policies to exchange-rate policies, as well as in Canada. Note that we estimated this effect while controlling for 'exchange rate pressure,' as discussed above: in these countries, smoother exchange rate behavior was achieved at the cost of bumpier interest rates. By contrast, we found volatility to *decline* when target rates were approaching the corridor's bounds in our sample's large 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.[17]

Other lessons. Finally, we summarize a number of results for future use in analysis of industrial countries' interbank markets.

We found some weak calendar patterns in interest rate volatility (Figure 4 and Tables 3 and 7). In most countries (with the exception of Italy and Canada), volatility is relatively high on Fridays. Volatility also tends to rise around end-months in Japan, the Euro zone, and post-1994 Canada, 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 6). Smaller-than-one coefficients for target rates in the mean

[17] We could not estimate the coefficients for pre-1992 Canada, because of the absence of a target rate in this sample; nor we could for the United Kingdom and the Euro zone, because the spread between the penalty rates and the target rates were held essentially fixed in these two samples.

equation reflect both time-aggregation (changes are often announced during business days; *effective* rates then aggregate transactions from both pre- and post-change transactions), and rationally anticipated changes (which are partially built into rates prior to the policy change). Intuitively, days with changes in policy rates displayed higher 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 volatility of overnight rates and to the presence of asymmetric effects in six of our eight samples. Non-trading days raise volatility of subsequent days only in the United States. Finally, we found the probability distributions of interest rate 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.

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. Our analysis reveals that few of the empirical regularities identified in U.S. markets—which have been the basis for most work on reserve markets in the past twenty years—can be retained as solid stylized facts, i.e., as 'natural' features of reserve markets for central bankers to take as given and for finance scholars to explain theoretically. Rather, the behavior of short-term interest rates appears to reflect, usually in intuitive ways, cross-sectional and time-series differences in institutional details and style of central bank intervention. While realistic market frictions emphasized by most previous research help explain the observed behavior of short-term interest rates, their nature and size are likely to be rather similar across countries, hence unlikely to be the source of the sharp differences in the behavior of interbank markets that we document. By contrast, institutional details and central bank operating procedures have been and will remain quite different across the world's main financial markets. They should figure prominently in future theoretical and empirical research on money markets.

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Figure 1
Benchmark mean estimates: maintenance period effects
(mean difference from first day of the period and 95 percent confidence band)

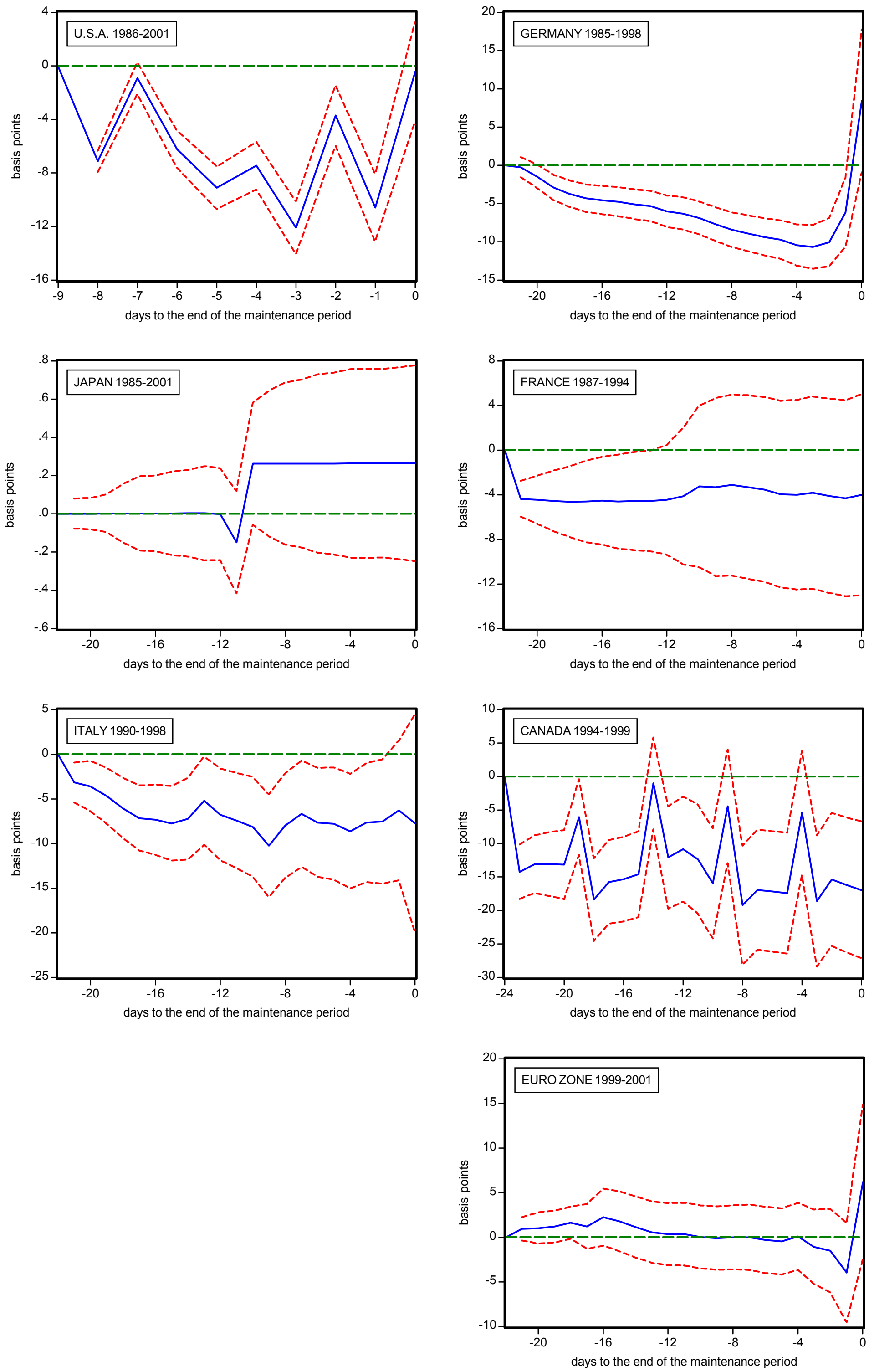

Figure 2
Benchmark mean estimates: weekday effects
(mean difference from Monday and 95 percent confidence band)

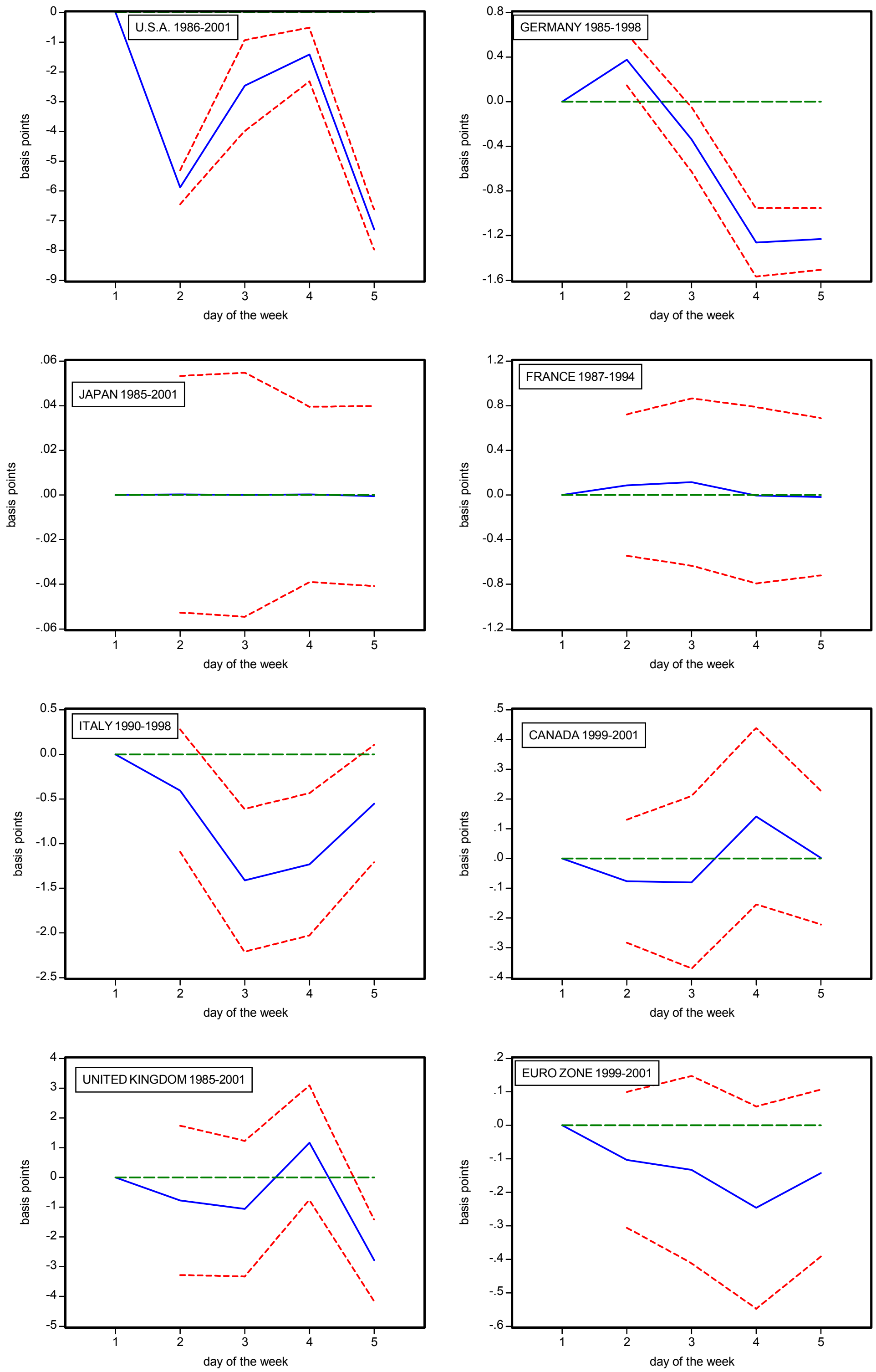

Figure 3
Benchmark variance estimates: maintenance period effects
(ratio to standard deviation of the last day and 95 percent confidence band)

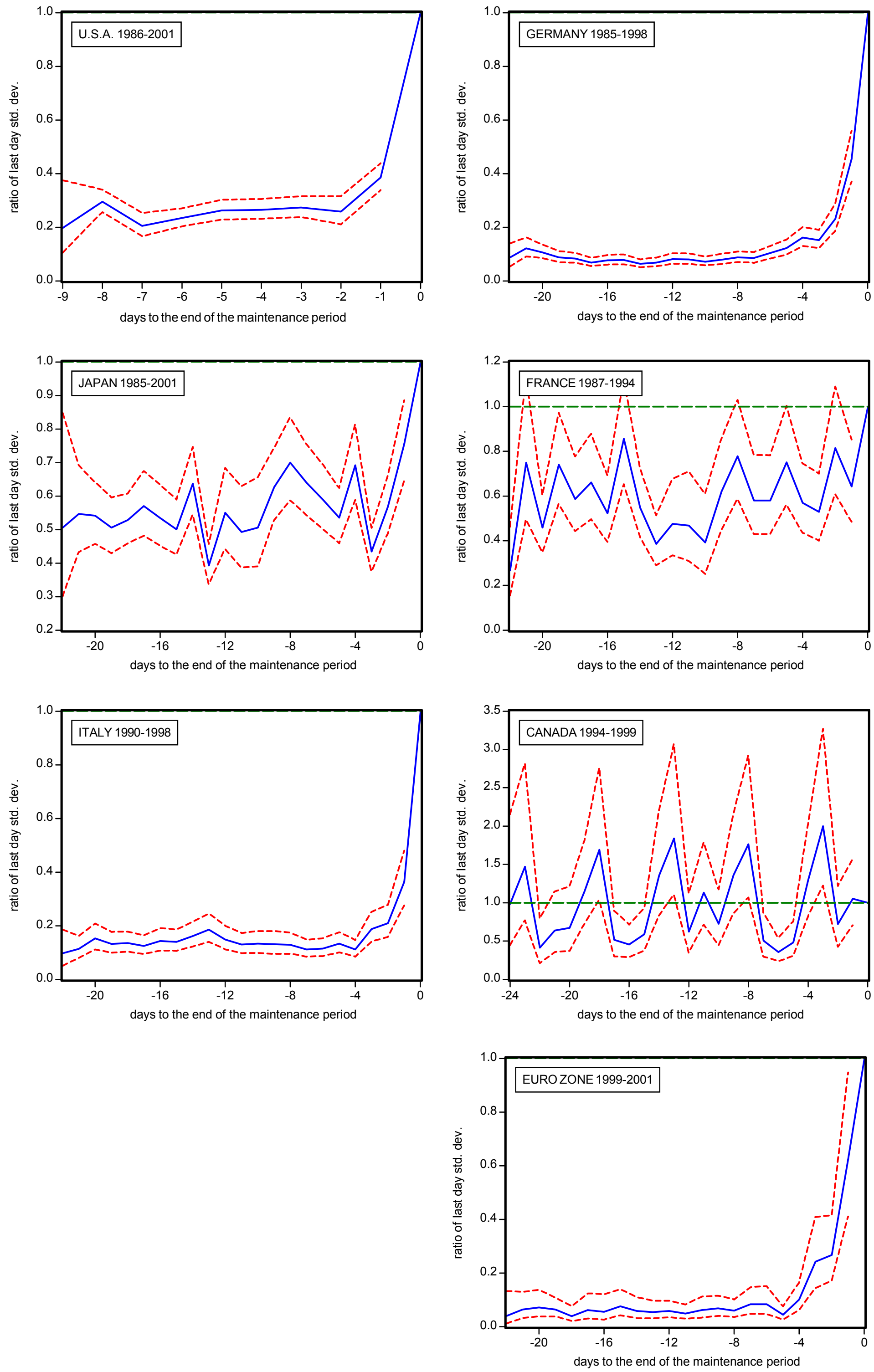

Figure 4
Benchmark variance estimates: weekday effects
(ratio to standard deviation of Monday and 95 percent confidence band)

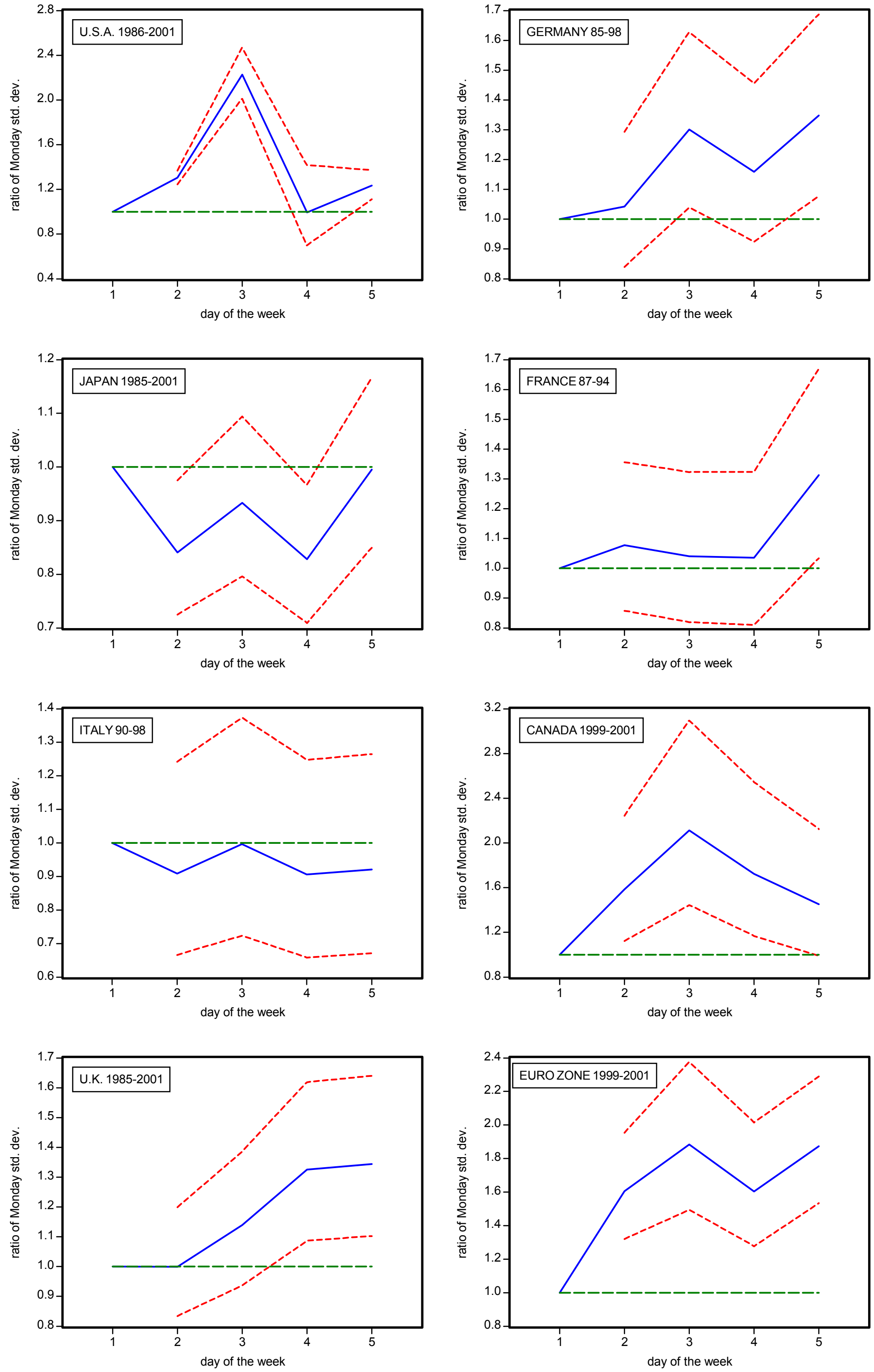

Figure 5

Extended mean estimates: maintenance period effects
(mean difference from first day of the period and 95 percent confidence band)

Extended variance estimates: maintenance period effects
(ratio to standard deviation of the last day and 95 percent confidence band)

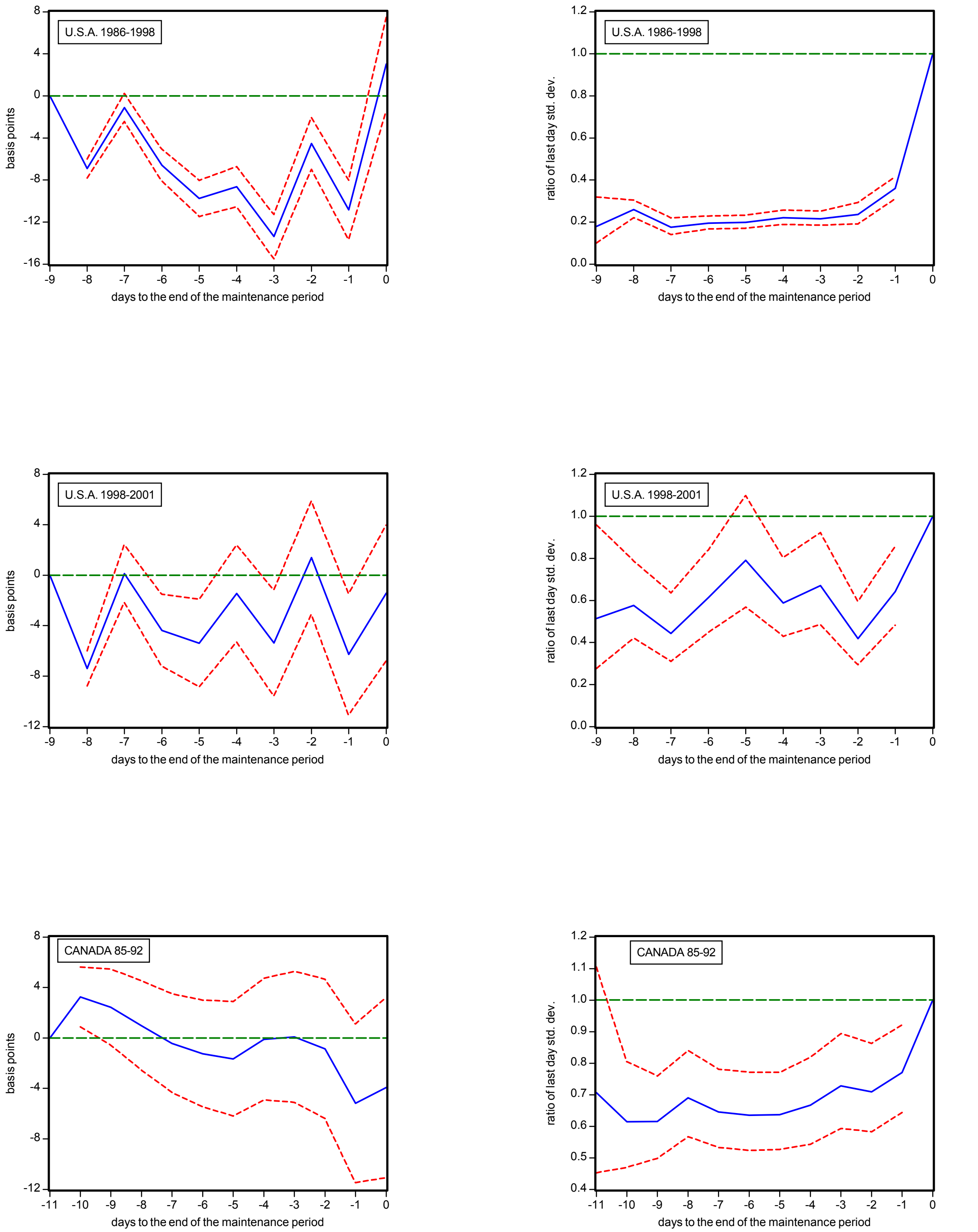

Table 1
Data, reserve requirements, and other central bank operating procedures in the G-7 Countries
(description applies to end-sample)

	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	01/29/99-06/27/01
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 Francaise 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 and vault cash	Deposits at central bank	Deposits at central bank	Deposits at central bank and 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	--	--	--	Repurchase tender rate	--	--	Bank rate -0.5% on positive balances	Rate on marginal deposit facility
Below market facility	Discount rate	Discount rate until March 1995	Discount rate	--	--	Rate on ordinary advances	--	--
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
Day before end of months 1,2,4,5,7,8,10,11	0.022 *	0.000		-0.002		0.001	-0.013	-0.014 *
	(0.007)	(0.000)		(0.013)		(0.003)	(0.013)	(0.003)
End of months 1,2,4,5,7,8,10,11	0.092*	0.002 *		-0.004		0.016 *	0.060 *	0.022 *
	(0.007)	(0.001)		(0.015)		(0.003)	(0.013)	(0.010)
Day after end of months 1,2,4,5,7,8,10,11	-0.009	-0.004 *		-0.010		-0.003	-0.031 *	-0.011
	(0.007)	(0.001)		(0.012)		(0.004)	(0.015)	(0.006)
Day before end of quarter	0.051	0.000	0.017	-0.012	0.000	0.006	0.025	0.005
	(0.031)	(0.002)	(0.038)	(0.016)	(0.014)	(0.007)	(0.025)	(0.015)
End of quarter	0.182 *	0.002 *	0.151 *	0.014	0.024	0.009	0.146 *	0.105 *
	(0.026)	(0.001)	(0.072)	(0.017)	(0.014)	(0.008)	(0.023)	(0.020)
Day after end of quarter	-0.154 *	-0.004 *	0.053 *	-0.027	-0.013	-0.005	-0.099 *	-0.134 *
	(0.031)	(0.002)	(0.027)	(0.016)	(0.016)	(0.008)	(0.022)	(0.018)
Day before end of year	0.054	-0.000	0.068	-0.001	-0.028	-0.011	0.028	
	(0.103)	(0.008)	(0.138)	(0.032)	(0.128)	(0.024)	(0.077)	
End of year	-0.524 *	0.020 *	0.422 *	0.115 *	0.208 *	-0.008	0.122 *	
	(0.065)	(0.009)	(0.173)	(0.023)	(0.064)	(0.013)	(0.054)	
Day after end of year	0.636 *	0.005	0.090 *	-0.189 *	-0.264 *	0.010	-0.030	
	(0.086)	(0.015)	(0.041)	(0.027)	(0.102)	(0.011)	(0.067)	
Day before 1-day holiday	-0.009	0.000	0.002	-0.002	-0.008	-0.003		0.101 *
	(0.016)	(0.000)	(0.005)	(0.016)	(0.020)	(0.009)		(0.046)
Day after 1-day holiday	0.037 *	0.000	0.004	-0.001	-0.061 *	0.019		-0.084
	(0.018)	(0.001)	(0.005)	(0.019)	(0.018)	(0.011)		(1.272)
Day before 3-day holiday	-0.023 *	-0.009 *	0.010	0.017	0.017	0.002	-0.189 *	
	(0.007)	(0.001)	(0.010)	(0.010)	(0.013)	(0.004)	(0.025)	
Day after 3-day holiday	0.219 *	0.003 *	0.028 *	-0.005	0.016	0.001	0.168 *	
	(0.011)	(0.001)	(0.009)	(0.010)	(0.014)	(0.005)	(0.032)	
Day before 4-day holiday		0.011	-0.024 *	-0.004	-0.025		-0.098 *	0.022
		(0.010)	(0.010)	(0.022)	(0.044)		(0.031)	(0.142)
Day after 4-day holiday		-0.025 *	0.030 *	-0.110 *	0.024		0.106 *	0.061
		(0.012)	(0.012)	(0.018)	(0.064)		(0.051)	(0.037)
Day before 5-day holiday		-0.006						
		(0.003)						
Day after 5-day holiday		0.004						
		(0.002)						
(One minus) coefficient of change in day one on changes in previous period's:								
last day	-0.824 *	-0.871 *	-0.954 *	-0.429 *	-0.909 *	-0.293		-0.792 *
	(0.018)	(0.046)	(0.018)	(0.088)	(0.031)	(0.195)		(0.040)
day before last	-0.703 *	-0.687 *	-0.954 *	-0.159	-0.824 *	-0.121		-1.039 *
	(0.025)	(0.061)	(0.043)	(0.138)	(0.079)	(0.177)		(0.073)
two days before last	-0.477 *	-0.499 *	-0.658 *	-0.247	-0.540 *	-0.160		-0.768 *
	(0.025)	(0.077)	(0.058)	(0.133)	(0.116)	(0.150)		(0.102)
three days before last	-0.285 *	-0.050	-0.825 *	-0.121	-0.684 *	-0.164		-0.844 *
	(0.025)	(0.083)	(0.100)	(0.149)	(0.119)	(0.121)		(0.066)
four days before last	-0.207 *	0.010	-0.633 *	-0.292 *	-0.008	0.201		-1.074 *
	(0.029)	(0.064)	(0.093)	(0.145)	(0.157)	(0.150)		(0.202)

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
End of months 1,2,4,5,7,8,10,11, or the previous and following days	0.121 (0.122)	1.278 * (0.205)		-0.029 (0.325)		0.382 (0.225)	-0.093 (0.107)	1.516 * (0.560)
End of quarter, or the previous and following days	1.857 * (0.153)	3.470 * (0.227)	0.489 * (0.228)	0.905 * (0.394)	0.221 (0.295)	0.545 (0.346)	-0.084 (0.163)	2.868 * (0.696)
End of year, or the previous and following days	2.189 * (0.315)	1.407 * (0.241)	0.549 (0.389)	0.609 (0.457)	2.129 * (0.464)	0.204 (0.576)	0.437 (0.288)	5.679 * (1.110)
t is the first day of the maintenance period	0.889 (0.620)	0.658 * (0.195)	2.269 * (0.236)	1.409 * (0.346)	1.378 * (0.314)	0.161 (0.506)		2.780 * (0.598)
t is between 1/10/1991 and 2/6/1991	2.924 * (0.614)							
λ	0.564 * (0.037)	0.986 * (0.002)	0.902 * (0.010)	0.969 * (0.005)	0.947 * (0.008)	0.489 * (0.045)	1.330 * (0.084)	0.607 * (0.051)
α	0.884 * (0.092)	0.475 * (0.023)	0.693 * (0.109)	0.475 * (0.047)	0.751 * (0.084)	2.120 * (0.194)	0.638 * (0.041)	1.939 * (0.300)
θ	0.316 * (0.047)	0.067 * (0.014)	-0.060 (0.033)	0.169 * (0.030)	-0.033 (0.039)	0.561 * (0.137)	-0.009 (0.028)	0.329 * (0.118)
λ (2)							-0.336 * (0.083)	
α (2)							-0.499 * (0.043)	
θ (2)							0.006 (0.030)	
Fraction by which each previous non-trading day raises variance of day *t*	0.495 * (0.151)	0.173 * (0.092)	0.115 (0.120)	-0.052 (0.089)	-0.004 (0.144)	0.253 (0.208)	0.306 * (0.140)	-0.029 (0.232)
Degrees of freedom of *t*-distribution	2.625 * (0.156)	2.664 * (0.071)	2.228 * (0.079)	2.560 * (0.123)	2.505 * (0.131)	2.059 * (0.010)	3.949 * (0.228)	3.090 * (0.618)

Table 4

Extended estimates: Maintenance period mean effects

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

	United States		Japan	Germany	Italy	Canada		Euro zone
Days from end of Maintenance period	pre-07/98	post-07/98				pre-1992	post-1994	
0	0.139 * (0.017)	0.048 * (0.012)		0.133 * (0.038)	-0.031 (0.048)	0.023 (0.014)	0.009 (0.008)	0.103 * (0.032)
1	-0.063 * (0.006)	-0.077 * (0.009)		0.033 * (0.016)	0.013 (0.016)	-0.040 * (0.012)	-0.009 (0.008)	-0.020 (0.018)
2	0.089 * (0.006)	0.068 * (0.008)		0.008 (0.007)	0.000 (0.010)	-0.009 (0.009)	0.032 * (0.008)	-0.004 (0.010)
3	-0.047 * (0.004)	-0.039 * (0.008)		-0.001 (0.004)	0.011 (0.009)	0.002 (0.009)	-0.124 * (0.016)	-0.013 (0.009)
4	0.011 * (0.004)	0.039 * (0.008)		-0.008 (0.005)	-0.009 (0.006)	0.015 (0.008)	0.122 * (0.010)	0.006 (0.003)
5	-0.032 * (0.003)	-0.010 (0.010)		-0.005 (0.003)	-0.001 (0.007)	-0.004 (0.008)	-0.005 (0.004)	-0.001 (0.002)
6	-0.055 * (0.004)	-0.045 * (0.008)		-0.005 (0.003)	-0.010 (0.005)	-0.008 (0.008)	-0.002 (0.004)	-0.003 (0.003)
7	0.058 * (0.005)	0.075 * (0.009)		-0.005 * (0.002)	0.011 (0.006)	-0.015 (0.009)	0.018 * (0.005)	-0.000 (0.004)
8	-0.069 * (0.005)	-0.074 * (0.007)		-0.007 * (0.002)	0.022 * (0.006)	-0.015 (0.009)	-0.131 * (0.011)	0.001 (0.002)
9	0.025 * (0.006)	0.035 * (0.009)		-0.008 * (0.002)	-0.020 * (0.008)	-0.002 (0.009)	0.110 * (0.010)	-0.001 (0.002)
10			0.003 * (0.001)	-0.006 * (0.002)	-0.007 (0.008)	0.048 * (0.010)	-0.034 * (0.006)	-0.003 (0.002)
11			0.000 (0.001)	-0.003 (0.002)	-0.008 (0.007)	0.019 (0.021)	-0.021 (0.012)	-0.001 (0.002)
12				-0.007 * (0.002)	-0.018 * (0.008)		0.012 (0.009)	-0.002 (0.002)
13				-0.002 (0.002)	0.022 * (0.010)		-0.105 * (0.016)	-0.006 * (0.001)
14				-0.003 (0.002)	0.005 (0.009)		0.135 * (0.011)	-0.006 * (0.002)
15				-0.002 (0.002)	-0.005 (0.006)		0.007 (0.004)	-0.005 (0.004)
16				-0.003 (0.002)	-0.000 (0.007)		0.006 (0.005)	0.010 (0.007)
17				-0.006 * (0.002)	-0.012 * (0.006)		0.032 * (0.005)	-0.005 (0.009)
18				-0.009 * (0.002)	-0.016 * (0.007)		-0.121 * (0.011)	0.004 * (0.002)
19				-0.015 * (0.003)	-0.012 (0.007)		0.071 * (0.013)	0.002 (0.002)
20				-0.014 * (0.004)	-0.004 (0.010)		0.002 (0.010)	-0.002 (0.005)
21				-0.002 (0.007)	-0.035 * (0.011)		-0.003 (0.010)	0.007 (0.008)
22				0.010 (0.027)	-0.090 * (0.026)		0.012 (0.009)	0.107 * (0.013)
23							-0.130 * (0.019)	
24							0.049 * (0.020)	

Table 5

Extended estimates: Maintenance period variance effects

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

	United States		Japan	Germany	France	Italy	Canada		Euro zone
Days from end of maintenance period:	pre-07/98	post-07/98					pre-1992	post-1994	
0	-0.554	-2.360 *	-0.533 *	-1.536 *	-1.241 *	-2.154 *	-0.530 *	-4.660 *	-1.016 *
	(0.284)	(0.378)	(0.162)	(0.204)	(0.287)	(0.277)	(0.179)	(0.377)	(0.419)
1	-2.599 *	-3.246 *	-1.084 *	-2.865 *	-0.592 *	-3.160 *	-0.687 *	-4.708 *	-2.603 *
	(0.287)	(0.356)	(0.152)	(0.216)	(0.293)	(0.279)	(0.196)	(0.361)	(0.431)
2	-3.441 *	-4.100 *	-1.380 *	-3.713 *	-1.494 *	-3.375 *	-0.629 *	-5.253 *	-2.723 *
	(0.324)	(0.401)	(0.154)	(0.224)	(0.274)	(0.290)	(0.205)	(0.412)	(0.516)
3	-3.624 *	-3.162 *	-0.885 *	-3.618 *	-1.156 *	-4.420 *	-0.813 *	-3.319 *	-4.368 *
	(0.280)	(0.359)	(0.174)	(0.220)	(0.279)	(0.277)	(0.205)	(0.442)	(0.482)
4	-3.581 *	-3.425 *	-1.187 *	-4.181 *	-0.730 *	-4.059 *	-0.896 *	-3.981 *	-6.186 *
	(0.284)	(0.345)	(0.159)	(0.230)	(0.283)	(0.280)	(0.190)	(0.347)	(0.539)
5	-3.785 *	-2.831 *	-0.986 *	-4.447 *	-1.339 *	-4.464 *	-0.904 *	-6.049 *	-5.020 *
	(0.279)	0.369	(0.169)	(0.222)	(0.284)	(0.293)	(0.194)	(0.347)	(0.585)
6	-3.826 *	-3.336 *	-0.932 *	-4.900 *	-1.213 *	-4.407 *	-0.878 *	-6.214 *	-5.010 *
	(0.284)	(0.352)	(0.168)	(0.234)	(0.297)	(0.281)	(0.191)	(0.348)	(0.565)
7	-4.041 *	-3.987 *	-0.551 *	-4.741 *	-0.656 *	-4.180 *	-0.733 *	-6.257 *	-5.693 *
	(0.328)	(0.402)	(0.187)	(0.228)	(0.278)	(0.299)	(0.197)	(0.424)	(0.505)
8	-3.258 *	-3.465 *	-0.521 *	-4.986 *	-1.275 *	-4.063 *	-0.965 *	-3.909 *	-5.196 *
	(0.287)	(0.364)	(0.184)	(0.243)	(0.331)	(0.330)	(0.211)	(0.406)	(0.544)
9	-3.992 *	-3.690 *	-0.999 *	-5.258 *	-2.053 *	-4.009 *	-0.995 *	-4.040 *	-5.750 *
	(0.628)	(0.673)	(0.261)	(0.228)	(0.430)	(0.301)	(0.269)	(0.359)	(0.617)
10			-0.703 *	-4.966 *	-1.584 *	-4.115 *	-0.779	-5.121 *	-6.002 *
			(0.249)	(0.243)	(0.418)	(0.283)	(0.443)	(0.379)	(0.524)
11			-1.786 *	-4.916 *	-1.617 *	-3.847 *		-4.282 *	-5.470 *
			(0.205)	(0.238)	(0.357)	(0.286)		(0.358)	(0.544)
12			-1.639 *	-5.235 *	-2.121 *	-3.448 *		-5.479 *	-6.169 *
			(0.161)	(0.237)	(0.286)	(0.291)		(0.460)	(0.601)
13			-1.315 *	-5.398 *	-1.487 *	-3.657 *		-3.544 *	-5.678 *
			(0.173)	(0.229)	(0.269)	(0.290)		(0.371)	(0.607)
14			-1.397 *	-5.000 *	-1.095 *	-4.192 *		-4.279 *	-5.130 *
			(0.169)	(0.239)	(0.283)	(0.290)		(0.352)	(0.609)
15			-1.267 *	-5.083 *	-1.620 *	-4.073 *		-5.899 *	-5.938 *
			(0.174)	(0.231)	(0.281)	(0.286)		(0.343)	(0.746)
16			-1.087 *	-5.259 *	-1.020 *	-4.363 *		-5.811 *	-5.603 *
			(0.172)	(0.217)	(0.285)	(0.276)		(0.373)	(0.691)
17			-0.965 *	-4.765 *	-1.138 *	-4.022 *		-5.911 *	-6.478 *
			(0.154)	(0.225)	(0.282)	(0.274)		(0.439)	(0.656)
18			-1.333 *	-4.706 *	-0.852 *	-4.076 *		-3.788 *	-5.432 *
			(0.169)	(0.221)	(0.284)	(0.294)		(0.386)	(0.507)
19			-1.207 *	-4.325 *	-1.372 *	-3.612 *		-3.788 *	-5.113 *
			(0.177)	(0.238)	(0.295)	(0.314)		(0.378)	(0.633)
20			-1.373 *	-4.069 *	-0.746	-4.441 *		-5.522 *	-5.441 *
			(0.240)	(0.294)	(0.401)	(0.361)		(0.577)	(0.743)
21			-1.532 *	-4.677 *	2.237 *	-4.354 *		-5.295 *	-6.348 *
			(0.500)	(0.499)	(0.559)	(0.624)		(0.544)	(1.256)
22								-6.269 *	
								(0.600)	
23								-4.083 *	
								(0.483)	
24								-3.475 *	
								(0.737)	

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
Monday								0.018 *	
								(0.006)	
Tuesday			0.004 *		-0.004	0.002	-0.000	-0.008	-0.001
			(0.001)		(0.003)	(0.005)	(0.001)	(0.005)	(0.001)
Wednesday			-0.007 *		-0.009 *	-0.038 *	0.000	-0.002	0.000
			(0.001)		(0.003)	(0.006)	(0.001)	(0.005)	(0.001)
Thursday			-0.010 *		0.002	0.016 *	0.002	0.023 *	-0.001
			(0.001)		(0.003)	(0.006)	(0.001)	(0.006)	(0.001)
Friday			0.001		0.007 *	0.023 *	-0.002	-0.038 *	0.001
			(0.001)		(0.003)	(0.006)	(0.001)	(0.007)	(0.001)
Day before end- month 1,2,4,5,7,8,10,11	0.023 *	-0.000		-0.000		0.011	0.000	-0.015	-0.013 *
	(0.008)	(0.001)		(0.011)		(0.025)	(0.003)	(0.013)	(0.003)
End-month 1,2,4,5,7,8,10,11	0.089 *	-0.000		0.000		0.032	0.012 *	0.060 *	0.021 *
	(0.007)	(0.001)		(0.007)		(0.031)	(0.003)	(0.013)	(0.010)
Day after end-month 1,2,4,5,7,8,10,11	-0.006	-0.003 *		-0.000		0.061 *	-0.002	-0.031 *	-0.010
	(0.007)	(0.001)		(0.008)		(0.022)	(0.003)	(0.015)	(0.006)
Day before end-quarter	0.044	-0.001 *	0.019	-0.011	0.003	0.042	0.003	0.024	0.004
	(0.032)	(0.000)	(0.039)	(0.012)	(0.016)	(0.030)	(0.007)	(0.024)	(0.016)
End-quarter	0.170 *	0.018 *	0.136	0.013	0.026	0.032	0.019 *	0.144 *	0.106 *
	(0.026)	(0.002)	(0.071)	(0.009)	(0.017)	(0.046)	(0.007)	(0.023)	(0.017)
Day after end-quarter	-0.134 *	-0.014 *	0.052	-0.011	-0.015	0.067 *	-0.014 *	-0.099 *	-0.136 *
	(0.029)	(0.003)	(0.027)	(0.012)	(0.018)	(0.033)	(0.007)	(0.021)	(0.018)
Day before end-year	0.065	-0.001	0.054	0.001	-0.031	0.032	-0.012	0.028	
	(0.114)	(0.005)	(0.126)	(0.034)	(0.140)	(0.057)	(0.037)	(0.082)	
End-year	-0.515 *	0.024 *	0.351	0.123 *	0.208 *	-0.152 *	-0.010	0.120 *	
	(0.065)	(0.011)	(0.180)	(0.018)	(0.070)	(0.069)	(0.044)	(0.056)	
Day after end-year	0.648 *	0.001	0.099 *	-0.190 *	-0.261 *	0.043	0.015	-0.030	
	(0.097)	(0.010)	(0.040)	(0.019)	(0.107)	(0.044)	(0.014)	(0.066)	
Day before 1-day holiday	-0.011	0.000	0.003	0.001	-0.006	0.082	-0.009		0.102 *
	(0.016)	(0.002)	(0.005)	(0.017)	(0.023)	(0.064)	(0.011)		(0.037)
Day after 1-day holiday	0.039 *	-0.000	0.005	-0.001	-0.060 *	0.036	0.021		-0.085
	(0.016)	(0.000)	(0.005)	(0.018)	(0.020)	(0.081)	(0.026)		(1.239)
Day before 3-day holiday	-0.023 *	-0.005	0.008	0.011	0.017	-0.001	0.002	-0.187 *	
	(0.007)	(0.001) *	(0.009)	(0.007)	(0.014)	(0.020)	(0.004)	(0.024)	
Day after 3-day holiday	0.217 *	0.002	0.028 *	-0.001	0.014	0.052 *	0.000	0.162 *	
	(0.011)	(0.001)	(0.009)	(0.008)	(0.014)	(0.017)	(0.005)	(0.033)	
Day before 4-day holiday		0.004	-0.023 *	0.000	-0.010			-0.104 *	0.020
		(0.011)	(0.010)	(0.019)	(0.054)			(0.029)	(0.148)
Day after 4-day holiday		-0.023	0.030 *	-0.087 *	0.025			0.109 *	0.063 *
		(0.010) *	(0.012)	(0.020)	(0.074)			(0.046)	(0.026)
Day before 5-day holiday		-0.002							
		(0.003)							
Day after 5-day holiday		0.003							
		(0.003)							
Day *t* change when target is changed by 1 on the same day	0.423 *	0.246 *	0.069 *				0.844 *	0.670 *	0.292 *
	(0.038)	(0.054)	(0.020)				(0.026)	(0.064)	(0.072)
Day *t* change when ceiling is changed by 1 on the same day	-0.034		0.256 *	0.006	0.165	0.097 *	0.099 *		
	(0.056)		(0.052)	(0.034)	(0.103)	(0.043)	(0.021)		
Day *t* change when floor is changed by 1 on the same day		0.329 *	-0.034	0.058 *	0.262 *				
		(0.086)	(0.034)	(0.021)	(0.093)				
(One minus) coefficient of change in day one on changes in previous period's:									
last day	-0.835 *	-0.863 *	-0.953 *	-0.206 *	-0.926 *	-0.272 *	-0.272		-0.797 *
	(0.017)	(0.049)	(0.019)	(0.082)	(0.031)	(0.054)	(0.169)		(0.040)
day before last	-0.688 *	0.697 *	-0.954 *	-0.102	-0.790 *	-0.279 *	-0.118		-1.047 *
	(0.026)	(0.062)	(0.043)	(0.098)	(0.076)	(0.065)	(0.177)		(0.087)
two days before last	-0.474 *	-0.564 *	-0.632 *	-0.013	-0.583 *	-0.319 *	-0.306 *		-0.766 *
	(0.025)	(0.082)	(0.059)	(0.140)	(0.116)	(0.095)	(0.155)		(0.111)
three days before last	-0.301 *	-0.055	-0.793 *	0.044	-0.755 *	-0.099	-0.217		-0.854 *
	(0.026)	(0.082)	(0.097)	(0.156)	(0.112)	(0.087)	(0.128)		(0.069)
four days before last	-0.207 *	-0.009	-0.615 *	-0.175	0.117	0.047	0.203		-1.092 *
	(0.029)	(0.062)	(0.085)	(0.128)	(0.146)	(0.107)	(0.166)		(0.222)

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
Monday		0.525	1.977	0.619	2.359 *	-2.632 *	-8.558 *	-0.977 *	-1.801 *
		(0.761)	(1.119)	(0.911)	(1.070)	(0.471)	(0.376)	(0.393)	(0.907)
Tuesday		-0.125	0.051	0.118	-0.123	0.048	0.516	-0.032	0.720 *
(deviation from Monday)		(0.150)	(0.215)	(0.217)	(0.321)	(0.186)	(0.305)	(0.178)	(0.355)
Wednesday		0.104	0.461	0.082	0.074	0.306	0.785 *	0.209	1.069 *
(deviation from Monday)		(0.161)	(0.227)	(0.230)	(0.328)	(0.217)	(0.347)	(0.192)	(0.392)
Thursday		-0.069	0.300	0.063	-0.099	0.711 *	1.158 *	0.480 *	0.912 *
(deviation from Monday)		(0.155)	(0.227)	(0.235)	(0.330)	(0.275)	(0.340)	(0.195)	(0.394)
Friday		0.169	0.521 *	0.213	-0.097	0.440 *	0.846 *	0.509 *	0.914 *
(deviation from Monday)		(0.160)	(0.224)	(0.228)	(0.327)	(0.214)	(0.329)	(0.195)	(0.377)
End of months 1,2,4,5,7,8,10,11,	0.143	0.790 *		-0.031		0.295	0.468 *	-0.060	1.486 *
or the previous and following days	(0.122)	(0.198)		(0.322)		(0.175)	(0.181)	(0.107)	(0.555)
End of quarter, or the previous	1.853 *	2.983 *	0.576 *	0.905 *	0.352	0.338	1.008 *	-0.059	2.905 *
and following days	(0.151)	(0.233)	(0.230)	(0.389)	(0.296)	(0.272)	(0.295)	(0.160)	(0.663)
End of year, or the previous	2.310 *	1.558 *	0.589	1.132 *	2.107 *	-0.128	0.374	0.464	5.621 *
and following days	(0.322)	(0.239)	(0.400)	(0.513)	(0.446)	(0.540)	(0.473)	(0.289)	(1.069)
Fraction by which each previous non-	0.502 *	0.157	0.114	-0.091	0.038	0.009	0.308	0.251	-0.158
trading day raises variance of day *t*	(0.155)	(0.090)	(0.121)	(0.075)	(0.161)	(0.089)	(0.201)	(0.128)	(0.108)
t is the first day of the period	0.715	0.740 *	2.169 *	1.229 *	1.193 *	0.361	-0.726		2.675 *
	(0.551)	(0.202)	(0.247)	(0.345)	(0.310)	(0.239)	(0.487)		(0.602)
ERM indicator			0.034 *	0.037 *	0.064 *			0.013 *	
			(0.008)	(0.007)	(0.015)			(0.005)	
t from 1/10/1991 to 2/6/1991 (U.S.); constant term (France); repo change dummy (U.K.)	2.813 *			0.000				-0.879 *	
	(0.614)			(0.002)				(0.379)	
	pre-91 post-91								
Position of target in corridor	-1.613* -7.734*	-25.685 *	-2.361 *	0.265 *	3.667 *		1.686 *		
	(0.739) (1.821)	(2.104)	(0.920)	(0.052)	(1.341)		(0.786)		
t is the day of a target change	0.517 *	1.931 *	0.152				0.689 *	0.891 *	1.366 *
	(0.232)	(0.314)	(0.163)				(0.185)	(0.181)	(0.634)
t is the day of a ceiling change	0.549		2.049 *	1.509 *	1.091 *	-0.294	0.104		
	(0.338)		(0.484)	(0.292)	(0.331)	(0.195)	(0.226)		
t is the day of a floor change		2.549 *	-0.851	0.127	-0.552				
		(0.402)	(0.447)	(0.287)	(0.489)				
λ	0.579 *	0.976 *	0.881 *	0.980 *	0.940 *	0.985 *	0.792 *	1.305 *	0.610 *
	(0.036)	(0.002)	(0.012)	(0.004)	(0.009)	(0.006)	(0.029)	(0.086)	(0.053)
α	0.812 *	0.592 *	0.733 *	0.345 *	0.688 *	0.228 *	0.686 *	0.639 *	1.828 *
	(0.075)	(0.030)	(0.125)	(0.034)	(0.079)	(0.031)	(0.062)	(0.041)	(0.271)
θ	0.321 *	0.023	-0.071 *	0.209 *	-0.089 *	-0.013	0.131 *	-0.006	0.296 *
	(0.043)	(0.018)	(0.036)	(0.027)	(0.040)	(0.020)	(0.044)	(0.028)	(0.114)
λ (2)								-0.312 *	
								(0.085)	
α (2)								-0.493 *	
								(0.044)	
θ (2)								0.003	
								(0.030)	
Degrees of freedom of	2.749 *	2.731 *	2.235 *	2.529 *	2.630 *	5.994 *	3.585 *	4.256 *	3.252 *
t-distribution	(0.164)	(0.088)	(0.090)	(0.114)	(0.172)	(0.898)	(0.321)	(0.268)	(0.692)

Table A.1 (data plotted in charts)

Benchmark estimates: Maintenance period mean effects

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

Days from end of maintenance period	United States	Japan	Germany	France	Italy	Canada	Euro zone
0	0.101 *	0.000	0.135 *	0.003	-0.015	-0.008	0.102 *
	(0.013)	(0.000)	(0.040)	(0.010)	(0.046)	(0.008)	(0.032)
1	-0.069 *	0.000	0.034 *	-0.002	0.012	-0.008	-0.024
	(0.005)	(0.001)	(0.016)	(0.007)	(0.017)	(0.009)	(0.018)
2	0.084 *	0.000	0.007	-0.003	0.001	0.032 *	-0.004
	(0.005)	(0.000)	(0.007)	(0.008)	(0.010)	(0.008)	(0.009)
3	-0.046 *	-0.000	-0.001	0.002	0.010	-0.132 *	-0.012
	(0.004)	(0.000)	(0.004)	(0.006)	(0.008)	(0.016)	(0.009)
4	0.017 *	0.000	-0.008	-0.000	-0.009	0.120 *	0.006
	(0.004)	(0.000)	(0.005)	(0.006)	(0.006)	(0.010)	(0.003)
5	-0.029 *	0.000	-0.004	-0.004	-0.001	-0.003	-0.002
	(0.004)	(0.002)	(0.003)	(0.009)	(0.006)	(0.004)	(0.001)
6	-0.053 *	0.000	-0.005	-0.002	-0.010	-0.003	-0.003
	(0.003)	(0.001)	(0.003)	(0.006)	(0.005)	(0.003)	(0.002)
7	0.062 *	-0.000	-0.004	-0.002	0.013 *	0.023 *	0.000
	(0.004)	(0.000)	(0.002)	(0.007)	(0.005)	(0.005)	(0.004)
8	-0.071 *	-0.000	-0.007 *	0.002	0.022 *	-0.148 *	0.001
	(0.004)	(0.001)	(0.003)	(0.009)	(0.006)	(0.013)	(0.002)
9	0.027 *	0.000	-0.008 *	0.001	-0.021 *	0.115 *	-0.001
	(0.005)	(0.001)	(0.002)	(0.009)	(0.007)	(0.011)	(0.002)
10		0.004 *	-0.006 *	0.009	-0.007	-0.036 *	-0.003
		(0.001)	(0.002)	(0.012)	(0.008)	(0.006)	(0.002)
11		-0.001 *	-0.003	0.003	-0.007	-0.015	-0.000
		(0.001)	(0.002)	(0.014)	(0.007)	(0.011)	(0.002)
12		-0.000	-0.007 *	0.001	-0.016 *	0.012	-0.002
		(0.000)	(0.002)	(0.010)	(0.007)	(0.008)	(0.002)
13		-0.000	-0.002	0.000	0.020 *	-0.111 *	-0.006 *
		(0.000)	(0.002)	(0.005)	(0.010)	(0.017)	(0.002)
14		0.000	-0.003	0.001	0.005	0.136 *	-0.007 *
		(0.000)	(0.002)	(0.006)	(0.009)	(0.012)	(0.002)
15		-0.000	-0.002	-0.001	-0.004	0.008	-0.005
		(0.000)	(0.002)	(0.008)	(0.007)	(0.005)	(0.004)
16		0.000	-0.003	0.001	-0.002	0.004	0.010
		(0.000)	(0.002)	(0.007)	(0.007)	(0.004)	(0.007)
17		-0.000	-0.006 *	0.000	-0.011	0.026 *	-0.004
		(0.000)	(0.002)	(0.009)	(0.006)	(0.005)	(0.009)
18		-0.001	-0.008 *	-0.001	-0.014 *	-0.123 *	0.004 *
		(0.000)	(0.002)	(0.008)	(0.007)	(0.013)	(0.002)
19		0.000	-0.014 *	-0.001	-0.011	0.071 *	0.002
		(0.000)	(0.003)	(0.008)	(0.006)	(0.012)	(0.002)
20		0.000	-0.013 *	-0.001	-0.004	-0.001	0.001
		(0.000)	(0.004)	(0.007)	(0.009)	(0.010)	(0.006)
21		0.000	-0.002	-0.044 *	-0.032 *	0.000	0.009
		(0.000)	(0.007)	(0.008)	(0.011)	(0.009)	(0.007)
22		0.000	0.008	-0.009	-0.083 *	0.011	0.111 *
		(0.003)	(0.026)	(0.013)	(0.023)	(0.008)	(0.013)
23						-0.142 *	
						(0.020)	
24						0.056 *	
						(0.019)	

Table A.2 (data plotted in charts)

Benchmark estimates: Maintenance period variance effects

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

	United States	Japan	Germany	France	Italy	Canada	Euro zone
Days from end of maintenance period:							
1	-1.103 *	-0.560 *	-1.545 *	-0.884 *	-2.024 *	0.098	-0.937 *
	(0.310)	(0.158)	(0.206)	(0.282)	(0.277)	(0.399)	(0.417)
2	-3.010 *	-1.130 *	-2.893 *	-0.411	-3.125 *	-0.659	-2.646 *
	(0.314)	(0.151)	(0.216)	(0.292)	(0.281)	(0.528)	(0.442)
3	-3.813 *	-1.667 *	-3.721 *	-1.273 *	-3.344 *	1.386 *	-2.844 *
	(0.353)	(0.149)	(0.224)	(0.279)	(0.292)	(0.492)	(0.524)
4	-3.696 *	-0.738 *	-3.607 *	-1.128 *	-4.390 *	0.515	-4.595 *
	(0.310)	(0.162)	(0.218)	(0.269)	(0.274)	(0.452)	(0.487)
5	-3.759 *	-1.251 *	-4.166 *	-0.573 *	-4.032 *	-1.468 *	-6.255 *
	(0.313)	(0.153)	(0.229)	(0.290)	(0.276)	(0.452)	(0.535)
6	-3.780 *	-1.058 *	-4.472 *	-1.091 *	-4.324 *	-2.066 *	-4.972 *
	(0.311)	(0.163)	(0.221)	(0.300)	(0.286)	(0.423)	(0.593)
7	-4.008 *	-0.894 *	-4.892 *	-1.088 *	-4.387 *	-1.366 *	-4.980 *
	(0.315)	(0.166)	(0.232)	(0.300)	(0.278)	(0.542)	(0.567)
8	-4.271 *	-0.714 *	-4.792 *	-0.501	-4.104 *	1.136 *	-5.641 *
	(0.357)	(0.176)	(0.226)	(0.280)	(0.299)	(0.504)	(0.517)
9	-3.545 *	-0.935 *	-5.023 *	-0.954 *	-4.071 *	0.618	-5.388 *
	(0.315)	(0.171)	(0.242)	(0.324)	(0.323)	(0.462)	(0.529)
10	-4.346 *	-1.363*	-5.274 *	-1.876 *	-4.034 *	-0.647	-5.580 *
	(0.696)	(0.259)	(0.227)	(0.443)	(0.301)	(0.484)	(0.604)
11		-1.415 *	-5.034 *	-1.518 *	-4.089 *	0.245	-6.061 *
		(0.244)	(0.242)	(0.417)	(0.288)	(0.459)	(0.521)
12		-1.196 *	-4.989 *	-1.487 *	-3.810 *	-0.945	-5.713 *
		(0.218)	(0.236)	(0.353)	(0.291)	(0.585)	(0.518)
13		-1.870 *	-5.307 *	-1.905 *	-3.377 *	1.220 *	-5.844 *
		(0.152)	(0.237)	(0.285)	(0.284)	(0.510)	(0.592)
14		-0.902 *	-5.439 *	-1.204 *	-3.642 *	0.612	-5.692 *
		(0.158)	(0.226)	(0.277)	(0.283)	(0.485)	(0.634)
15		-1.385 *	-5.093 *	-0.311	-3.929 *	-1.060 *	-5.169 *
		(0.164)	(0.238)	(0.271)	(0.281)	(0.454)	(0.605)
16		-1.255 *	-5.102 *	-1.298 *	-3.888 *	-1.583 *	-5.792 *
		(0.170)	(0.230)	(0.281)	(0.287)	(0.456)	(0.772)
17		-1.124 *	-5.309 *	-0.830 *	-4.174 *	-1.318 *	-5.598 *
		(0.168)	(0.215)	(0.286)	(0.277)	(0.543)	(0.706)
18		-1.277 *	-4.854 *	-1.069 *	-4.001 *	1.051 *	-6.492 *
		(0.140)	(0.224)	(0.282)	(0.275)	(0.489)	(0.663)
19		-1.365 *	-4.707 *	-0.600 *	-4.051 *	0.274	-5.501 *
		(0.164)	(0.219)	(0.273)	(0.294)	(0.458)	(0.524)
20		-1.228 *	-4.411 *	-1.561 *	-3.758 *	-0.801	-5.286 *
		(0.169)	(0.234)	(0.276)	(0.312)	(0.592)	(0.653)
21		-1.207 *	-4.152 *	-0.578	-4.356 *	-0.898	-5.523 *
		(0.235)	(0.288)	(0.414)	(0.355)	(0.587)	(0.730)
22		-1.364 *	-4.782 *	-2.642 *	-4.662 *	-1.776 *	-6.466 *
		(0.517)	(0.483)	(0.548)	(0.645)	(0.658)	(1.222)
23						0.773	
						(0.650)	
24						-0.037	
						(0.782)	

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
Mean parameters:							
Monday						0.018 *	
						(0.007)	
Tuesday	0.000	0.004 *	0.001	-0.004	-0.001	-0.008	-0.001
	(0.000)	(0.001)	(0.003)	(0.003)	(0.001)	(0.005)	(0.001)
Wednesday	-0.000	-0.007 *	0.000	-0.010 *	0.000	-0.003	-0.000
	(0.000)	(0.001)	(0.003)	(0.003)	(0.001)	(0.006)	(0.001)
Thursday	0.000	-0.009 *	-0.001	0.002	0.002	0.022 *	-0.001
	(0.000)	(0.001)	(0.003)	(0.003)	(0.001)	(0.007)	(0.001)
Friday	-0.000	0.000	-0.000	0.007 *	-0.001	-0.039 *	0.001
	(0.000)	(0.001)	(0.004)	(0.003)	(0.001)	(0.007)	(0.001)
Variance parameters:							
Monday	-0.640	2.474 *	0.446	4.422 *	-4.122 *	-0.811 *	-1.790
	(0.857)	(1.111)	(1.001)	(1.140)	(0.488)	(0.411)	(1.066)
Tuesday	-0.347 *	0.055	0.150	-0.191	0.922 *	-0.001	0.946
(deviation from Monday)	(0.148)	(0.215)	(0.230)	(0.312)	(0.346)	(0.182)	(0.512)
Wednesday	-0.138	0.501 *	0.080	-0.007	1.496 *	0.261	1.267 *
(deviation from Monday)	(0.159)	(0.223)	(0.240)	(0.321)	(0.382)	(0.196)	(0.548)
Thursday	-0.378 *	0.279	0.069	-0.197	1.087 *	0.564 *	0.948
(deviation from Monday)	(0.155)	(0.226)	(0.246)	(0.320)	(0.390)	(0.199)	(0.545)
Friday	-0.010	0.597 *	0.545 *	-0.164	0.743	0.592 *	1.258 *
(deviation from Monday)	(0.158)	(0.223)	(0.239)	(0.317)	(0.381)	(0.198)	(0.538)