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Abstract

We use transaction-level data and detailed modeling of the high-frequency behavior of federal funds-Eurodollar yield spreads to provide evidence of strong integration between the federal funds and Eurodollar markets, the two core components of the dollar money market. Our results contrast with previous research indicating that these two markets are segmented, showing them to be well integrated even at high (intraday) frequency. We document several patterns in the behavior of federal funds-Eurodollar spreads, including liquidity effects from trading volume on yield spreads' volatility. Our analysis supports the view that targeting federal funds rates alone is sufficient to stabilize rates in the (much larger) dollar money market as a whole.

Key words: federal funds, Eurodollar, market segmentation

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1 Introduction

Whether the markets for federal funds and Eurodollars — the two core components of the dollar money market — are well integrated is an issue relevant for both financial analysis and the execution of monetary policy.

From the viewpoint of the former, it is important to re-evaluate recent evidence of segmentation between the markets for federal funds and Eurodollars (Cyree *et al.*, 2003; Lee, 2003a,b; Demiralp *et al.*, 2004) for at least two reasons. First, such evidence is surprising, given the similar regulatory treatment of these two instruments since 1990. The spreads between federal funds and Eurodollar rates documented in these studies seem to imply unexploited arbitrage opportunities for institutions willing to borrow in one market and lend in the other. What may cause essentially identical instruments to trade at different prices?

Second, if the federal funds and Eurodollar markets are not well integrated, then by the time the funds market opens — at about 8:00 daily in New York — information accrued during the overnight closure (including about events in Europe and Asia) would not be fully reflected in federal funds rates. If so, like other markets subject to periodic closures, the funds market should exhibit unusual turbulence after its morning opening, as investors trade funds to rebalance their portfolios in accord with night-time news (Brock and Kleidon, 1992; Hong and Wang, 2000). Federal funds and Eurodollar rates may then deviate significantly from each other, especially in the morning, when price discovery should be intense in the funds market. Conversely if these two markets are well integrated: because of the overnight availability of Eurodollars, opening federal funds rates should already incorporate all news accrued overnight, investors' liquid holdings should already be near their desired levels, and federal funds rates should align well with Eurodollar rates throughout the day.

The degree of integration of the federal funds and the Eurodollar markets is also critical for the execution and transmission of monetary policy. The Federal Reserve defines its policy target only in terms of trades executed the federal funds market which, as a result, anchors the whole term structure of U.S. interest rates. However, as Figure 1 illustrates, the Eurodollar market is a larger and increasingly important source of funding for U.S. banks, having grown in such role from about half to about twice the size of the federal funds market since the mid-1980s. This evolution clearly shapes our understanding of the monetary transmission mechanism. For instance, if the federal funds and Eurodollar markets are not well integrated, one may wonder if the Fed ought to redefine its target more broadly, to encompass trades executed in both the federal funds and the Eurodollar markets.

To help assess these issues, this paper provides a detailed analysis of the extent of integration of the markets for federal funds and for Eurodollar deposits. We use a new set of transaction-level data, obtained from one of the largest U.S.-based dollar money brokers, and detailed empirical modeling of the daily and intra-day behavior of federal funds - Eurodollar interest spreads, to provide evidence of close integration of the markets for federal funds and Eurodollars that contrasts with the evidence of segmentation offered by previous studies.

To document this view, and trace the source of differences between our and previous results, we use a sequence of estimates based on progressively finer representations of the data, ranging from *daily quote-based London-NY* spreads to *daily transaction-based NY-NY* spreads, to *hourly transaction-based NY-NY* spreads. This analysis allows us to trace the key reason for previous evidence of federal funds - Eurodollars segmentation to its reliance — conditioned by data availability — on a comparison of Eurodollar rates from London with federal funds rates from New York. This comparison lets structural differences between the London and New York markets (including differences in investor mix) interfere with the estimation of federal funds - Eurodollar premia. By contrast, our aggregation of data from a common trading environment and a relatively homogeneous pool of investors, allows showing federal funds - Eurodollar premia to be small and essentially unpredictable.

Our detailed, high-frequency perspective allows us to document other features of the joint behavior of the federal funds and Eurodollar markets. Among these, we document significant liquidity effects: the volatility of yield spreads falls when trading volume rises, showing that market liquidity enhances the integration of our two market segments. We also show that daily news on money market conditions, as captured by results of morning Federal Reserve open market auctions, are absorbed quickly — within a couple of hours — into yield spreads. Altogether, the evidence that we present supports a view of strong integration between the two core components of the dollar money market.

2 The federal funds and the Eurodollar markets

Until December 1990, the federal funds market was the premier stage for U.S. banks' trading of unsecured, short-term loans of immediately available funds. The main reason for this prominence was that the Federal Reserve's *Regulation* D, requiring banks operating in the United States to maintain reserve funds in proportion to their deposit liabilities, exempted from reserve requirements certain borrowings from banks and other institutions — so called "federal funds."[1] This exemption effectively gives rise to a market — the federal funds market — in which these exempt liabilities are created.[2] Given Federal Reserve procedures aimed at stabilizing federal funds rates around a target, the federal funds market has also acted historically as the anchor for the market for liquid dollar instruments and for the term structure of dollar interest rates as a whole.

The other main source of unsecured dollar funds has been, historically, the market for Eurodollar deposits.[3] Until 1990, use of the Eurodollar market by U.S.-based banks (includ-

[1] For simplicity, we shall usually refer to all institutions active in our markets as "banks." Yet, neither of our two markets is strictly an "interbank" market. For instance, funds borrowed from certain non-bank institutions are also exempt from reserve requirements, and thus qualify as "federal funds."

[2] The phrase "federal funds market" is often used with reference to just the market's brokered segment, which hosts the great majority of trading between large institutions, and on which our analysis focuses. However, trades can also be arranged directly between borrowing and lending institutions, with small, more retail-oriented banks often trading with larger banks that are also active in the brokered market. Pricing in the direct market is often linked automatically to the prevailing brokered rate, and many direct loans are automatically rolled over, unless otherwise requested by one of the two parties. Demiralp *et al.* (2004) note that direct trading of federal funds has lost relative importance in recent years.

[3] The term "Eurodollar deposits" refers to dollar-denominated deposit liabilities of banking institutions

ing U.S. branches of foreign banks) was stunted by reserve requirements on net borrowings due to their non-U.S. offices and International Banking Facilities, i.e., Eurodollar liabilities. These regulations effectively segmented the federal funds and the Eurodollar markets.

At the end of 1990, the privilege accorded to federal funds relative to Eurodollars was essentially eliminated when reserve requirements on Eurodollar liabilities were set to zero. This reform allowed the Eurodollar market to begin playing a role similar to that historically provided by the federal funds market for U.S. banks. It also expanded the set of institutions from which U.S. banks could borrow at essentially the same terms as in the funds market.[4] As a result, since 1990, the growth of U.S. banks' borrowing in the Eurodollar market has outstripped that of the federal funds market. In absolute terms, U.S. banks' Eurodollar borrowing now outweighs significantly their federal funds borrowing, even in just the overnight segment (Figure 1; see also Demiralp *et al.*, 2004, for further discussion).

Given the effective substitutability of federal funds and Eurodollar deposits for U.S. banks, the evidence uncovered by Cyree *et al.* (2003), Lee (2003a,b), and Demiralp *et al.* (2004) that yields on these instruments show sizable and predictable gaps is surprising. Some of this evidence can be explained by its inclusion of data from the pre-1990 Eurodollar liberalization period. However, using only post-1990 data, Cyree *et al.* (2003) and Demiralp *et al.* (2004) find evidence of predictable federal funds - Eurodollar yield spreads.[5] These results suggest that mixing data from different regulatory regimes is unlikely to be the

operating outside the United States. Thus, banks operating in the United States, including branches and agencies of foreign banks, do not — by definition — borrow Eurodollars. However, they can borrow Eurodollars indirectly through their non-U.S. offices or International Banking Facilities.

[4] While lenders of federal funds are limited by *Regulation* D, lending in the Eurodollar market is limited only by restrictions on which institutions may hold Eurodollar deposits. For instance, U.S. banks can borrow Eurodollars from money funds (through their foreign affiliates), but cannot borrow federal funds from them, since borrowings from money funds are not exempt from reserve requirements.

[5] For instance, Demiralp *et al.* (2004) find spreads of three-four basis points in the middle of each ten-day reserve period, and of nine-ten points at quarter- and year-ends, while Cyree *et al.* (2003) find yield gaps of five-six basis points on Fridays and on settlement Wednesdays.

source of evidence of segmentation of the dollar money market.

Some previous evidence of federal funds - Eurodollar segmentation, comparing London-mid-day Eurodollar rates with New York-mid-day or daily-averaged funds rates, may also reflect a time-aggregation bias: the London-New York time lag causes Eurodollar rates to lead federal funds rates, possibly causing correlated (i.e., conditionally predictable) yield spreads.[6] Using intra-day Eurodollar quotes, however, Lee (2003b) partly addresses issues of time synchronization, and still finds evidence of federal funds - Eurodollar segmentation.

Another possibility is that issues of data quality may weigh on previous comparisons of Eurodollar quotes from London with federal funds transaction rates from New York. As discussed below, quote data provide only a blurred perspective on micro-level market conditions. Structural differences between London and New York also complicate the estimation of the rates at which similar institutions would trade federal funds and Eurodollars in similar environments — which is the relevant benchmark for assessment of market integration. For instance, as discussed below, differences in investor mix between London and New York may cause counterparty risk — which is a normal component of integrated markets — to contaminate the estimation of federal funds - Eurodollar spreads — which should vanish if these equivalent instruments traded in an integrated market. Sorting out the contribution of these factors to previous evidence of money market segmentation is a key goal of our analysis.

3 Empirical strategy

The common definition of market integration requires assets with the same risk characteristics to yield identical expected returns when trading in a well integrated market. (Expected return differentials among assets with *different* risk characteristics should be predictable based on information on relevant risk factors.) Hence, yield spreads between fixed-income

[6] For instance, if Eurodollar and federal funds rates move in the same direction during two consecutive days, the sampling lead of Eurodollars over federal funds rates would cause measured spreads to be serially correlated, even if federal funds and Eurodollar rates are identical at all times during the day.

assets (such as unsecured interbank loans) with similar risk characteristics *and* trading in an integrated market, should be unpredictable at all times, based on current information.

In accord with this definition, we examine the predictability of overnight federal funds - Eurodollar spreads by estimating a time-series model that builds on standard one-factor models of interest rates, augmented to include variables that previous studies have shown to affect means and volatilities of very-short-term interest rates. (For instance: Griffiths and Winters, 1995; Hamilton, 1996; Balduzzi *et al.*, 1998; Cyree and Winters, 2001; Bartolini *et al.*, 2002.) Our approach reflects the view that, if certain variables drive the high-frequency dynamics of interest rate *levels*, they may predict interest rate *spreads* as well. We leave it to the data to determine whether such presumption is empirically valid or not.

Let $\Delta_t \equiv r_t^{federal\ funds} - r_t^{Eurodollars}$ denote the spread of overnight federal funds over Eurodollar rates in period t. (We shall later specify what is meant by "federal funds" and "Eurodollar" rates at "t".) We write the model describing the evolution of Δ_t as

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

where ν_t is a mean-zero, unit-variance i.i.d. error term; μ_t is the conditional mean of Δ_t; and σ_t is its conditional Exponential GARCH (EGARCH) volatility parameter.

To model μ_t and σ_t, we begin by including a set of n autoregressive terms $\Sigma_{i=1}^{n} \rho_i \mu_{t-i}$ in the equation for μ_t, and we define σ_t as a function of a distributed lag of a set of independent variables, as in standard EGARCH models of interest rates (see, for instance, Hamilton, 1996, and Andersen and Lund, 1997). Specifically, when working with daily data, we include as lagged terms the effective (i.e., volume-weighted) spreads in the previous n days. When working with hourly data, we also include past hourly spreads among the regressors, with the restriction that each spread can depend only on previous spreads from the same day.

Next, we include in the equations for μ_t and σ_t a set of deterministic and stochastic factors that previous studies have identified as determinants of overnight interest rate dynamics.

Specifically, we include in the mean and variance equations, respectively, two vectors of "calendar" dummies, δ_{c_t} and ξ_{c_t}, to capture the behavior of yield spreads on holidays, mid-months, end-months, end-quarters, one- and three-day holidays, FOMC meeting days, and the days before and after them. We also include a dummy for the New York blackout of August 14, 2003, which interrupted federal funds trading from mid-afternoon to end-day.

Next, to capture the impact on spreads of the accounting structure for reserve requirements, we include in the equations for μ_t and σ_t^2, respectively, the dummies δ_{d_t} and ξ_{d_t}, with $d_t = 1, \ldots, 10$ identifying days in the reserve period.[7] When working with hourly data, we also include the hourly dummies δ_{h_t} and ξ_{h_t} in the two equations,[8] with $h_t = 1, 2, ..., 10$ identifying hourly intervals from 8:00-9:00 to 17:00-18:00 in each business day.[9]

Finally, we include other money market factors, Ω_t, that may have a different impact on federal funds and Eurodollar yields, and may therefore affect yield spreads. When working with both daily and hourly data, we include (lagged) changes in federal funds target rates. When working with hourly data only, we also include (contemporaneous and lagged) trading volumes and marginal rates realized on Federal Reserve open market auctions (see details below), which may provide news on current market conditions to banks.

The resulting equations for mean and variance of federal funds - Eurodollar spreads are:

$$\mu_t = \Sigma_{i=1}^{n} \rho_i \mu_{t-i} + \delta_{d_t} + \delta_{h_t} + \delta_{c_t} + \psi \Omega_t \ , \tag{2}$$

[7] For details on U.S. reserve requirements, see the Federal Reserve's *Regulation* D. In sum, institutions collecting transaction deposits in the United States must hold reserves against such deposits as either cash or deposits at the Federal Reserve. Reserve balances are measured daily after the closing of *Fedwire*, the Federal Reserve's electronic payment system (normally at 18:30), and are averaged over "reserve maintenance" periods that begin every other Thursday and end two weeks later on "settlement" Wednesday. Banks must also keep non-negative reserve balances at the Federal Reserve at the end of each day. Penalties apply for insufficient reserves at the end of each reserve period and for negative balances at the end of each day.

[8] Because of the simultaneous presence of fixed daily effects, one linear restriction is required to identify the hourly coefficients. We estimate our hourly coefficients by restricting their sum to zero.

[9] This is the interval of effective overlap of open hours in our two markets. In principle, the Eurodollar market is open around the clock, due to time lags between Europe, Asia, and the United States. However, there is little trading between its closing in New York at 18:00 and its subsequent opening in Asia. The federal funds market opens effectively at 8:00 and closes at 18:30, with the closing of *Fedwire*.

$$\log\left(\sigma_t^2\right) = \lambda \log\left(\sigma_{t-1}^2\right) + (1-\lambda\mathrm{L})(\xi_{d_t} + \xi_{h_t} + \xi_{c_t} + \omega\Omega_t) + \kappa\left|\nu_{t-1}\right| + \theta\nu_{t-1} \ , \qquad (3)$$

where λ is the autoregressive EGARCH coefficient and L is the lag operator. This specification allows for an asymmetric response of $\log\left(\sigma_t^2\right)$ to positive and negative shocks when $\theta \neq 0$, and for fat tails in interest rate innovations by assuming a t distribution for ν_t.

4 Data

To estimate our model, we obtained transaction-level federal funds and Eurodollar data from *Euro Brokers*, one of the largest brokers in the dollar money market, from February 11, 2002, to September 24, 2004, or 660 business days. Specifically, we obtained all federal funds trades arranged by *Euro Brokers,* as well as all Eurodollar trades arranged by *Euro Brokers*' New York headquarters over the sample period. For each transaction we obtained the amount dealt, applicable interest rate, settlement and maturity dates, trade completion time (in hour/minute/second format), and a "federal funds" vs. "Eurodollar" identifier. We obtained no information on the parties involved in each trade.

The data were in good shape, reflecting *Euro Brokers*' simultaneous electronic execution and recording of trades. To prune possible residual errors, however, we screened the data using computer routines and by hand, which caused us to discard about 400 observations (less than $^1/_4$ percent of the total).[10] We then retained only spot overnight trades (i.e., loans settling on the day they are arranged, and maturing on the next business day), or 96 percent of our original trades; and we dropped all trades completed outside the common open hours of our two reference markets, from 8:00 to 18:00. Our final data included 105,617 federal funds and 61,359 Eurodollar trades. We arranged these trades by execution time into 10 hourly intervals and computed effective federal funds and Eurodollar rates as volume-weighted rates within each day and hourly interval. We treated the resulting series of effective daily and

[10] We discarded trades recorded as completed on week-ends, holidays, or days prior to the current date; trades at zero rates or at rates exceeding the federal funds target by more than five percent; two trades for \$0.01; and one trade for \$61 billion.

hourly rates as the basic ingredients of our analysis.[11]

The remaining data include daily effective federal funds rates, which the Federal Reserve computes as volume-weighted averages from trades executed by the major federal funds brokers (including *Euro Brokers*), and Eurodollar rates, for which the standard source is the *British Bankers' Association*'s sampling of bid-side quotes faced daily, just before 11:00, by major banks in London. We obtained these series from the Board of Governors of the Federal Reserve. Finally, we obtained daily marginal rates on Federal Reserve open-market repo operations from the Federal Reserve Bank of New York, which publishes these rates daily at about 9:50, upon completion of its morning open-market auctions.

5 Preliminary data analysis

As it is normally the case with studies of over-the-counter markets, our study must rely on a subset of the data universe, hence on the presumption that the limited data available are representative of overall market conditions. To assess this conjecture to the extent possible, we compared the daily "effective" (i.e., transaction-weighted) federal funds rates obtained from our data with the series of daily effective rates published by the Fed and calculated using data from all major brokers (including *Euro Brokers*).

Comparing the two series yields a mean absolute deviation between the *Euro Brokers*

[11] A small data problem was caused by the end-day data reconciliation that *Euro Brokers* conducts over a 20-30 minute interval between 17:00 and 18:30. During this interval, the electronic recording of trades is halted. Incoming trades are queued until the reconciliation ends, after which they are time-stamped in bulk, preserving their original sequence. To estimate the execution time of trades with delayed recording, we assumed it to be uniformly distributed over the interruption interval. In all, less than 5,000 trades (3 percent of the total) were affected and possibly mis-classified, as they were executed during reconciliation intervals straddling our one-hour intervals. However, the actual misclassification is likely to be much smaller, as only trades distributed very unevenly during the interruption could be incorrectly assigned to an adjacent time interval: a few trades completed minutes after 18:00 may have been included in our 17:00-18:00 interval, while a few trades completed minutes before 18:00 may have been excluded from the analysis.

and the published (broader) series of 0.7 basis points, with no evidence of serial correlation in the deviations. Specifically, a regression of the spread {*Euro Brokers rate - published rate*} on its own lag and on a constant, yields an autoregressive coefficient of 0.011 (with a standard error of 0.039), a constant term of -0.0009 (with a standard error of 0.0005), and an r^2 of 0.0007. Additional lags are also small and insignificant. This evidence suggests that our data can be viewed as an unbiased sample of price conditions at the *daily* frequency. The presumption is that the same should be true also at the *intra-day* frequency.

Table 1 documents summary features of these data. In assessing these features, note that money market brokers act as pure intermediaries: they do not trade off their own accounts, nor do they charge variable bid/ask spreads. Rather, they charge both lenders and borrowers a fixed fee of about 50¢ for each $1 million traded, which corresponds to 1.8 annualized basis points for overnight trades. Hence, all our data refer to the rates actually charged by lenders to borrowers in our two reference markets.

As shown in Table 1, the range of trade sizes is very similar in our two reference markets: $0.5 millions to $4 billions for federal funds, and $0.47 millions to $3.1 billions for Eurodollars. Mean trade sizes are quite different, however: $81 millions for federal funds, and $201 millions for Eurodollars. This gap points to a possible difference in size between participants in the two markets: the Eurodollar market may draw a greater share of larger, more internationally-oriented institutions, which are more likely to operate foreign branches or International Banking Facilities through which they can borrow Eurodollars. This evidence is consistent with the slightly higher average rates observed in the federal funds market compared to the Eurodollar market documented in the last row of Table 1 (0.3 basis points): larger institutions may be able to borrow at marginally lower rates than smaller institutions.[12]

Figure 2 shows the main object series of our analysis, namely, federal funds - Eurodollar

[12] An alternative explanation of the small average excess of federal funds over Eurodollar rates may be that most non-bank institutions can lend Eurodollars but not federal funds and, given this constraint, may contribute to marginally softer conditions in the Eurodollar market. However, this explanation would require segmentation between the two markets, which contrasts with the evidence presented below.

spreads defined as: 1. *Daily* published NY *effective* federal funds rates *minus* London *quoted* Eurodollar rates; 2. *Daily Euro Brokers* NY federal funds rates *minus* NY Eurodollar rates; 3. *Hourly Euro Brokers* NY federal funds rates *minus* NY Eurodollar rates. For visual reference only (see our subsequent discussion of the relevance of transaction fees), we plot in the figure also 'transaction fee bands' at ± 1.8 basis points.

Figure 2 shows the series in the top and bottom panels to be much more volatile than the series in the middle panel. In fact, the series in the bottom panel cannot be compared directly with the other two series, since it is defined on a higher (hourly) frequency, and is therefore expected to appear more volatile. The top two series can be compared, however, and the top-panel series suggests greater federal funds - Eurodollar segmentation than the mid-panel series. This (correct) perception requires formal assessment, however, since the relevant benchmark is the spreads' predictability, rather than just its volatility.

6 Estimation and results

We estimated our model by maximum likelihood, using numerical optimization. As in Andersen and Lund (1997), we smoothed the function $|\nu_t|$ at the origin by using the twice-differentiable approximation $|\nu_t| = \frac{\frac{\pi}{2} - \cos(K\nu_t)}{K}$, for $|\nu_t| < \frac{\pi}{2K}$, setting $K = 20$. To select the autoregressive EGARCH structure, we analyzed the correlogram of squared standardized residuals, leading in most cases to an EGARCH model with a single autoregressive term, and in one case to a model with two autoregressive terms. (Standard tests showed insignificant higher lags and no residual conditional heteroskedasticity.)

We summarize our results by presenting, for each of our regressions, two specifications of the model. First, a general specification that includes all the independent variables discussed in Section 3. This specification eases comparison with previous studies and allows, when working with hourly data, to assess the impact of trading volume and of intra-day releases of news on market conditions. However, trading volume is unknown to market participants in real time, and must be discarded from specifications testing for the predictability of spreads, along with other insignificant variables that blur the model's explanatory power. For this reason, we present also a more parsimonious empirical specification, obtained by a standard general-to-specific method, by sequentially discarding the least significant variables. (We set the minimal p value for retention in the model at 0.05.)

Before discussing our results, we should place them into quantitative context. The key question is: When are predictable federal funds - Eurodollar spreads large enough to provide evidence of segmentation? One may be tempted to set the relevant threshold at the cost of executing trades in this market, about 1.8 basis points. However, lacking information on the portfolio position and trading activities of the conceptual "marginal trader" in this market, such fee is not very informative of the relevant cost of arbitraging over federal funds - Eurodollar spreads. This is because investors that do *not* participate at all in these markets will compare spreads to *twice* the 1.8 basis points trading fee, for this represents the cost of a round-trip (e.g., to borrow federal funds and lend Eurodollars). Investors already active in one of the two markets, however, may need to pay such fee only once, to exploit an observed spread, while investors already active in both markets may incur a smaller (or nil) charge, if they can suitably re-size their trades without additional transactions. (See Rhee and Chang, 1992, for discussion of the distinction between two-way and one-way arbitrage.)

In practice, in this market, a spread of two basis points would certainly catch investors' attention, while a spread of three or more basis points would definitely steer a bank away from one instrument and into the other. Should spreads of such or greater magnitude arise systematically on certain days, as estimated in previous studies, one would be surprised to observe active trading in these days at all: few borrowers would accept to borrow at a predictably "high" rate, and few lenders would choose to lend at a predictably "low" rate. At the opposite end, one basis point is the minimum contractual increment in this market. Therefore, systematic spreads of fractions of a single basis point can be effectively exploited only by very active participants in these two markets, and only by those mustering sufficient credit lines — as both borrowers and lenders. One should keep these illustrative magnitudes in mind when assessing the results that follows.

6.1 Step 1: *Daily* NY federal funds vs. London Eurodollars

Our first set of results aims to replicate previous evidence of federal funds - Eurodollar segmentation, based on a comparison of daily published federal funds rates from New York with Eurodollar quotes from London. Results for both general and restricted versions of our model are shown in the first two columns of Table 2, with reserve period effects from the restricted regression also plotted in Figure 3 with their 95 percent confidence interval.

These estimates point to several sources of predictability in federal funds - Eurodollar spreads. First among these are the large three-basis points effects estimated for days five, six, and nine of each reserve period, with all coefficients from day four onward precisely estimated as larger than one basis point. There are also large effects estimated for month-ends (about four basis points), quarter-ends (three basis points, which cumulate with month-end effects to yield predictable spreads of 6.5 basis points), days following three-day holidays and FOMC meetings, and days around mid-months (all estimated at about two basis points). These effects are cumulative. For instance, days following either three-day holidays or FOMC days that also fall on the fifth day of a reserve period, show systematic spreads of about six basis points; similarly for other combinations of the coefficients in Table 2(a).

Spreads are also conditionally predictable. We found two significant autoregressive coefficients: 0.145 for the first daily lag, and 0.092 for the second daily lag. To illustrate these effects, note that the spreads' daily standard deviation is about five basis points. Then, observation of the previous day's spread allows investors to predict, typically, a current daily spread of ± 0.8 basis points, in addition to the unconditional effects discussed above.

Based on similar results, previous studies have appropriately flagged evidence of segmentation between the federal funds and the Eurodollar markets.

6.2 Step 2: *Daily* NY federal funds vs. NY Eurodollars

Virtually all evidence of predictability disappears when estimating our model with transaction-based data drawn entirely from the New York market. To ease comparison, the estimates shown in columns 1 and 3 of Table 2 differ only by the substitution of quote-based London-NY spreads (in column 1) with transaction-based NY-NY spreads (column 3). Column 4 of Table 2 then shows a restricted set of estimates, which drops statistically insignificant variables from the regressions reported in column 3.

The first notable aspect of these results is that reserve-period effects have shrunk to about 1/10 of their previous size, peaking at 0.34 basis points on the reserve period's fifth and tenth day (see also Figure 3). Other calendar effects exhibit the same dramatic decline: there are now only two statistically significant calendar effects, those for days preceding end-months and one-day holidays, both estimated at 0.34 basis points. Spreads are somewhat more serially correlated than in our previous regressions: the first autoregressive coefficient is now 0.212, and the four statistically significant coefficients cumulate to 0.521. However, the sharp decline in the spreads' typical magnitude — their standard deviation is now 1.3 basis points — implies that each day's spread helps predict, on average, only one-fourth of a basis point of the following day's spread. (Similarly for higher lags.) Clearly, these results show minimal predictability of daily federal funds- Eurodollar spreads.

Our interpretation of these results is that by aggregating federal funds and Eurodollar rates from New York transaction-based data we can eschew two key pitfalls in the estimation of federal funds - Eurodollar premia.

First, by using data on completed Eurodollar trades, rather than on offer rates prevailing among major banks in London, we can greatly improve the quality of the raw data. Quote-based data, the only ones available to previous studies of the Eurodollar market, offer a weak basis for micro-structural analysis of over-the-counter markets, where negotiation and bilateral relationships are key to price determination. Quotes are not updated in real time, and may expire before leading to any trade. Even when hit by an interested party, a quote provides only a starting point for a negotiation, whose eventual outcome hinges on factors such as borrowers' identity, availability of credit lines, and then-current market conditions.

Second, by virtue of being drawn entirely from the New York market, our data are sampled from a much more homogeneous environment than when drawn from London for

Eurodollars and from New York for federal funds. This is because the London and New York markets differ significantly in terms of payment conventions and investor mix. For instance, most Eurodollar transactions arranged in London settle through the CHIPS payments infrastructure, while most Eurodollar trades in our sample settle on Fedwire, just as our sample's federal funds transactions. Also, for reasons that include the temporary overlap of operating hours between Asia and Europe, the London Eurodollar market draws many more Asian (especially Japanese) banks than the New York market. In recent years, these institutions have often displayed lower and more volatile credit ratings, and faced higher funding costs, than most institutions active in the New York money market. If different groups of investors (e.g., investors based in Asia and those based in Europe or the United States) follow different patterns of participation in the market over time, predictable patterns in *measured* federal funds - Eurodollar spreads may arise even when federal funds and Eurodollars are perfectly substitutable — hence command identical yields — from the viewpoint of *any given* investor. By controlling for trading environment and, to a large extent, investor pool, our analysis goes a long way towards filtering the effect of changes in counterparty risk and institutional premia from estimated funds - Eurodollars premia.[13]

Finally, we noted in Section 2 that intra-day timing issues may also be relevant. The Eurodollar rates used in previous research are usually drawn at just before 11:00 in London, while federal funds rates are only available for later New York times, or on a daily-averaged basis. While this is potentially a serious problem, our analysis in this section shows that much of the predictability in federal funds - Eurodollar spreads disappears as soon as we control for trading environment but not for time-of-trading. Hence, time-aggregation appears to play no significant role in previous evidence of federal funds - Eurodollar segmentation.

[13] It would be even more satisfactory to control for investor characteristics by using direct information on each transaction's trading parties. However, we obtained no such information from *Euro Brokers*.

6.3 Step 3: *Intra-day* NY federal funds vs. NY Eurodollars

A key issue left open in the previous section is whether absence of predictable patterns in federal funds - Eurodollar spreads at the daily level masks predictability — hence, effective segmentation — *intra*-day: are federal funds and Eurodollar yields as closely aligned during the business day as they are *on average* at the daily frequency?

Columns 5 and 6 of Table 2 show the relevant results, by documenting our most detailed representation of the empirical behavior of federal funds - Eurodollar spreads.

The first notable feature of these results is that reserve-period effects estimated from daily data are confirmed in high-frequency estimation: all reserve period effects are estimated at less than 1/3 basis points (Table 2(a) and Figure 3). Even the slightest hint of cyclical, intra-period behavior of spreads has now disappeared. All other calendar effects are also estimated at near zero. Indeed, the small standard errors of these coefficients show that systematic federal funds - Eurodollar spreads are precisely estimated to be small, rather than just statistically insignificant because of their large standard errors.

Federal funds and Eurodollar yields are also closely aligned intra-day, as shown in Table 2(c) and Figure 4. The largest predictable spread is estimated from 8:00 to 9:00, when federal funds trade 0.63 basis points firmer than Eurodollars, and likely reflects the thinness of the funds market during its first trading hour. The effects are much weaker during the rest of the day, peaking at 0.32 basis points (in absolute terms) in the third hour of trading.

Next, Table 2(d) documents the spreads' weak autoregressive structure, both at the daily level (the first daily autoregressive coefficient is only 0.086, and the four statistically significant coefficients cumulate to 0.241) and at the intra-day level (the first hourly autoregressive coefficient is 0.141, and the four significant coefficients cumulate to 0.270). Once again, we can illustrate these estimates with reference to the typical magnitude of the changes in daily spreads, whose standard deviation of daily spreads is 1.7 basis points. In this case, observation of previous day average spreads allows investors to predict only 0.14 basis points (in absolute, average terms) of the next hourly spread. Similarly, the 1.3 basis points standard deviation of hourly spreads implies that 0.18 basis points of each hourly spread can be predicted based on the spread observed in the previous hour.

Our intra-day perspective allows us to investigate other features of the joint behavior of our two markets. Specifically, we uncovered a significant link between trading volume and spreads' volatility: more active trading keeps federal funds and Eurodollars rates more closely aligned. The estimated link is substantial: the semielasticity of spreads' variance to changes in trading volume (either federal funds or Eurodollars) is 0.25-0.28. With an hourly standard deviation of (log) changes in federal funds and Eurodollar trading volumes of 113 and 114 percent, respectively, the standard deviation of spreads may change by 50-55 percent in response to typical changes in trading volume. (This effect is partly undone in the subsequent hour of trading, after which we found no impact of volume on volatility.) Although the volatility of hourly spreads is itself not large (its standard deviation is 1.3 basis points), this result shows that liquidity effects are operative in the dollar money market: more intense trading brings about closer integration of its two core segments.[14]

Finally, we investigated how spreads respond to news about market conditions, as captured by results of the Federal Reserve's daily open market auctions. Our measure of "news" is the stop-out rate on Federal Reserve daily short-term repo auctions against Treasury collateral, normalized by the target federal funds rate. This spread is announced at about 9:50 daily, shortly after the completion of any short-term repo operation that might have been arranged that day, and may be viewed by investors as indicative of whether the liquidity provided by the Fed at the auction will be consistent with keeping the average cost of funds near its target through end-day.

Using this measure of "market news," we found statistically significant — yet small — effects of news on federal funds - Eurodollar spreads in the two trading hours following the news release. Table 2(d) shows that each 5 basis points rise in the stop-out rate causes spreads to shrink by about 0.15 of a basis point in each of the subsequent two hours. (Subsequent

[14] By contrast, trading volume has virtually no effect on *mean* spreads. See column 5 in Table 2(d).

coefficients were insignificant.) Intuitively, the sign of this effect indicates that news from open market auctions transmit more promptly to the Eurodollar market, which is more active than the funds market at the time of the release.

7 Conclusions

The two core components of the unsecured overnight bank funding market — the market for federal funds and the market for Eurodollars — are well integrated, with rates on these instruments displaying small and largely unpredictable spreads. This conclusion holds both at the daily and at the higher intra-day frequency.

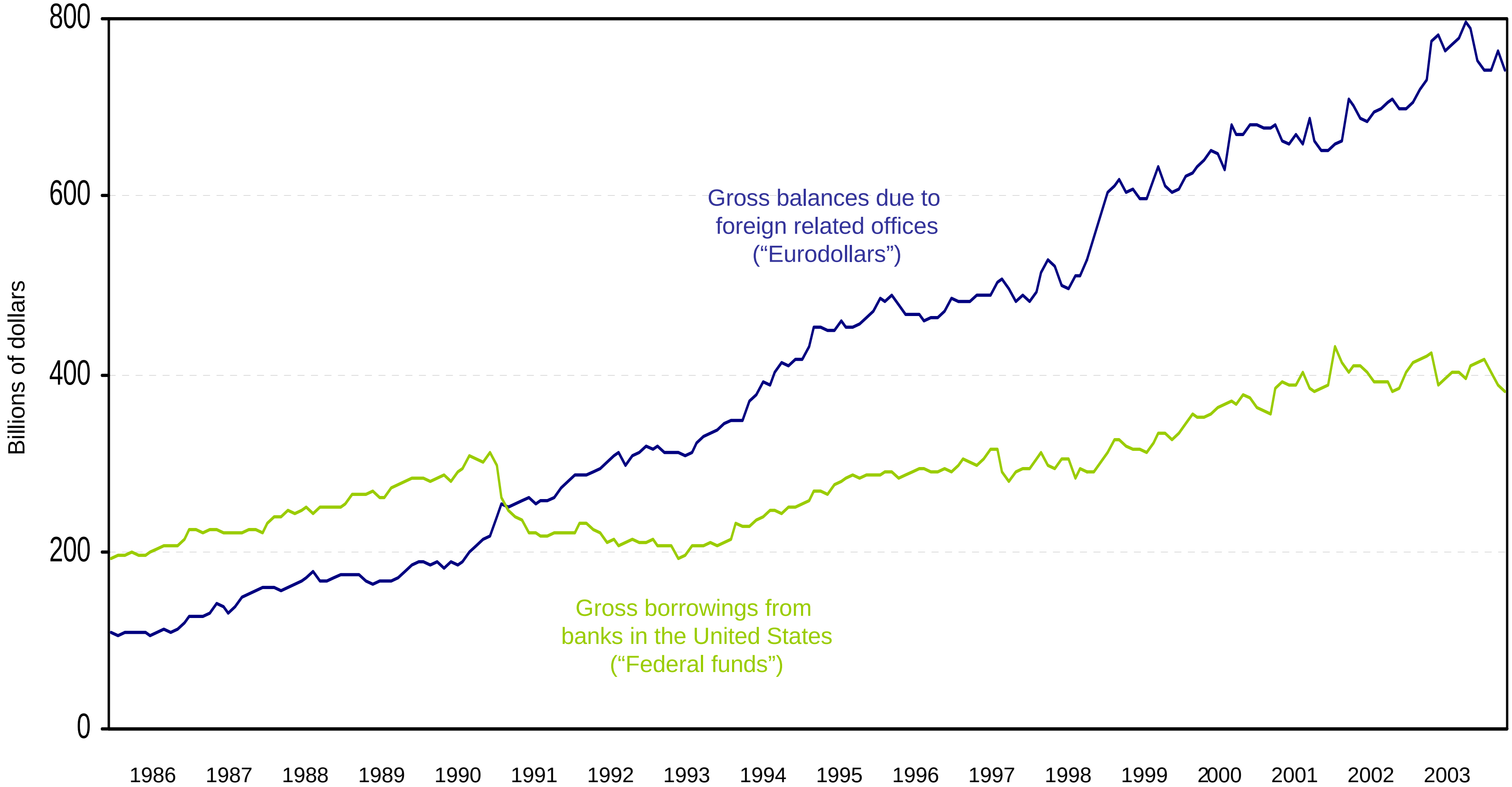
Our analysis shows that previous evidence of federal funds - Eurodollar segmentation likely reflects the difficulty of stripping off interest rate spreads characteristics unrelated to how a *given set of investors* views federal funds relative to Eurodollars in a *given trading environment*. Using previously unavailable high-quality, high-frequency data on money market trading, drawn entirely from the New York market, we document close alignment of federal funds and Eurodollar yields throughout the business day. Our accessory results include evidence of liquidity effects: higher money market trading volume lowers the volatility of spreads, thus keeping federal funds and Eurodollar yields more closely in line.

Close integration of federal funds and Eurodollar trading has two immediate implications. From the viewpoint of financial analysis, it implies that, thanks to the overnight availability of Eurodollars, by the time the funds market opens each day, news accrued overnight should be already impounded into both Eurodollar and federal funds rates.

From the viewpoint of policy design and analysis of the transmission of monetary policy, our results suggest that it makes little difference that the Federal Reserve targets only rates in the federal funds market, and does not include trades executed in the larger Eurodollar market into its target.

Figure 1

Liabilities of Commercial Banks in the United States



Note: Balances due to foreign related offices and borrowings from banks in the United States include, and are used as proxies for movements in, overnight Eurodollar and federal funds liabilities, respectively; but these data also include other sources of U.S. banks' liabilities to foreign and other domestic banks. Source: Board of Governors, Federal Reserve

Figure 2

Federal Funds - Eurodollar Spreads

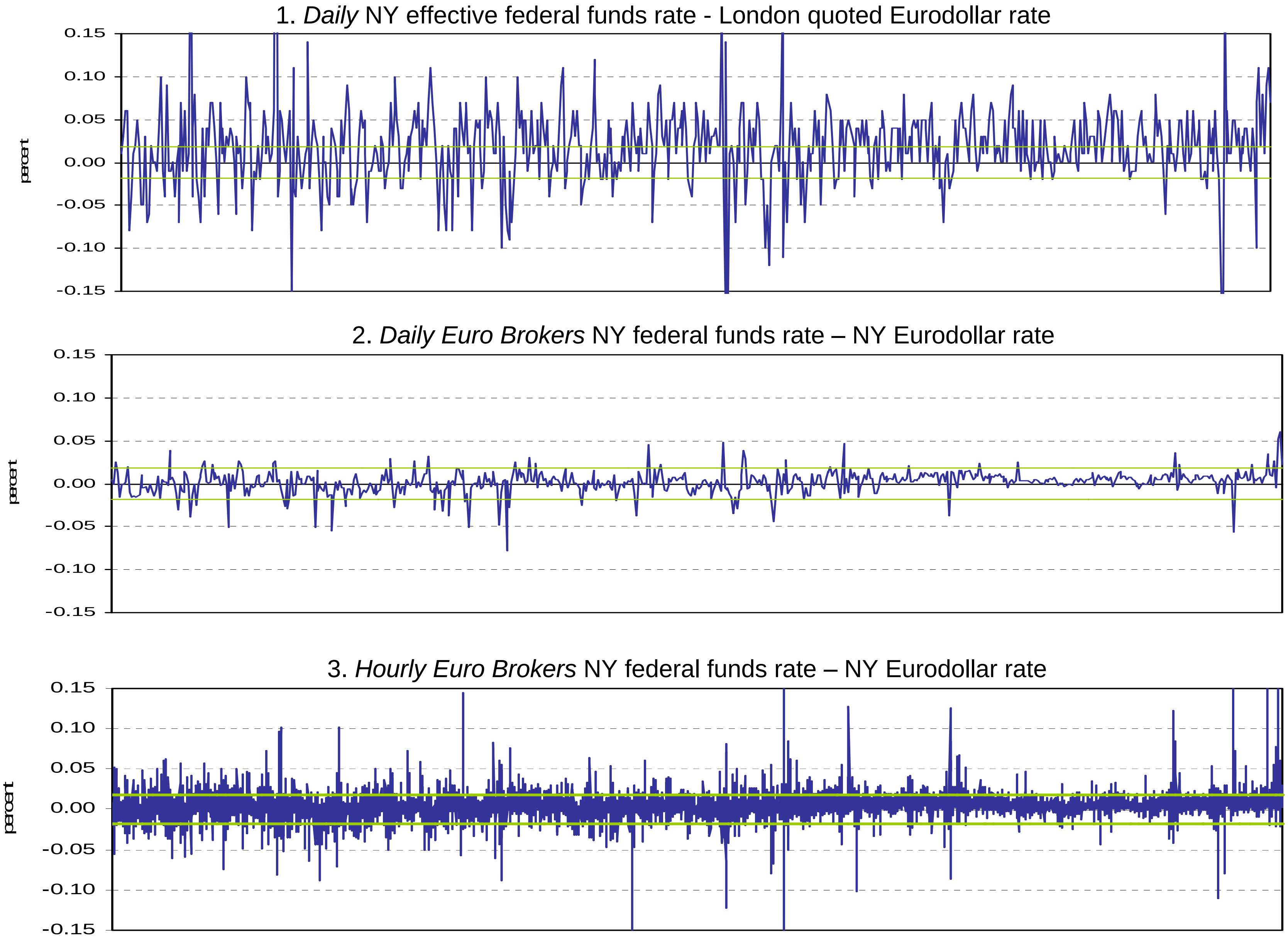


Figure 3

Federal Funds – Eurodollar Spreads: Mean Calendar Effects

(with 95% confidence interval of estimates)

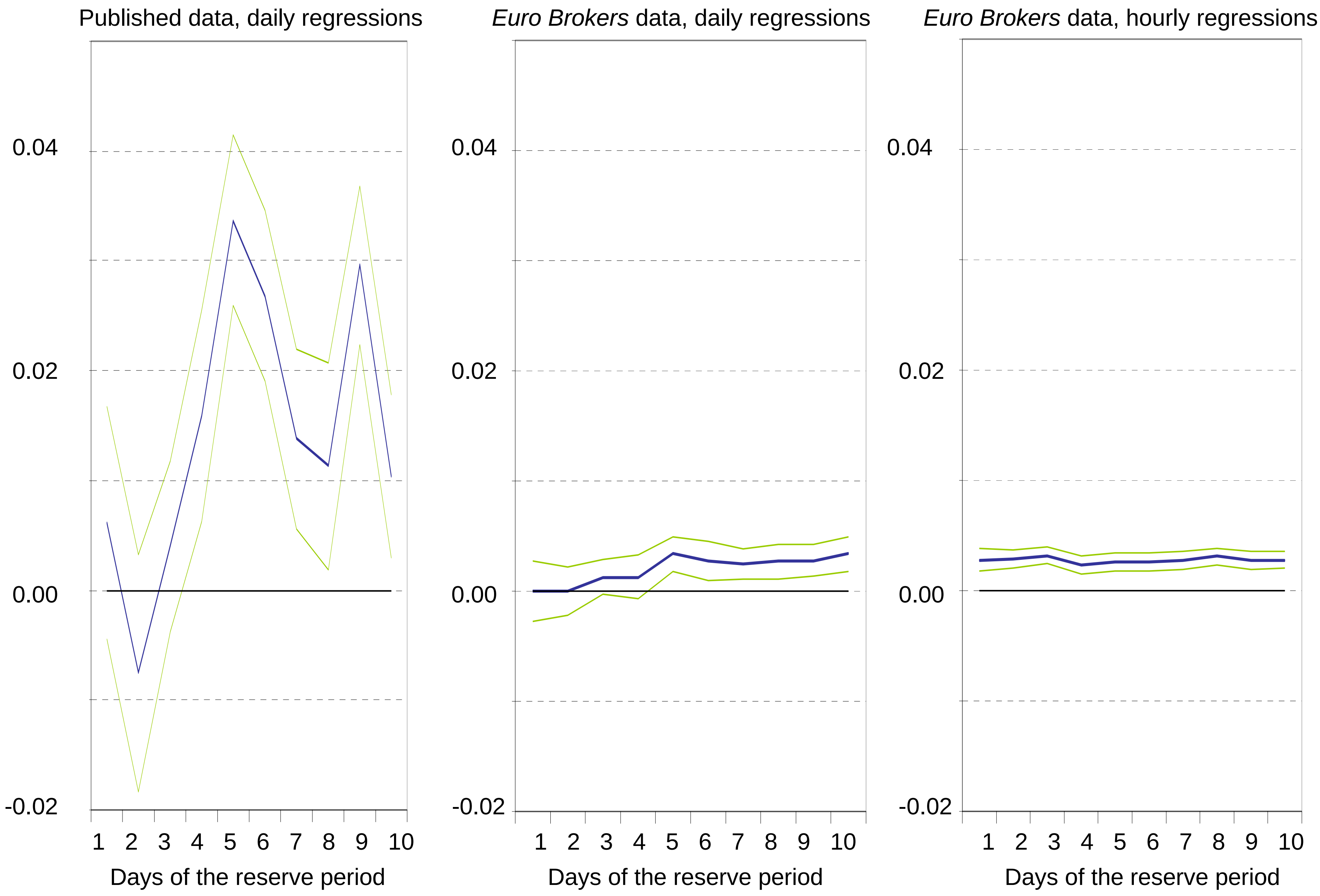


Figure 4

Federal Funds – Eurodollar Spreads: Mean Hourly Effects

(with 95% confidence interval of estimates)

Euro Brokers data, hourly regressions

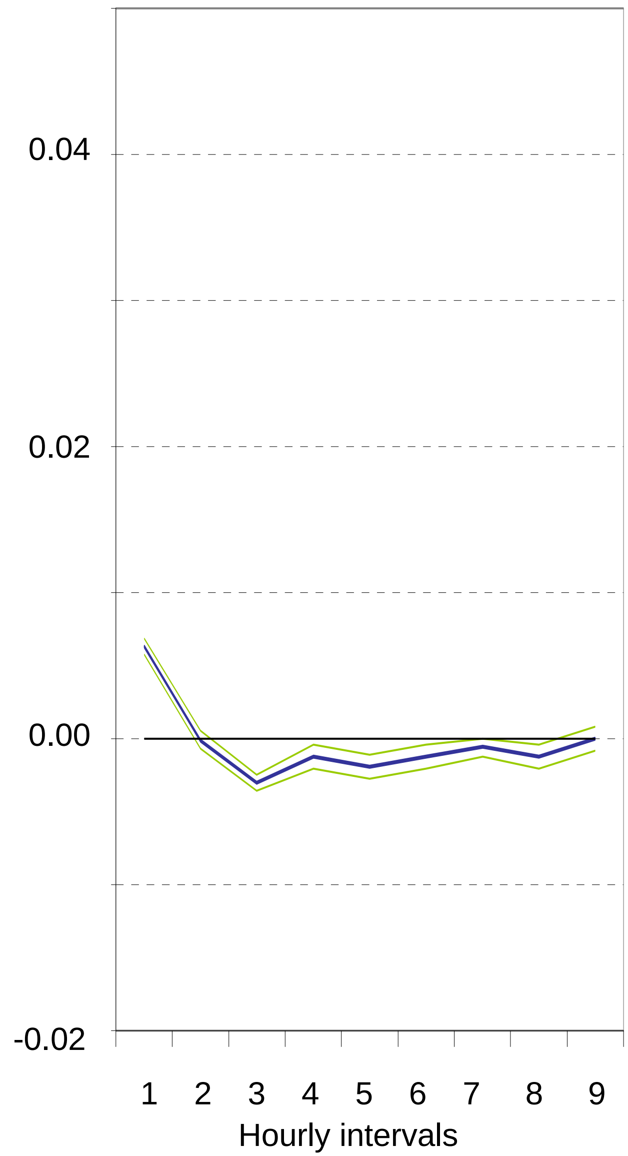


Table 1

Transaction-level data: Summary information

	Federal funds	Eurodollars
Sample	February 11, 2002 – September 24, 2004 (660 business days)	
Number of trades	105,617	61,359
Largest trade size	$4 billion	$3.1 billion
Smallest trade size	$0.5 million	$0.47 million
Mean trade size	$81 million	$201 million
Median trade size	$50 million	$135 million
Highest rate	2.06 percent	3.28 percent
Lowest rate	0.096 percent	0.031 percent
Largest deviations from target rate	-1.38 / 0.98 percent	-1.47 / 2.03 percent
Average deviation from target rate	0.00872 percent	0.00525 percent

Table 2 (a)

Mean federal funds – Eurodollar spreads: Reserve period and calendar effects

(standard errors in parentheses; * and ** indicate significance at the 5% and 1% level, respectively)

	Published data, daily regression		*Euro Brokers* data, daily regression		*Euro Brokers* data, hourly regression	
	General model	Restricted model	General model	Restricted model	General model	Restricted model
Days of the reserve period, δ_{dt}						
1	0.0080	0.0061	0.0000	0.0000	0.0030**	0.0028**
	(0.0058)	(0.0053)	(0.0014)	(0.0014)	(0.0004)	(0.0005)
2	-0.0093	-0.0075	-0.0002	0.0000	0.0032**	0.0029**
	(0.0057)	(0.0054)	(0.0012)	(0.0011)	(0.0004)	(0.0004)
3	0.0036	0.0040	0.0019*	0.0013	0.0035**	0.0032**
	(0.0042)	(0.0039)	(0.0008)	(0.0008)	(0.0004)	(0.0004)
4	0.0149**	0.0159**	0.0019	0.0013	0.0025**	0.0023**
	(0.0052)	(0.0048)	(0.0010)	(0.0010)	(0.0004)	(0.0004)
5	0.0354**	0.0337**	0.0034**	0.0034**	0.0029**	0.0026**
	(0.0040)	(0.0039)	(0.0008)	(0.0008)	(0.0004)	(0.0004)
6	0.0257**	0.0268**	0.0029**	0.0027**	0.0029**	0.0026**
	(0.0038)	(0.0039)	(0.0008)	(0.0009)	(0.0004)	(0.0004)
7	0.0134**	0.0138**	0.0027**	0.0025**	0.0028**	0.0027**
	(0.0042)	(0.0041)	(0.0008)	(0.0007)	(0.0004)	(0.0004)
8	0.0098*	0.0113*	0.0030**	0.0027**	0.0035**	0.0031**
	(0.0050)	(0.0047)	(0.0008)	(0.0008)	(0.0004)	(0.0004)
9	0.0294**	0.0296**	0.0036**	0.0028**	0.0031**	0.0027**
	(0.0034)	(0.0036)	(0.0008)	(0.0007)	(0.0004)	(0.0004)
10	0.0099**	0.0104**	0.0034**	0.0034**	0.0031**	0.0028**
	(0.0036)	(0.0037)	(0.0008)	(0.0008)	(0.0004)	(0.0004)
Special calendar days, δ_{ct}						
Day before end of months	-0.0032	--	-0.0033**	-0.0034*	-0.0004	--
	(0.0078)	--	(0.0012)	(0.0016)	(0.0008)	--
End of months	-0.0400**	-0.0380**	-0.0050*	--	-0.0015	--
	(0.0097)	(0.0057)	(0.0023)	--	(0.0009)	--
Day after end of months	-0.0015	--	-0.0011	--	-0.0008	--
	(0.0077)	--	(0.0017)	--	(0.0008)	--
Day before end of quarter	-0.0291	-0.0273**	-0.0022	--	0.0002	--
	(0.0163)	(0.0100)	(0.0057)	--	(0.0015)	--
End of quarter	0.0018	--	0.0047	--	0.0009	--
	(0.0243)	--	(0.0061)	--	(0.0032)	--
Day after end of quarter	0.0154	--	-0.0019	--	-0.0023	--
	(0.0218)	--	(0.0052)	--	(0.0019)	--
Day before 1-day holiday	-0.0230	--	-0.0043	-0.0034*	0.0012	--
	(0.0133)	--	(0.0091)	(0.0016)	(0.0019)	--
Day after 1-day holiday	-0.0157	--	-0.0001	--	0.0025	--
	(0.0146)	--	(0.0041)	--	(0.0014)	--
Day before 3-day holiday	0.0232	--	0.0009	--	-0.0012	--
	(0.0162)	--	(0.0093)	--	(0.0021)	--
Day after 3-day holiday	0.0428*	0.0262*	0.0025	--	-0.0018	--
	(0.0173)	(0.0109)	(0.0047)	--	(0.0017)	--
Day before the 15th of the month	0.0152*	0.0152*	-0.0001	--	-0.0006	--
	(0.0061)	(0.0060)	(0.0013)	--	(0.0006)	--
15th of the month	0.0081	--	0.0005	--	0.0011	--
	(0.0114)	--	(0.0016)	--	(0.0007)	--
Day after 15th of the month	-0.0185*	-0.0207**	-0.0023	--	-0.0006	--
	(0.0073)	(0.0056)	(0.0015)	--	(0.0006)	--
Day before FOMC meeting	0.0031	--	-0.0009	--	0.0003	--
	(0.0074)	--	(0.0015)	--	(0.0007)	--
Day of FOMC meeting	0.0001	--	0.0014	--	0.0004	--
	(0.0079)	--	(0.0021)	--	(0.0008)	--
Day after FOMC meeting	0.0213*	0.0205**	0.0001	--	-0.0008	--
	(0.0088)	(0.0064)	(0.0020)	--	(0.0008)	--
NY black-out (Aug. 14, 2003)	0.1591**	0.1513**	-0.0058**	-0.0056**	-0.0023	--
	(0.0071)	(0.0444)	(0.0017)	(0.0011)	(0.0026)	--

Table 2 (b)

Volatility of federal funds – Eurodollar spreads: Reserve period and calendar effects

(standard errors in parentheses; * and ** indicate significance at the 5% and 1% level, respectively)

	Published data, daily regression		*Euro Brokers* data, daily regression		*Euro Brokers* data, hourly regression	
	General model	Restricted model	General model	Restricted model	General model	Restricted model
Days of the reserve period, ξ_{dt}						
1	-6.099**	-5.961**	-7.536**	-7.285**	-6.521**	-6.656**
	(0.255)	(0.262)	(0.839)	(0.913)	(0.290)	(0.318)
2	-6.309**	-6.169**	-7.800**	-7.551**	-6.700**	-6.753**
	(0.274)	(0.244)	(0.822)	(0.883)	(0.296)	(0.321)
3	-7.141**	-6.895**	-8.462**	-8.261**	-6.844**	-6.946**
	(0.264)	(0.274)	(0.849)	(0.930)	(0.304)	(0.331)
4	-6.656**	-6.494**	-8.242**	-8.154**	-6.841**	-6.979**
	(0.357)	(0.289)	(0.832)	(0.910)	(0.298)	(0.325)
5	-6.827**	-6.644**	-8.502**	-8.395**	-6.737**	-6.833**
	(0.275)	(0.284)	(0.836)	(0.927)	(0.296)	(0.323)
6	-6.983**	-6.725**	-8.670**	-8.338**	-6.912**	-6.994**
	(0.290)	(0.293)	(0.806)	(0.890)	(0.294)	(0.321)
7	-6.674**	-6.490**	-8.864**	-8.553**	-6.933**	-7.012**
	(0.335)	(0.302)	(0.816)	(0.899)	(0.295)	(0.321)
8	-6.643**	-6.470**	-8.360**	-8.258**	-6.886**	-7.008**
	(0.263)	(0.241)	(0.845)	(0.920)	(0.297)	(0.324)
9	-7.087**	-6.826**	-8.498**	-8.335**	-6.880**	-6.967**
	(0.287)	(0.227)	(0.860)	(0.941)	(0.298)	(0.324)
10	-7.129**	-6.893**	-8.648**	-8.529**	-6.801**	-6.879**
	(0.272)	(0.256)	(0.804)	(0.898)	(0.296)	(0.329)
Special calendar days, ξ_{ct}						
Day before end of months	0.274	--	-0.649	--	0.395**	0.490**
	(0.606)	--	(0.427)	--	(0.145)	(0.119)
End of months	0.809	--	0.925	1.377**	0.766**	0.849**
	(0.658)	--	(0.517)	(0.350)	(0.161)	(0.150)
Day after end of months	-0.036	--	0.022	--	0.529**	0.536**
	(0.601)	--	(0.638)	--	(0.166)	(0.160)
Day before end of quarter	0.207	--	2.768**	2.098**	0.235	--
	(0.830)	--	(0.751)	(0.567)	(0.254)	--
End of quarter	0.412	--	0.398	--	1.469**	1.396**
	(0.893)	--	(0.868)	--	(0.271)	(0.265)
Day after end of quarter	1.176	--	1.444	1.566*	0.700**	0.791**
	(0.848)	--	(0.979)	(0.705)	(0.261)	(0.257)
Day before 1-day holiday	-0.184	--	1.499*	1.270*	0.839**	0.828**
	(0.682)	--	(0.755)	(0.546)	(0.243)	(0.242)
Day after 1-day holiday	0.103	--	0.301	--	0.227	--
	(0.886)	--	(0.727)	--	(0.263)	--
Day before 3-day holiday	-0.502	--	-2.399*	-2.030*	-0.920**	-0.968*
	(0.939)	--	(0.988)	(0.816)	(0.315)	(0.313)
Day after 3-day holiday	-0.502	--	-0.340	--	0.109	--
	(1.160)	--	(0.938)	--	(0.331)	--
Day before the 15th of the month	0.071	--	0.180	--	0.376**	0.400**
	(0.372)	--	(0.358)	--	(0.131)	(0.128)
15th of the month	0.947**	0.858**	0.554	--	0.621**	0.613**
	(0.346)	(0.331)	(0.420)	--	(0.129)	(0.129)
Day after 15th of the month	0.651	--	-0.005	--	0.356**	0.309*
	(0.345)	--	(0.320)	--	(0.131)	(0.130)
Day before FOMC meeting	0.168	--	-0.337	--	-0.043	--
	(0.450)	--	(0.493)	--	(0.159)	--
Day of FOMC meeting	-0.063	--	0.304	--	0.212	--
	(0.571)	--	(0.616)	--	(0.160)	--
Day after FOMC meeting	0.440	--	0.418	--	-0.017	--
	(0.481)	--	(0.432)	--	(0.149)	--
NY black-out (Aug. 14, 2003)	-25.276**	--	-13.511**	-18.136**	-1.049	--
	(2.398)	--	(2.160)	(2.784)	(0.693)	--

Table 2 (c)

Mean and volatility of federal funds – Eurodollar spreads: Hourly effects

(standard errors in parentheses; * and ** indicate significance at the 5% and 1% level, respectively)

	Published data, daily regression		*Euro Brokers* data, daily regression		*Euro Brokers* data, hourly regression	
	General model	Restricted model	General model	Restricted model	General model	Restricted model
Hourly effects on mean spreads, δ_{ht}						
1	--	--	--	--	0.0074**	0.0063**
	--	--	--	--	(0.0004)	(0.0003)
2	--	--	--	--	-0.0001	-0.0001
	--	--	--	--	(0.0004)	(0.0003)
3	--	--	--	--	-0.0032**	-0.0030**
	--	--	--	--	(0.0003)	(0.0003)
4	--	--	--	--	-0.0012**	-0.0012**
	--	--	--	--	(0.0004)	(0.0004)
5	--	--	--	--	-0.0023**	-0.0019**
	--	--	--	--	(0.0004)	(0.0004)
6	--	--	--	--	-0.0020**	-0.0012**
	--	--	--	--	(0.0004)	(0.0004)
7	--	--	--	--	-0.0009*	-0.0006
	--	--	--	--	(0.0004)	(0.0003)
8	--	--	--	--	-0.0007	-0.0012**
	--	--	--	--	(0.0004)	(0.0004)
9	--	--	--	--	0.0001	-0.0000
	--	--	--	--	(0.0004)	(0.0004)
Hourly effects on volatility of spreads, ξ_{ht}						
1	--	--	--	--	-1.154**	-1.067**
	--	--	--	--	(0.111)	(0.105)
2	--	--	--	--	-1.530**	-1.328**
	--	--	--	--	(0.111)	(0.106)
3	--	--	--	--	-1.748**	-1.349**
	--	--	--	--	(0.104)	(0.100)
4	--	--	--	--	-1.477**	-1.0067**
	--	--	--	--	(0.110)	(0.010)
5	--	--	--	--	-1.558**	-0.890**
	--	--	--	--	(0.122)	(0.100)
6	--	--	--	--	-1.570**	-0.928**
	--	--	--	--	(0.124)	(0.102)
7	--	--	--	--	-1.489**	-1.058**
	--	--	--	--	(0.116)	(0.099)
8	--	--	--	--	-1.262**	-1.044**
	--	--	--	--	(0.105)	(0.099)
9	--	--	--	--	-1.218**	-1.070**
	--	--	--	--	(0.094)	(0.094)

Table 2 (d)

Federal funds – Eurodollar spreads: Other regression statistics

(standard errors in parentheses; * and ** indicate significance at the 5% and 1% level, respectively)

	Published data, daily regression		*Euro Brokers* data, daily regression		*Euro Brokers* data, hourly regression	
	General model	Restricted model	General model	Restricted model	General model	Restricted model
1-day lagged spread effect on mean	0.150**	0.145**	0.220**	0.212**	0.089**	0.086**
	(0.039)	(0.036)	(0.030)	(0.030)	(0.013)	(0.013)
2-day lagged spread effect on mean	0.091**	0.092**	0.114**	0.116**	0.050**	0.049**
	(0.031)	(0.033)	(0.028)	(0.029)	(0.012)	(0.012)
3-day lagged spread effect on mean	0.039	--	0.104**	0.112**	0.043**	0.048**
	(0.031)	--	(0.030)	(0.032)	(0.011)	(0.011)
4-day lagged spread effect on mean	-0.006	--	0.089*	0.082**	0.055**	0.048**
	(0.026)	--	(0.029)	(0.029)	(0.011)	(0.012)
1-hour lagged spread effect on mean	--	--	--	--	0.138**	0.141**
	--	--	--	--	(0.013)	(0.014)
2-hour lagged spread effect on mean	--	--	--	--	0.055**	0.058**
	--	--	--	--	(0.014)	(0.014)
3-hour lagged spread effect on mean	--	--	--	--	0.032*	0.037*
	--	--	--	--	(0.015)	(0.015)
4-hour lagged spread effect on mean	--	--	--	--	--	0.034*
	--	--	--	--	--	(0.016)
Federal funds trading volume on mean	--	--	--	--	0.0004**	--
	--	--	--	--	(0.0002)	--
Eurodollar trading volume on mean	--	--	--	--	-0.0009**	--
	--	--	--	--	(0.0002)	--
1-lag federal funds trading volume on mean	--	--	--	--	-0.0005**	--
	--	--	--	--	(0.0002)	--
1-lag Eurodollar trading volume on mean	--	--	--	--	0.0001	--
	--	--	--	--	(0.0001)	--
2-lag federal funds trading volume on mean	--	--	--	--	-0.0001	--
	--	--	--	--	(0.0002)	--
2-lag Eurodollar trading volume on mean	--	--	--	--	0.0003*	--
	--	--	--	--	(0.0001)	--
Federal funds trading volume on volatility	--	--	--	--	-0.277**	--
	--	--	--	--	(0.030)	--
Eurodollar trading volume on volatility	--	--	--	--	-0.251**	--
	--	--	--	--	(0.031)	--
1-lag federal funds trading volume on volatility	--	--	--	--	0.011	--
	--	--	--	--	(0.031)	--
1-lag Eurodollar trading volume on volatility	--	--	--	--	0.065*	--
	--	--	--	--	(0.031)	--
target rate change effect on mean	-0.002	--	-0.019	--	0.017	0.035**
	(0.102)	--	(0.035)	--	(0.021)	(0.013)
Absolute target rate change effect on variance	1.741	1.772*	2.476	--	2.020	--
	(0.953)	(0.855)	(2.933)	--	(3.024)	--
1-lag Fed auction stop-out - target rate on mean	--	--	--	--	-0.035	-0.034**
	--	--	--	--	(0.008)	(0.008)
2-lag Fed auction stop-out - target rate on mean	--	--	--	--	-0.027	-0.026**
	--	--	--	--	(0.009)	(0.009)
3-lag Fed auction stop-out - target rate on mean	--	--	--	--	-0.008	--
	--	--	--	--	(0.010)	--
EGARCH parameters						
δ_1	0.498**	0.505**	0.986**	0.980**	1.398**	1.428**
	(0.193)	(0.151)	(0.009)	(0.011)	(0.138)	(0.139)
α_1	0.425**	0.439**	0.153**	0.209**	0.238**	0.223**
	(0.129)	(0.120)	(0.046)	(0.052)	(0.029)	(0.028)
χ_1	-0.097	-0.128	-0.046	-0.047	-0.020	-0.028
	(0.083)	(0.076)	(0.033)	(0.038)	(0.020)	(0.020)
δ_2	--	--	--	--	-0.400**	-0.431**
	--	--	--	--	(0.138)	(0.138)
α_2	--	--	--	--	-0.202**	-0.190**
	--	--	--	--	(0.027)	(0.027)
χ_2	--	--	--	--	0.015	0.024
	--	--	--	--	(0.020)	(0.020)
Degrees of freedom of *t* distribution	5.723**	4.979**	3.559**	3.487**	4.506**	4.190**
	(1.034)	(0.843)	(0.568)	(0.545)	(0.242)	(0.213)

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