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On the Relationship Between the Very Short Forward and the Spot Interest Rate*

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Abstract

This paper revisits the relationship between the forward and the spot interest rate. In contrast to much of the literature we investigate at the very short maturities. The "tomorrow next" rate is the forward interest rate, but has the same maturity as the overnight rate. We estimate an asymmetry in predictability of the very short forward interest rate across different markets. This asymmetry depends on whether the forward rate is greater or less than the current spot rate. To explain this we develop a theoretical framework that incorporates institutional settings, based on interviews with Japanese market participants, such as a penalty for overdrafts, and the inability of securities firms to procure funds.

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Keywords: Term Structure, Predictability, Money Market

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1. Introduction

Do long-term interest rates reflect expected future short-term rates? Or, more precisely, does the implied forward interest rate[1] forecast the future spot interest rate? According to the rational expectations theory of the term structure, the answer is yes. However, most empirical investigations of the term structure have rejected this prediction of the expectations hypothesis. Because the validity of the expectations hypothesis is of crucial importance, due to its fundamental role in term structure theory, a large literature has been built around this relatively simple question of whether forward rates, or yield spreads, can forecast future spot rates.

One area of research has been to examine how predictability varies across different maturities. Some of the earliest studies, by Shiller, Campbell, and Schoenholtz (1983), Mankiw and Miron (1986) and Simon (1989), look at interest rates with a maturity of three months. Subsequently, researchers have extended these studies and examined longer maturities, shorter maturities and a range of maturities.[2] As a result, the literature covers maturities ranging from two weeks to several years. The current consensus is that the ability of the implied forward interest rate to predict the future spot rate varies across maturities. Moreover, a graph of the slope coefficients, in a regression of realized spot rates on forward rates, displays a smile-shaped pattern referred to in the literature as the predictability smile.

Another direction that the research has taken has been to investigate the relationship between the predictive power of the forward interest rate and monetary policy. Many of these studies attribute the unsatisfactory predictive ability of forward rates, low information

[1] Throughout the paper we interchange the terms "implied forward interest rate" and "forward interest rate."
[2] See, for example, Fama and Bliss (1987) and Cook and Hahn (1990) (longer maturities), Hardouvelis (1988) and Mishkin (1988) (shorter maturities) and Campbell and Shiller (1991), Campbell (1995) and Roberds and Whiteman (1999) (range of maturities).

content of the term structure, to interest rate smoothing behavior by the Federal Reserve System.[3] However, Balduzzi, Bertola and Foresi (1997) show that it is expectations of changes in the target that drives the spread between short-term rates and the overnight federal funds rate. They argue that the erroneous anticipation of future changes in monetary policy is a possible cause of the unsatisfactory predictability performance of forward rates.

Nevertheless, regardless of the direction of research, forward and spot interest rates at the shortest maturities have not been fully utilized by the literature. While some researchers have used some of the shortest spot interest rates, such as the overnight rate, in analysis[4] they compare the overnight spot rate with rates on maturities over a week, and not with the forward rate at the shortest maturities. Ignoring the shortest maturities results in several critical oversights. First, by not studying the overnight rate, we have no information on the predictability smile at the very short end of the term structure. Second, since the overnight interest rate is generally regarded as the primary operational target of central banks, forward and spot rates of very short maturities must contain information about the central bank's attitude toward market operations. Finally, the simpler structure of the very short-term money market, relative to longer-term markets, makes it easier to identify the causes of the predictability failure.

In this paper, we introduce a new set of very short forward and spot interest rates neither well recognized in, nor well-utilized by the literature. The very short forward interest rates we consider are the "tomorrow next" (TN) rate and the "spot next" (SN) rate, each

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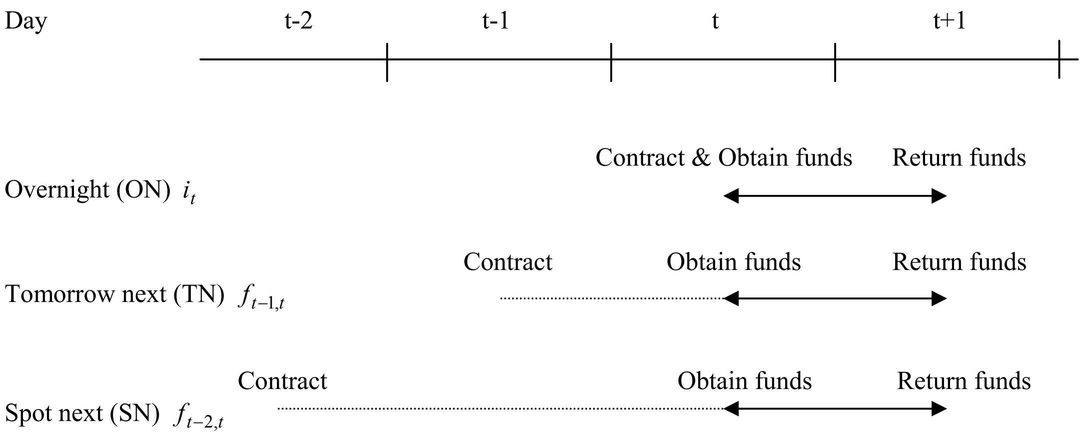
[3] See Mankiw and Miron (1986), Simon (1990), McCallum (1994), Rudebusch (1995) and Roberds, Runkle, and Whiteman (1996).

[4] See Balduzzi, Bertola and Foresi (1997), Griffiths and Winters (1996), Roberds, Runkle and Whiteman (1996), Simon (1990) and Longstaff (2000). The exception is Saito, Shiratsuka, Watanabe and Yanagawa (2001), who employ both spot and forward rates at the shortest maturities in Japan. Their analysis focuses on the specific events of periodic settlements.

having the same maturity as the overnight (ON) rate. The relationship amongst these rates is illustrated below:



Using these rates we successfully estimate the asymmetric predictability of the forward interest rate for four currencies: Eurodollars, Eurosterling, Japanese Yen and Italian Lire. We observe the asymmetry when we compare the predictability from a sample in which the forward rate is higher than the current spot rate, to a sample in which the forward rate is lower than the current spot rate. We find that market institutions may explain this asymmetry.

The plan of the paper is as follows. In section 2 we briefly summarize some of the existing literature. We begin by deriving the implications of the expectations hypothesis for the relationship between the forward interest rate and the future spot interest rate. We then focus our discussion around the main findings of the literature. Section 3 discusses the sources and construction of our data in more detail. In particular, institutional differences across money markets lead us to look at different instruments in the Eurocurrency market as opposed to the Italian domestic money market. In section 4, prior to estimation, we take a closer look at market behavior. In particular, we analyze the behavior of very short-term market participants in order to determine if this behavior is constrained by institutional settings. The findings of this section then form the basis for our estimation in section 5 and the theoretical model of section 6. Our simple theoretical framework demonstrates how market institutions coupled with an asymmetric loss function leads to the asymmetric predictability of the forward rate. Section 7 concludes.

2. Previous Literature

The relationship between the forward interest rate and the future spot interest rate has produced a large body of literature.[5] The primary focus of the research has been to test the rational expectations hypothesis of the term structure. Under the expectations hypothesis, the forward rate is a combination of a shorter spot interest rate and a longer spot rate with maturity twice that of the shorter one. The use of these maturities is a standard practice in the literature.

Let $i_{1,t}$ be the interest rate on the shorter (one-period) bond and $i_{2,t}$ the interest rate on the longer (two-period) bond. Under the expectations hypothesis we are indifferent between holding the longer maturity bond or a series of shorter maturity bonds, or in other words the current long-term rate should be equal to the average of expected short-term rates over the duration of the bond,

$$f_{t,t+1} = 2i_{2,t} - i_{1,t}. \qquad (2.1)$$

Assuming rational expectations,

$$i_{1,t+1} = E_t(i_{1,t+1}) + \varepsilon_{t+1}, \qquad (2.2)$$

[5] Similar investigations have also been implemented extensively in the foreign exchange market as well. See Lewis (1995) and Engel (1995) for surveys of this literature.

where ε_{t+1} is the forecast error orthogonal to the time t information set. Subtracting i_t^1 from both sides of equation (2.2), and assuming that the forward interest rate, $f_{t,t+1}$, is the unbiased estimator of i_{t+1}^1 yields

$$i_{1,t+1} - i_{1,t} = f_{t,t+1} - i_{1,t} + \varepsilon_{t+1}, \qquad (2.3)$$

which provides the testing equation:

$$i_{1,t+1} - i_{1,t} = \alpha + \beta[f_{t,t+1} - i_{1,t}] + \varepsilon_{t+1} \qquad (2.4)$$

with null hypotheses, $\alpha = 0$ and $\beta = 1$. Since the error term, ε_{t+1}, is uncorrelated with the right-hand side regressors, OLS provides consistent coefficient estimates.

The coefficient β has been estimated over a range of maturities, from two weeks to five years, and for different market instruments,[6] including Treasury Bills, Certificate of Deposits (CDs), Eurodollars[7] and Commercial Paper (CP). Cook and Hahn (1990) and Rudebusch (1995) summarize the main results of the literature as follows:[8]

1) The estimates of β are significantly less than 1 for almost all instruments, data sets and maturities.

2) The estimates of β for interest rates of short maturities (from two weeks to two months) are significantly positive.

3) The estimates of β for interest rates of medium maturities (from 3 months to 12 months) are not significantly different from zero.

4) The estimates of β for interest rates of long maturities (more than one or two years) appear to be significantly positive.

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[6] Although U.S. Treasury securities (bills, notes, and bonds) are generally regarded as closest to the theoretical ideal because of their negligible default risk, and no call provisions after 1985, other market instruments have also been used for analysis. However, we limit our discussion to US dollar denominated assets. For research using assets denominated in other currencies see Mishkin (1991), Hardouvelis (1994) and Jorion and Mishkin (1991).

[7] See Jegadeesh and Pennacchi (1996).

[8] See Fama (1984), Fama and Bliss (1987), Mishkin (1988), Hardouvelis (1988), Campbell and Shiller (1991) and Roberds, Runkle and Whiteman (1996) for details.

While the "predictability smile," outlined by points (2)-(4), is a concern to economists,[9] the failure of the null of $\beta = 1$ is the most significant of these results. β not being unity implies that the forward rate is not an unbiased estimator of the future spot rate, which is inconsistent with the expectations hypothesis.

In addition to these standard estimations, in which the longer rate has maturity twice that of the shorter spot rate, other studies use long rates with maturities more than twice as long as the maturities of the short rates. In these non-standard estimations, since the errors overlap, the standard error of β must be corrected for serial correlation. Simon (1990), Campbell and Shiller (1991), Campbell (1995) and Roberds and Whiteman (1999) report the results from these estimations, with findings similar to the above results.

There are three major possible explanations for the failure of the null of $\beta = 1$: (1) a failure of the rational expectations hypothesis, (2) the expected future spot rate not being equal to the forward rate or (3) a time-varying term premium. For example, Froot (1989) uses survey data to discuss irrational expectations of bond market participants, and Mankiw and Miron (1986) show how variation in the term premium can bias the predictability coefficients downward, while Saito et al (2001) analyzed the end of quarter spike in forward rates.

In addition, several studies relate the predictability failure to monetary policy. Mankiw and Miron (1986) and Roberds, Runkle, and Whiteman (1996) attempt to link the

[9] The varying predictability at different horizons allows us to derive many possible implications on the cause of the predictability failure. For example, improved forecasting performance at the longer horizons may imply some long run predictability arising from business cycle effects, while the inability of the spread to forecast movements in the future spot rate for medium term securities may be due to the central bank's success, at the 3 month to 12 month horizon, at smoothing movements in interest rates. See Roberds and Whiteman (1999) and Rudebusch (1995) for attempts to explain the pattern.

failure to changes in monetary policy regimes. In these models, when the central bank attempts to stabilize interest rates, it smoothes out daily interest rate fluctuations, resulting in increased difficulty in predicting future spot rates. The period after the establishment of the Federal Reserve System in 1915 and the periods of the federal funds rate target regime (1974 to 1979 and 1989 to present) are examples of interest rate smoothing behavior by the central bank. By dividing the sample according to the monetary policy regime, and testing for significant differences in predictability across sub-samples, they show that prior to the founding of the Federal Reserve System, the spread between long rates and short rates had substantial predictive power for the path of interest rates.

3. Data Description

In this paper we study very short spot and forward interest rates in both Eurocurrency and domestic money markets.[10] In the Eurocurrency markets, many transactions are made in the form of time deposits between banks or between a bank and a non-bank institution. The dominance of time deposit transactions in the Eurocurrency markets is due to the fact that there is no reserve requirement for Eurocurrency deposits. As a result most participants in the market rely heavily on brokers when they trade time deposits. Quotes are denominated in various currencies, including US Dollars, UK Sterling, Euros and Japanese Yen. Maturities range from very short (ON) to one year, including forward (TN and SN) rates. For each interest rate, liquidity in the markets for the ON, TN and SN rates is quite high. For example, the bid and ask spreads of the ON, TN and SN Eurodollar markets from 1/1/98 to 7/31/98 are no bigger than 1/8 % and the spreads are almost always identical across ON, TN and SN

[10] Eurodollars, Eurosterling, domestic Italian Lire and domestic Japanese Yen are actively traded examples of these instruments. For the first three assets, data are available through Datastream, while Tokyo Tanshi provides data for the Japanese market. For a description of the Eurocurrency ON, TN and SN rates see Dufey and Giddy (1994, p. 206) and Stigum (1990, p. 887).

transactions. In our regressions we use the medium quotes, or the averages of the bid and ask, of the ON and TN interest rates for Eurodollars and Eurosterling.[11] The data in the sample consists of daily interest rates quoted at 16:30 GMT from 1/9/95 to 12/31/99 for Eurodollars and 1/9/95 to 8/9/2002 for Eurosterling. The sample cover the entire period for which data are available.

Interbank funds, with maturities including the very short spot (ON) and forward (TN and SN) rates, are the short-term instruments traded in the Japanese domestic money market and the Italian domestic money market. The markets for these interest rates are considered to be liquid, although the size of the ON market is considerably larger than either the TN or SN markets.[12] The interbank interest rates are known as call rates in Japan and as ATIC (Italian Treasurers Association) rates in Italy. We use the average of the bid and ask rates quoted at 16:30 in Italy and the daily weighted average rates in Japan.[13] Again our data are on a daily basis and cover the entire period for which each database provides data, 5/19/94 to 11/14/97 for Japan and 4/1/88 to 8/7/2002 for Italy.[14]

4. Institutional Structure of the Very Short-Term Money Market

4.1. The Case of Japan[15]

In this section we take a closer look at the organization of the short-term money market. Since the results of this section influence how we implement our estimations it is necessary that we fully understand the institutional structure of the very short-term money

[11] Currently these currencies comprise the only available set of data for which both the ON and TN rates are actively traded.
[12] One market participant interviewed believed the ON market to be about ten times larger than the TN market.
[13] The suggestion to use Japanese data was made by Shigenori Shiratsuka.
[14] For Japan, periods with a series of financial institution bankruptcies, and near zero interest rates are omitted from the sample. It should be noted that Italy, one of member countries of the euro, has adopted EONIA (Euro OverNight Index Average) since 1999.
[15] This section is based on interviews conducted with people in charge of money market transactions at money market brokerages, city banks, foreign banks and the central bank (Bank of Japan).

market. Moreover, by closely examining the activities in this market, we are able to gain better insights into possible reasons for the failure of the forward rate to accurately predict the future spot rate. These findings are then directly incorporated into our theoretical framework, where they prove critical to providing a theoretical foundation for our empirical results.

Our principal finding is that participants in the very short-term money market appear to follow simpler rules than participants in longer-maturity bond markets. Longer-term bond markets, such as the one for 10-year Treasury bonds have many complicating factors. First, bondholders in these markets are not just limited to financial institutions, but also include consumers and non-financial companies. Second, the longer the holding period, the more substitutes there are for bonds, such as bank deposits, stocks or real estate. Finally, the purchase/sales decision of bonds depends strongly on the future outlook of the economy, which is highly subjective and hardly observable.

In contrast, participants in the very short-term money market are, for the most part, limited to financial institutions, and for these firms there are not many alternatives to short-term money market instruments. Furthermore, what participants consider when making their purchase/sales decisions are the elements affecting the daily flow of funds, such as government expenditures, market operations by the central bank and other market participants' procurement/investment behavior. In this relatively simple market with a limited number of players, the driving forces, or the institutional constraints that prevent market participants from acting rationally, are easier to observe.

In the following subsections, we touch upon who participates—either raising or investing funds—in these markets. We then discuss how these participants act in response to changes in the investment environment, and what sort of role financial authorities have in the market. While our findings are true for the Japanese market, for which we were able to obtain a large amount of information through interviews, they cannot be automatically applied to other markets we are still, based on the information gathered, able to make inferences about the institutional structure of very short-term money markets in other countries. It is also important to note that, in the case of Japan, factors such as market participants' attitude toward funds procurement differ when we compare the current economic situation, in which the monetary authority has condoned quantitative easing with the overnight rate near zero, and the situation prior to the autumn of 1997, when interest rates were significantly positive and no one recognized the possibility of default in the unsecured call market.[16]

4.1.1. Participants in Japan's Very Short-Term Money Market

Our primary focus is on markets with large amounts of very short-term transactions, namely the unsecured call market, the Euroyen market, the forex swap market and the repurchase agreement (repo) market. The repo market differs from the other markets in that funds are invested and raised by putting up collateral.[17] However, when the setting of interest rates in the repo market based on collateral value is deducted, the rate in the repo market, under normal conditions, is basically the same as in the other markets. Table 4.1 summarizes the main players on both the investment and procurement sides of the Japanese very short-term money market.

[16] Annotations are added to our explanations whenever it is believed that a certain observation may be unique to the current situation, in which the overall trust in Japanese domestic banks has been shaken.
[17] Collateral often takes the form of government bonds.

From the table it is clear that there are not many procurers of funds. The main players in the market are limited to city banks, foreign banks and securities firms that need to raise funds in order to hold bonds. The investment side is more diverse, and in contrast to the procurement side, players are fixed in particular markets. Investment trusts, for example, invest at the overnight (ON) rate because a portion of their funds must be available within the day due to the nature of their investments. Similarly, agricultural cooperative banks and life and non-life insurers, all of whom invest a great portion of their funds at the ON rate, tend to restrict their investments to that market. If, and when, they do decide to adjust their position, they do not put their funds into the tomorrow next (TN) market, but instead move to longer-term markets, such as the one-month and three-month bond markets. The reason for investors to be fixed in certain markets and not procurers is due to the fact that for investors the opportunity cost of being unable to lend is much smaller than the various penalties incurred in the event of an overdraft.[18] Based on these observations, we focus on the procurers and outline their behavior in the ON and TN markets.

4.1.2. Main Players on the Procurement Side

1) Securities Companies

Although securities firms have current accounts at the Bank of Japan they are not legally required to hold reserves. They also tend to actively use the repo market, where bonds and cash are traded, but by custom settlements are not carried out on the day of the transaction *t+0*, but on the following day, *t+1*, or later.[19] Therefore, securities firms rely on

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[18] In Japan, the overdraft penalty is set at the discount rate plus 6%, while in the US it is the federal funds rate plus 4%. Although Borio (1997) implies that there are overnight, overdraft penalties in the UK and Italian money markets, we do not have the exact penalty rates.

[19] The Japan Securities Dealers Association's Committee for Reform of the Securities Clearing and Settlement System proposed the creation of a *t+0* bond repo market in March 2000. However, there is little chance this will materialize soon as critics argue that *t+0* transactions are already conducted on the secured call market.

the TN or later markets should they need very short-term funds. They will rarely turn to the ON market.[20]

Participants on the investment side of the very short-term money market are aware of this situation, and therefore, credit lines for securities firms on the ON unsecured call market are either non-existent or extremely small. This, coupled with concerns over whether clerical procedures for ON market procurements will go smoothly, further lessens the incentives for securities firms to raise funds in the ON market. Given these circumstances, we can say that securities companies are active participants in the TN market, but not in the ON market.[21]

2) City Banks and Foreign Banks

In contrast to securities firms, both city banks and foreign banks are required to hold reserves. Moreover, on any given day these banks are often faced with the sudden need for a large amount of funds. Because banks usually predict the amount of funds that they will need approximately two days in advance, they usually, with a reasonable degree of accuracy, know the amount of money that they will need to have on hand on a particular day. Therefore, it is possible for these banks to choose the rate at which they want to raise funds—the ON rate, the TN rate or the SN rate. Finally, city banks and foreign banks raise funds on both the ON and TN or later markets.

However, if and when the amount of funds needed on a particular day is large, these players would rather not wait until the next day to raise funds on the ON market, but will instead raise a portion of the amount needed from in the TN market, even if they

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These critics also point out that the creation of the *t+0* market would only serve to complicate market-to-market clerical work.

[20] At most some of the major brokerages will obtain ON finds on the unsecured call market, although this is very rare.

[21] Foreign investment firms with banking affiliates procure funds at overnight rates, and therefore are, in general, not affected by these limitations.

must pay a higher rate. This is most likely due to the belief by those in charge of fund procurement that the possibility of overdraft stemming from unforeseeable circumstances, such as clerical errors, rise sharply with the size of the transaction.

Through experience market participants have learned that interest rates rise when the amount of funds procured is large. Furthermore, the incentive to raise funds by the end of the day, even at the higher TN rate, increases with the approach of the final day of a reserve maintenance period, or the last day of a quarter. This is because heavier than normal penalties[22] are levied when it becomes clear that reserve requirements have not been met, and the financial institution's account statement shows a deficit in the BOJ's current account.

As discussed previously, players on the investment side of the short-term money market are fixed in certain markets, usually the overnight market. Those in charge of investments at these firms are more concerned with keeping labor costs down than with continually searching for the best returns. As a result they simply set rates high enough such that they earn a small positive amount of interest each day. Because of this low rate city banks mainly procure funds on the ON market,[23] however, when they are faced with the task of raising a large amount of funds they quickly procure funds in the forward market. In addition, city banks often have separate divisions in charge of the ON (unsecured call) market and the TN or later (repo, Euroyen and foreign exchange swap) markets. There are implicit restrictions to the amount of funds that each section can extend to the other. Thus, it

[22] If reserve requirements are not met at the end of a reserve maintenance period, banks are penalized by the discount rate plus 3.75%. End of quarter overdrafts do not carry an explicit financial penalty, but rather a reputational one, as the offending bank is publicly rebuked.

[23] Prior to the default in the unsecured call market owing to the collapse of Sanyo Securities Co. in the fall of 1997, market players, such as city banks, had little recognition of liquidity risk. They often borrowed at the overnight rate, which was the lowest rate available, and proceeded to extend long-term loans.

is extremely difficult for those in charge of the TN market, if they are unable to raise the necessary amount of funds in that market, to ask another section for the funds to procure a large amount from the ON market. Oftentimes, a section unable to meet its fund demands will be forced to pay an interest rate above the usual internal transaction rate. Such limitations sometimes result in city banks raising more funds than needed at the higher TN rate.

Although foreign banks experience sizable shocks to their reserves level, they, in general, hold a smaller amount of required reserves than city banks.[24] Hence, it is relatively easy for their reserves position to be negative at the end of day. In order to avoid the substantial penalties brought about by a negative reserve position, foreign banks have an incentive to procure funds in the forward market. Because the head office for these banks set a credit limit for the Japanese market,[25] even if the ON or TN rates become unnecessarily high, these banks will often be unable to hold a position for speculation.

While it is true that city banks and foreign banks can raise funds from both the ON and TN markets, once the amount of money they require exceeds a certain level, they attempt to raise at least a portion of the funds from the TN market. They do so even though they pay a higher rate because of fears of an unexpected overdraft. At the same time, market players are aware that market rates rise when this occurs. These factors, coupled with the behavior of securities firms, imply that speculation in the very short-term money market depends on the spread between the forward rate and the current spot rate.

[24] Daily average of required reserves for a large-sized city bank ranges from 200 billion to 300 billion yen, while for a foreign bank average required reserves do not exceed 10 billion yen.

4.1.3. Monetary Control and Procurement

Presently in Japan, there is a significant amount of excess reserves, and there is absolutely no need for the BOJ to ensure that the reserves market is adequately supplied with liquidity. However, when interest rates were much higher, the accuracy of the BOJ's fund supply to the reserves market is said to have been more precise than any other industrialized country. This was characterized by the BOJ's accuracy in forecasting fund demand, and the banks' precision in putting up reserves with no deficiency or excess up to the million-yen mark. The accurate supply of funds resulted in two contrasting influences on banks' fund demand.

First off, BOJ pressure to ensure that legal reserve levels were accurately met was very strong, with the central bank even taking an unsympathetic view of unforeseen events, such as the late delivery of bills. Under such pressure, banks seeking to raise funds on the very short-term market had a strong incentive to ensure that they obtained the needed reserves, and as mentioned in the previous subsection, in the event the amount they required was large, they were more likely to turn to more certain means of procurement. In other words, these banks would increase the amount of money they raised in the TN market.

Conversely, it is also true that because the BOJ supplied the market with liquidity so accurately, those seeking to raise funds had a strong sense of security. With the belief that the BOJ would supply funds to the market and push interest rates down, some banks did not try to procure funds to maintain their reserves, at higher rates, until the last minute of the final day.[26] It is likely that these banks, unless they feel pressured to secure a large amount of

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[25] It appears that even though they are risk-free, there is a maximum ceiling for Bank of Japan current accounts.

[26] Through the course of interviews market participants revealed that the BOJ and other banks slapped "sanctions'' on banks that continued such practices by refusing to supply funds until the end of a reserves maintenance period.

funds, will not change their traditional stance of procuring at the ON rate on the final day of a maintenance day rather than securing money at the TN rate.

The impression gained through our interviews is that foreign banks tend to react sensitively to the BOJ's strictness toward meeting reserve requirements and will procure funds in advance, including at forward rates such as the TN rate. Japan's city banks, on the other hand, tend to wait until the last minute to raise funds, out of the firm belief that the BOJ will pump the necessary money into the market. Thus, the BOJ's accuracy in supplying funds to the market has two conflicting effects on speculation between the TN and ON rates, and it is difficult to say which is stronger.

4.2. Implications for Other Very Short-Term Money Markets

The Eurocurrency market for the UK pound sterling and the US dollar does not have the Japanese problem of time differences, and thus, ON trading exists. In the United States, funds procured via the repo market can be received on the day of the trade (t+0) and so it is possible to raise funds at the ON rate. Therefore, unlike in Japan, those seeking to procure funds probably find it easier to do so from both the ON and TN markets, and it is therefore likely that speculation between the two markets is easier than it is in Japan.

However, in the U.S., for example, large money center banks are able to procure funds for a longer period of time than foreign banks are able to.[27] Because of this, in the event that foreign banks need a large amount of funds, they most likely will obtain funds swiftly, including through forward rates such as the TN rate, and so it is possible that there is an inadequate amount of speculation between the ON and TN rates.

[27] Money center banks continue to procure funds into the evening, but foreign banks, with the exception of some creditworthy European banks, do not procure funds after 5 p.m.

Angelini (2000) focuses on the intraday choice of funds transactions among Italian money market participants. He finds that their choices are affected by the end-of-day balance uncertainties as well as by the interest rate. Although his focus is on when to procure or invest at the overnight rate within a day, it is possible that the choice between ON and TN funds is also affected by the uncertainties of the banks' end-of-day balance.

5. Estimations of Predictability

In the previous section, we discussed several factors preventing market participants from exploiting arbitrage opportunities. For example, market practices that limit overnight fund procurement by securities companies prevent them from speculating by procuring at the ON rate and investing at the TN rate when $TN_{t,t+1} > E[ON_{t+1}]$. In this case the predictability hypothesis will fail. Also, a "Chinese wall" for intra-company fund transactions penalizes the call market section of banks for procuring at the ON rate and the repo market section for investing at the TN rate. Instead the call market section procures funds at the low ON rate and charges extra fees to the repo market section. This drives a wedge between the ON rate and TN rate and we again expect the predictability hypothesis to fail. Finally, the central bank's commitment to supply funds accurately to the market has two opposing effects. First if the central bank is too lenient in providing liquidity, market participants will have no fear of an overdraft and the ON and TN rates will be identical. There will be no liquidity premium on the TN rate, in which case there is perfect predictability. Second, in supplying liquidity to the market the central bank's desire to ensure that the legal reserves are accurately met may generate extra demand for TN funds. If this is true, the equality between the TN and ON rates will no longer hold and we will see imperfect predictability.

In addition, the degree of speculation between the ON and TN interest rates varies according to the amount of transactions in the market. If the number of transactions is expected to be larger than usual, banks, particularly foreign banks in Japan strongly prefer TN funds in order to avoid both pecuniary and non-pecuniary penalties. The difference between $TN_{t,t+1}$ and ON_{t+1} will not be eliminated and β will be less than one. Common knowledge among participants is that the interest rate tends to rise with larger transaction amounts,[28] which implies $ON_t < E[ON_{t+1} \mid t]$. Based on these findings, we estimate different degrees of predictability of the forward interest rate according to the current forward-spot spread, which is possibly affected by the transactions amount.

5.1. Basic Equations

We begin with the standard equation, (2.4), based on the rational expectation hypothesis, as discussed in section 2. Let ON_t be the interest rate on a one-day maturity spot contract and TN_t be the interest rate on a one-day maturity one-day forward contract. From the rational expectations hypothesis, we have

$$ON_{t+1} = E_t(ON_{t+1}) + \varepsilon_{t+1}, \tag{5.1}$$

where ε_{t+1} is orthogonal to the information available on day t. In addition, by assuming that the forward interest rate, TN_t, is an unbiased estimator for ON_{t+1}, we obtain

$$ON_{t+1} = TN_t + \varepsilon_{t+1}. \tag{5.2}$$

This assumption may be violated if market participants have asymmetric loss functions and constraints, a possibility we discuss in the section 4. We follow general convention and

[28] This is substantiated by Furfine (2000) for the US federal funds market.

assume the interest rate process is a unit root. Taking differences we arrive at the test equation:

$$ON_{t+1} - ON_t = \alpha + \beta(TN_t - ON_t) + \varepsilon_{t+1}, \qquad (5.3)$$

with null $\alpha = 0$ and $\beta = 1$. Estimation results are reported in Table 5.1.

We find that β is significantly different from zero for all currencies, but the Japanese yen, and we are able to reject the null of $\beta = 1$ at the 1% level for all currencies but UK Euro-sterling. Our results are consistent with the existing literature on longer interest rates. Euro-sterling and Italian domestic Lire have high estimates for β at the very short end of the maturity horizon, adding further evidence for the predictability smile. This result, however, may not be a common feature across different currencies, since the Eurodollar and the Japanese yen forward rate have a rather low predictability of $\beta = 0.17$ and $\beta = 0.09$, respectively.[29]

5.2. Asymmetric Predictive Power Equations

In an attempt to capture the asymmetric procurement behavior, dependent on the forward-spot spread, we split the sample into two sub-samples and estimate β separately for each. We obtain an estimate of the predictability coefficient, β_1, when the forward rate is larger than the current spot rate, and an estimate of the predictability coefficient, β_2, when the forward rate is smaller than the current spot rate. Hence, equation (5.3) becomes

[29] We also observe a negative α for Italian Lire. A negative α implies that the TN rate has a constant positive term premium over the ON rate. The pure version of the expectations hypothesis does not allow for a non-zero α. However, since the non-pure version of the expectations hypothesis does allow for non-zero α we do not pay much attention to the significance of α.

$$ON_{t+1} - ON_t = \alpha_1 I(S_t^a > 0) + \alpha_2 I(S_t^a < 0) + \beta_1 (S_t^a) I(S_t^a > 0) + \beta_2 (S_t^a) I(S_t^a < 0) + \varepsilon_{t+1} \quad (5.4)$$

where $S_t^a = TN_t - ON_t$.

The results of this estimation are shown in Table 5.2.with the main results as follows:

1) For every currency, β_2 is significantly higher than β_1.[30]

2) For UK eurosterling, Italian Lire and Japanese Yen, β_2 is not significantly different from 1 at the 10% level. For Eurodollars and Japanese yen, β_1 is not significantly different from 0 at the 10% level.

3) α_1 and α_2 are sometimes significantly different from zero.

As discussed at the beginning of this section result (2) is consistent with our institutional accounts on the structure of the money market. Result (3) makes sense when we consider each financial institution's transaction cost. In the markets for Eurocurrency time deposits, most transactions are implemented through brokers who charge a 0.02% commission to each side of the transaction. Moreover, the financial institution incurs an additional cost for speculating, such as back office expenses and stamp duties. Hence, unless they can expect more than 0.04% in profits, institutions do not speculate with TN_t and ON_{t+1}.

The most striking of these results is that for every currency, β_2 is significantly higher than β_1. We are able to reject, with very high t-statistics, $\beta_1 = \beta_2$ across all currencies. Following our institutional discussion of section 4 we expect that the extent of speculation

[30] While we show that β_2 is significantly larger than β_1, around the value of forward-spot spread being zero there may be no-response zones due to transaction costs or rounding errors in reported numbers. To account for these possibilities, we divide the sample into three using two flexible threshold values. We then choose the thresholds to maximize the log likelihood function. With the exception of the US Eurodollar, one of these threshold values is close to zero. In addition, the β for the sample with a small TN-ON spread is significantly larger than the sample with the large TN-ON spread. Thus, it is appropriate for us to take zero as a threshold value.

will depend on the sign of the forward-spot spread. The estimation results are clearly consistent as β_1 is not necessarily significant, and more importantly β_1 is always smaller than β_2.

To analyze end-of-term[31] liquidity demand in the Japanese very short money market, Saito et al. (2001) used dummy variables. Our primary concern is whether, after accounting for the end-of-term effect on predictive power, the null, $\beta_1 = \beta_2$, holds. The results including the dummy variables are displayed in Table 5.3. As far as rejecting the null, there is not much difference between the results here and those in Table 5.2. We are still able to reject the null. What is striking, however, are the negative γs across currencies. In particular, the coefficients for the end-of-quarter dummies are all negative, although not all of them are significant, which may imply that the realized ON rate on day *t+1* moves opposite to the TN rate on day *t*.

In order to see the extent to which the current forward-spot spread affects future interest rates, we now turn to longer maturity bonds. In the Eurocurrency and domestic money markets, there are longer maturity bonds, such as one-week or two-week bonds with which we can easily implement our non-standard estimation for predictability. For currencies with available data, there are at most three sets of equations to be estimated. Following (5.3), we have

$$\frac{ON_{t+2} + ON_{t+1}}{2} - ON_t = \alpha + \beta\left(\frac{SN_t + TN_t}{2} - ON_t\right) + \varepsilon_{t+1}, \tag{5.5}$$

$$\frac{1}{6}\sum_{i=1}^{6} ON_{t+i} - ON_t = \alpha + \beta\left(\frac{7}{6}1W_t - \frac{1}{6}ON_t\right) + \varepsilon_{t+1}, \tag{5.6}$$

$$\frac{1}{13}\sum_{i=1}^{13} ON_{t+i} - ON_t = \alpha + \beta\left(\frac{14}{13}2W_t - \frac{1}{13}ON_t\right) + \varepsilon_{t+1}, \tag{5.7}$$

where SN_t is the spot next interest rate, $1W_t$ is the one-week interest rate and $2W_t$ is the two-week interest rate. As before, by dividing the sample according to the sign of the spread between the yield on the longer maturity and the overnight rate we obtain equations with which to test for the asymmetry in predictability:

$$\frac{ON_{t+2}+ON_{t+1}}{2}-ON_t=\alpha_1 I(S_t^b>0)+\alpha_2 I(S_t^b<0)$$
$$+\beta_1(S_t^b)I(S_t^b>0)+\beta_2(S_t^b)I(S_t^b<0)+\varepsilon_{t+1} \quad (5.8)$$

where $S_t^b=\frac{SN_t+TN_t}{2}-ON_t$

$$\frac{1}{6}\sum_{i=1}^{6}ON_{t+i}-ON_t=\alpha_1 I(S_t^c>0)+\alpha_2 I(S_t^c<0)$$
$$+\beta_1(S_t^c)I(S_t^c>0)+\beta_2(S_t^c)I(S_t^c<0)+\varepsilon_{t+1} \quad (5.9)$$

where $S_t^c=\frac{7}{6}1W_t-\frac{1}{6}ON_t$

$$\frac{1}{13}\sum_{i=1}^{13}ON_{t+i}-ON_t=\alpha_1 I(S_t^d>0)+\alpha_2 I(S_t^d<0)$$
$$+\beta_1(S_t^d)I(S_t^d>0)+\beta_2(S_t^d)I(S_t^d<0)+\varepsilon_{t+1} \quad (5.10)$$

where $S_t^d=\frac{14}{13}2W_t-\frac{1}{13}ON_t$

The results of the estimation are shown in Table 5.4.[32] Sample periods differ from Table 5.2 due to the availability of data. The common results across currencies are:

1) With longer maturities, β is unchanged or sometimes significantly larger in size.

2) With the exception of Italy, as the maturity lengthens, we tend not to reject the null hypothesis of $\beta_1=\beta_2$.

The degree of speculation between the very short-term spot (ON) and forward (TN or SN) rates is seriously affected by the current forward-spot spread. Speculation between the

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[31] By end-of-term we mean either end-of-quarter, end-of-month or end-of-reserve maintenance period.

[32] Sample periods differ from Table 5.2 due to the availability of data.

ON and longer maturity interest rates is relatively stable over the change in the forward-spot spread. The logic here is that a larger transaction amount results in a higher forward-spot spread, forcing banks, in fear of an increased probability of an overdraft, to secure funds in the TN or SN markets. In contrast, if the larger transaction is temporary, the longer-term interest rate will not respond, and thus the longer forward-spot spread will remain unchanged.

6. A Theoretical Model of Asymmetric Predictability

6.1. A Three-Period Model of the Bond Market

To explain the asymmetric predictability, which is especially conspicuous at the shortest maturities, we need to isolate factors especially relevant to the very short-term money market. In this section we develop a three-period model that combines an asymmetric loss function with institutional constraints to explain the estimated asymmetry. Our model relies heavily on our institutional discussion in section 4. We embed in the model two crucial market institutions:

1) A penalty for overnight overdrafts,[33]

2) Banks are required to prepare their funds a period in advance.[34]

The second assumption is based on two observations taken from our discussions with market participants. The first is that many securities firms in Japan procure only in the TN market and not in the ON market. The second is that banks tend to obtain a certain amount of TN funds because of the implicit barrier among procurement sections, and the increasing fear of an overdraft under certain circumstance.[35]

6.2. The Bond and Reserves Market

[33] This is an actual market practice that Furfine (2000) incorporates into his model of the US federal funds market.

[34] Even if a bank needs to borrow funds in the current period, there are limitations to this behavior.

Let t, $t+1$ and $t+2$ index time. A bank can participate in the bond market at the start of each day. There are bonds of two different maturities: overnight and two-day. These bonds are reimbursed at price equal to one at maturity. Funds from the sale of bonds convert into reserves. However, when bonds are reimbursed before maturity, their price is uncertain. Finally, banks purchase or sell bonds, but is assumed not to short sell them.[36]

6.3. Cost Minimization

Among its entire asset portfolio, a bank has a choice of purchasing overnight and/or two-day bonds. In addition, since holding reserves is viewed as costly, we assume that banks attempt to hold as little excess reserves as possible. Banks, however, are faced with possible exogenous shocks to their level of reserves. If reserves do drop below zero, banks are penalized by the overdraft amount. In order to avoid the penalty for overnight overdrafts, a bank would, therefore, keep their reserve level positive by redeeming overnight or two-day bonds at the beginning of each day. Considering this trade-off, a bank determines the amount of bonds to purchase and reserves to hold, in order to minimize its expected cost. For simplicity we assume shocks to reserves occur only on day $t+1$. We also assume that the shock has a standard normal distribution. The expected cost minimization of a bank can be written as follows:

$$\min_{\{b_t, B_t\}} E_t\left[b_t(q_t - 1) + B_t(Q_t - \alpha) + E_t(C_{t+1})\right], \tag{6.1}$$

$$\text{where} \quad C_{t+1} = \begin{cases} 0 & x_{t+1} \geq -b_t - \alpha B_t \\ -\theta(b_t + \alpha B_t + x_{t+1}) & \text{otherwise} \end{cases}$$

$$x_{t+1} \sim N(0,1) \quad \text{and} \quad E_t(\alpha) = 1$$

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[35] This assumption is also adopted in Holmstrom and Tirole (2001). However, their justification of the assumption differs from ours.
[36] This assumption is based on our institutional accounts.

b_t is the amount of overnight bonds purchased and q_t is the price of overnight bonds. B_t and Q_t are the corresponding amount and price for two-day bonds, and α is the uncertain payoff when two-day bonds are reimbursed before maturity. C_{t+1} is the penalty for overdrafts and x_{t+1} is a shock affecting the reserves level. The expected value of C_{t+1} is

$$
\begin{aligned}
E_t(C_{t+1}) &= \int_{-\infty}^{\infty} h(\alpha) \int_{-\infty}^{\infty} C_{t+1} f(x_{t+1}) dx_{t+1} d\alpha \\
&= -\theta \int_{-\infty}^{\infty} h(\alpha)\left[(b_t + \alpha B_t)\Phi(-b_t - \alpha B_t) - \phi(-b_t - \alpha B_t)\right] d\alpha
\end{aligned} \tag{6.2}
$$

Differentiating the bank's cost function with respect to b_t and B_t, we have

$$q_t = 1 + \theta \int_{-\infty}^{\infty} \Phi(-b_t - \alpha B_t) h(\alpha) d\alpha \tag{6.3}$$

$$Q_t = 1 + \theta \int_{-\infty}^{\infty} \alpha \Phi(-b_t - \alpha B_t) h(\alpha) d\alpha \tag{6.4}$$

and $\mathrm{cov}(\alpha, \Phi(-b_t - \alpha B_t)) < 0$, which implies $q_t > Q_t$. We can then define the overnight forward interest rate on day *t* as

$$f_{t,t+1} \equiv q_t - Q_t > 0 . \tag{6.5}$$

Since a bank is risk neutral, its rate of time preference is zero, and no shock to reserves is expected on day *t+2*. Therefore,

$$E_t(i_{t+1}) = 0 . \tag{6.6}$$

Given (6.5) and (6.6), we have

$$i_t (\equiv 1 - q_t) < E_t(i_{t+1}) < f_{t,t+1} (\equiv q_t - Q_t) . \tag{6.7}$$

In the case of a shock on day *t*, when we estimate equation (6.4), the null of the expectation hypothesis, $\beta_1 = 1$, will be rejected. In contrast, when there is no shock to reserves,

$$i_t = E_t(i_{t+1}) = f_{t,t+1}, \quad (6.8)$$

there will be no deviation of the forward rate from the expected future spot rate. In this case, the efficient market hypothesis of $\beta_2 = 1$ is less likely to be rejected.

Here we have modeled only the demand side of the market and not the supply side. This is justified by the observation made in section 4 that participants on the investment side of the very short-term money market alter their portfolios less frequently than participants on the procurement side. Overall, the settings and implications of this simple model are consistent with our institutional observations and empirical results, in which we find an asymmetric predictability of forward rates.

7. Conclusion

This paper revisits the relationship between the forward interest rate and the spot interest rate at the shortest maturities for Eurodollars, Eurosterling, the domestic Japanese Yen and the domestic Italian Lire markets—a set of interest rates that have not been fully utilized in the literature. Through interviews with participants in the Japanese money market, we find that it is possible for the forward rate to fail in predicting the future spot rate largely because of several key market constraints. These constraints include overdraft penalties, the inability of securities firms to procure funds in the ON market, and the inclination of banks to secure more funds with forward contract in the face of the higher possibility of an overdraft. Some of these constraints are found to be binding when the expected procurement needs are high, but not binding when otherwise.

Based on our institutional discussion, we find empirically striking pieces of evidence for asymmetric predictability. The asymmetry occurs when the forward rate minus the current spot rate is either positive or negative. The estimated coefficient of predictability is significantly closer to unity when the spread is negative, implying that the predictability hypothesis holds. We also develop a simple theoretical framework, to explain this asymmetry. Both the estimation results and the theoretical model are consistent with market practices.

Although we have proposed an explanation for the asymmetry in predictability, there is still further need for investigation. In our theoretical model, random fluctuations in reserves coupled with an asymmetric loss function and divided forward and spot bond markets give rise to the insufficient predictability. Therefore, to check the validity of the model, data on the exogenous factors affecting reserves demand are needed. Also, knowledge of the market institutions in countries other than Japan will enhance our understanding of the cause of the predictability failure.

Table 4.1: Market Participants in Japan's Very Short-Term Money Market

	Procurement		Investment
	Overnight (ON)	Tomorrow next (TN) and later	
Unsecured Call	City banks, foreign banks	City banks, foreign banks	Investment trusts, regional banks, second-tier regional banks, agricultural cooperative banks, life and non-life insurers, trust banks
Euroyen	----------[37]	Japanese banks (overseas branches), foreign banks	Japanese banks (domestic branches)
Forex Swap	----------[37]	Foreign banks,[38] Japanese banks	Japanese banks
Repo	----------[39]	Securities firms, city banks	Investment trusts, foreign banks

Note: modified from Chart 3 in Inaba et al. (2001)

[37] Due to time differences with overseas markets, practically no funds are raised at the overnight rate in the Euroyen and forex swap markets.

[38] Foreign banks are currently able to procure yen funds at negative interest rates on the forex swap market due to Japanese banks' strong demand for dollars. As a result, their presence in the market is increasing.

[39] There are customarily no overnight rate transactions in the repo market.

Table 5.1: Estimates of Predictability

$$ON_{t+1} - ON_t = \alpha + \beta(TN_t - ON_t) + \varepsilon_{t+1} \quad (5.3)$$

	α	β	$\beta=0$	$\beta=1$
U.S. Eurodollars: 1/9/95-12/31/99 (1299 observations)	0.003 (1.091)	0.170 (2.878)	***	***
UK Eurosterling: 1/9/95-8/9/2002 (1970 observations)	-0.014 (-0.657)	0.890 (11.439)	***	
Italy domestic Lire: 4/4/88-8/7/2002 (3742 observations)	-0.204 (-7.575)	0.654 (17.113)	***	***
Japanese domestic Yen: 5/19/94-11/14/97 (864 observations)	-0.003 (-1.138)	0.087 (0.418)		***

Note: t-values in parentheses. ***, **, * denote significance level of 1%, 5%, 10% respectively. Heteroskedasticity and autocorrelation consistent covariance is employed for standard errors.

Table 5.2: Estimates of Asymmetric Predictability

$$ON_{t+1} - ON_t = \alpha_1 I(S_t^a > 0) + \alpha_2 I(S_t^a < 0)$$
$$+ \beta_1 (S_t^a) I(S_t^a > 0)$$
$$+ \beta_2 (S_t^a) I(S_t^a < 0) + \varepsilon_{t+1} \quad (5.4)$$

where $S_t^a = TN_t - ON_t$ and $I(\cdot)$ is an indicator function equal to 1 if the condition in the parentheses is satisfied, and is equal to 0 otherwise.

	S^a>0				*S^a<0*				
	α_1	β_1	$\beta_1=0$	$\beta_1=1$	α_2	β_2	$\beta_2=0$	$\beta_2=1$	$\beta_1=\beta_2$
U.S. Eurodollars: 1/9/95-12/31/99 (1299 observations)	0.028 (4.684)	-0.002 (-0.036)		***	0.006 (0.338)	0.252 (2.018)	**	***	*
UK Eurosterling: 1/9/95-8/9/2002 (1970 observations)	0.070 (1.457)	0.469 (4.611)	***	***	0.095 (4.041)	0. 976 (48.85)	***		***
Italy domestic Lire: 4/4/88-8/7/2002 (3742 observations)	-0.178 (-5.97)	0.609 (15.932)	***	***	-0.154 (-3.02)	1.121 (6.927)	***		***
Japanese domestic Yen: 5/19/94-11/14/97 (864 observations)	0.009 (1.646)	-0.098 (-0.444)		***	-0.008 (-2.62)	0.977 (12.54)	***		***

Note: t-values in parentheses. ***, **, * denote significance level of 1%, 5%, 10% respectively. Heteroskedasticity and autocorrelation consistent covariance is employed for standard errors.

Table 5.3: Estimates of Asymmetric Predictability with dummy variables

$$ON_{t+1} - ON_t = \alpha_1 I(S_t^a > 0) + \alpha_2 I(S_t^a < 0)$$
$$+ \beta_1 (S_t^a) I(S_t^a > 0) + \beta_2 (S_t^a) I(S_t^a < 0)$$
$$+ \gamma_1 QF_{t+1}(S_t^a) + \gamma_2 OTMF_{t+1}(S_t^a) + \gamma_3 MPL_{t+1}(S_t^a)$$
$$+ \delta_i (MonetaryPolicyChange_i)(S_t^a) + \varepsilon_{t+1}$$

where $S_t^a = TN_t - ON_t$ and $I(\cdot)$ is an indicator function equal to 1 if the condition in the parentheses is satisfied, and is equal to 0 otherwise, QF is the dummy for the end of a quarter, OTMF is the dummy for the end of a month but the quarter end, and MPL is the dummy for the end of a reserve maintenance period. Since the UK and Italy do not have a multiple day reserve maintenance system at least some periods in the samples, they do not have MPL in the estimation.

Table 5.3a

	$S^a>0$				$S^a<0$				
	α_1	β_1	$\beta_1=0$	$\beta_1=1$	α_2	β_2	$\beta_2=0$	$\beta_2=1$	$\beta_1=\beta_2$
U.S. Eurodollars: 1/9/95-12/31/99 (1299 observations)	0.026 (3.662)	-0.008 (-0.127)		***	0.007 (0.405)	0.256 (2.039)	**	***	**
UK Eurosterling: 1/9/95-8/9/2002 (1970 observations)	0.071 (1.475)	0.471 (4.533)	***	***	0.094 (3.982)	0. 976 (49.126)	***		***
Italy domestic Lire: 4/4/88-8/7/2002 (3742 observations)	-0.176 (-5.924)	0.617 (15.579)	***	***	-0.155 (-3.045)	1.121 (6.914)	***		***
Japanese domestic Yen: 5/19/94-11/14/97 (864 observations)	-0.002 (-1.034)	0.378 (3.603)	***	***	-0.008 (-2.505)	0.978 (12.359)	***		***

Table 5.3b

	γ_1	γ_2	γ_3
U.S. Eurodollars	-0.019 (-0.267)	0.406 (2.676)	-0.058 (-0.817)
UK Eurosterling	-0.419 (-2.707)	0.046 (0.140)	
Italy domestic Lire	-0.576 (-10.497)	-0.013 (-0.128)	
Japanese domestic Yen	-0.061 (-0.284)	0.294 (2.222)	0.094 (0.328)

Note: t-values in parentheses. ***, **, * denote significance level of 1%, 5%, 10% respectively.

Heteroskedasticity and autocorrelation consistent covariance is employed for standard errors.

Table 5.4: Estimates of Asymmetric Predictability for Longer-term Maturities

$$ON_{t+1} - ON_t = \alpha + \beta(S_t^a) + \varepsilon_{t+1} \qquad (5.3)$$

$$\begin{aligned} ON_{t+1} - ON_t &= \alpha_1 I(S_t^a > 0) + \alpha_2 I(S_t^a < 0) \\ &\quad + \beta_1(S_t^a) I(S_t^a > 0) + \beta_2(S_t^a) I(S_t^a < 0) + \varepsilon_{t+1} \end{aligned} \qquad (5.4)$$

$$\frac{ON_{t+2} + ON_{t+1}}{2} - ON_t = \alpha + \beta(S_t^b) + \varepsilon_{t+1} \qquad (5.5)$$

$$\frac{1}{6}\sum_{i=1}^{6} ON_{t+i} - ON_t = \alpha + \beta(S_t^c) + \varepsilon_{t+1}, \qquad (5.6)$$

$$\frac{1}{13}\sum_{i=1}^{13} ON_{t+i} - ON_t = \alpha + \beta(S_t^d) + \varepsilon_{t+1}, \qquad (5.7)$$

Table 5.4a: US Eurodollars 1/9/95-12/31/99 (1299 observations)

	β	$\beta 1$	$\beta 2$	For $\beta 1 = \beta 2$
	(5.3)	*(5.4)*		
1-day ahead	0.170 (2.878)	-0.002 (-0.036)	0.252 (2.018)	*(3.402)
	(5.5)	*(5.8)*		
2-day ahead	0.222 (3.426)	-0.050 (-1.038)	0.315(2.498)	***(6.759)
	(5.6)	*(5.9)*		
6-day ahead	0.377(5.576)	0.254 (4.074)	0.333 (2.280)	(0.225)

Table 5.4b: UK Eurosterling 1/9/95-8/9/02 (1970 observations)

	β	$\beta 1$	$\beta 2$	For $\beta 1 = \beta 2$
	(5.3)	*(5.4)*		
1-day ahead	0.890 (11.44)	0.469 (4.611)	0.976 (48.85)	***(22.27)
	(5.5)	*(5.8)*		
2-day ahead	0.911 (14.94)	0.554 (5.670)	0.990 (141.3)	***(19.60)
	(5.6)	*(5.9)*		
6-day ahead	0.798 (20.64)	0.532 (5.805)	0.844 (103.0)	***(11.34)
	(5.7)	*(5.10)*		
13-day ahead	0.884 (29.76)	0.717(9.03)	0.925 (132.77)	***(6.76)

Table 5.4c: Italian Domestic Lire 4/1/93-12/29/98 (1499 observations)

	β	$\beta 1$	$\beta 2$	For $\beta 1 = \beta 2$
	(5.3)	*(5.4)*		
1-day ahead	0.596 (7.783)	0.569 (4.921)	0.694 (5.259)	(0.500)
	(5.5)	*(5.8)*		
2-day ahead	0.672(10.93)	0.670(7.301)	0.703(6.274)	(0.054)
	(5.6)	*(5.9)*		
6-day ahead	0.554(12.20)	0.511(6.929)	0.761(11.03)	**(6.275)
	(5.7)	*(5.10)*		
14-day ahead	0.631(10.48)	0.597(5.186)	0.839 (13.78)	*(3.407)

Note: t-values in parentheses. The rightmost parentheses are for F-values. ***,**,* denote significance level of 1%, 5%, 10% respectively.

Heteroskedasticity and autocorrelation consistent covariance is employed for standard errors.

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