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

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Abstract

In this paper we revisit the relationship between the forward interest rate and the spot interest rate at the shortest maturities. We introduce a new set of very short forward and spot interest rates that have not been fully utilized in the literature: the "tomorrow next" rate and the "spot next" rate, both of which have the same maturity as the overnight rate. Using these interest rates we demonstrate an asymmetric predictability of the forward interest rate. This asymmetry, which we find to be robust across different money markets, depends on whether the forward rate is greater or less than the current spot rate. Money market institutions, such as a penalty for end of day overdrafts, and the inability of securities firms to procure funds in certain markets may explain the asymmetry.

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1. Introduction

Can the implied forward interest rate[1] predict the future spot interest rate? According to the rational expectations theory of the term structure, the answer to the question 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 direction that the term structure literature has taken has been to investigate how predictability varies across different maturities. The earliest studies, including Shiller, Campbell, and Schoenholtz (1983), Mankiw and Miron (1986) and Simon (1989), examine interest rates with a maturity of three months. Subsequently, the maturity of the interest rates under analysis has been extended to both longer and shorter maturities. For example, Fama and Bliss (1987) and Cook and Hahn (1990) look at longer maturities, while Hardouvelis (1988) and Mishkin (1988) look at shorter maturities. Finally, Campbell and Shiller (1991), Campbell (1995) and Roberds and Whiteman (1999) examine a range of maturities.[2] The current consensus is that the ability of the implied forward interest rate to predict the future spot rate varies across maturities, and a graph of the slope coefficients, in a regression of realized spot rates on forward rates, displays a smile-shaped pattern.[3]

Researchers have also investigated the relationship between monetary policy and the predictive power of the forward interest rate. Many of these studies attribute the

[1] The implied forward interest rate will be called the forward interest rate.
[2] As a result, the literature covers maturities ranging from two weeks to several years.
[3] This pattern is known as the "predictability smile".

unsatisfactory predictability of forward rates to interest rate smoothing behavior by the Federal Reserve System.[4] However, Balduzzi, Bertola and Foresi (1997, hereafter BBF) show that it is expectations of changes in the target that drive the spreads between short-term rates and the overnight federal funds rate. Therefore, the erroneous anticipation of future changes in monetary policy can be the cause of the unsatisfactory predictability performance.

Nevertheless, whatever the direction of the 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[5] they compare the overnight spot rate with rates on maturities longer than a week, and not with the forward rate at the shortest maturities. Ignoring the shortest maturity rates results in several critical oversights. First, by not studying the overnight rate, we have no information on the predictability smile at the shortest maturities. Second, the overnight interest rate is generally regarded as the primary operational target of central banks. Therefore, forward and spot rates of very short maturities must contain information about the central bank's attitude toward market operations. Finally, because of the simpler structure of the very short-term money market, it is easier to identify the causes of the predictability failure than in longer-term markets.

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

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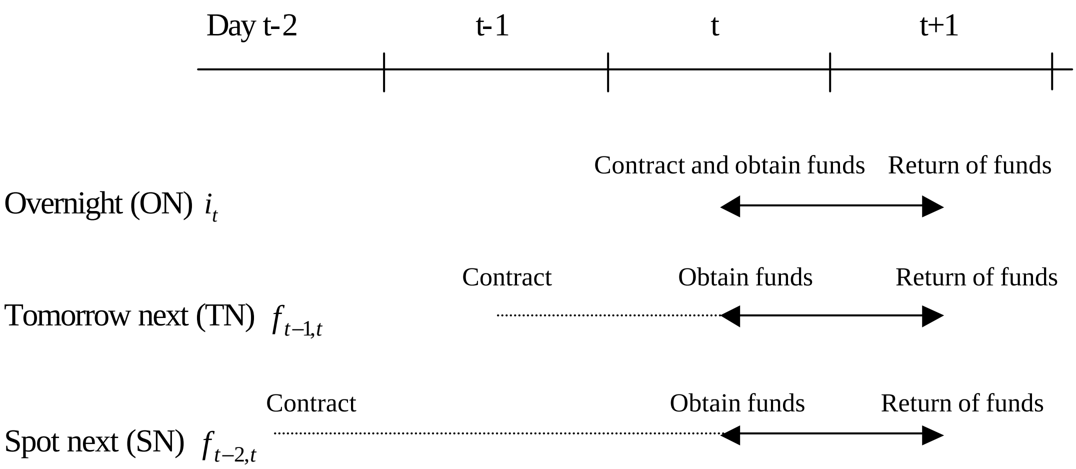
[4] See Mankiw and Miron (1986), Simon (1990), McCallum (1994), Rudebusch (1995) and Roberds, Runkle, and Whiteman (1996).

[5] See BBF, 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.

each having the same maturity as the overnight (ON) rate. The relationship amongst these rates is shown in the diagram 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 first derive 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. In section 3 we discuss the sources and construction of our data in more detail. In particular, institutional differences lead us to look at different instruments in the Eurocurrency market as opposed to the Italian domestic money market. Prior to estimation, in section 4, we analyze the behavior of very short-term market participants in order to determine if this behavior is constrained by institutional settings. Based on our findings we then discuss our estimation techniques and results in section 5. In section 6 we construct a simple theoretical framework that demonstrates how market institutions coupled with an asymmetric loss function leads to asymmetric predictability of the forward rate. In section 7, we touch upon alternative explanations for the predictability failure. Section 8 concludes.

2. Previous Literature

A study of the relationship between the forward interest rate and the future spot interest rate has produced a large body of literature,[6] the primary focus of which has been the testing of the rational expectations hypothesis. 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. We can then form a one period ahead forward contract by both selling the shorter bond and buying the longer bond in period t. Hence, the forward interest rate will be

$$f_{t,t+1} = 2i_{2,t} - i_{1,t}\,. \tag{2.1}$$

Assuming rational expectations,

$$i_{1,t+1} = E_t(i_{1,t+1}) + e_{t+1}\,, \tag{2.2}$$

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

where e_{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

$$i_{1,t+1} - i_{1,t} = f_{t,t+1} - i_{1,t} + e_{t+1}, \tag{2.3}$$

which provides the testing equation:

$$i_{1,t+1} - i_{1,t} = a + b[f_{t,t+1} - i_{1,t}] + e_{t+1} \tag{2.4}$$

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

The coefficient b in equation (2.4) has been previously estimated over a range of maturities, from two weeks to five years, and for many different market instruments,[7] including Treasury Bills, Certificate of Deposits (CDs), Eurodollars and Commercial Paper (CP).[8] Rudebusch (1995) and Cook and Hahn (1990) summarize the results in the literature[9] as follows:

- The estimates of b are significantly smaller than 1 for almost all instruments, data sets and maturities.

- Estimated b for interest rates of short maturities (from two weeks to two months) are significantly positive.

- Estimated b for interest rates of medium maturities (from 3 months to 12 months) are not significantly different from zero.

[7] Although U.S. Treasury securities (bills, notes, and bonds) are 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, the literature discussed in this section is limited to US dollar denominated assets.

[8] See Jegadeesh and Pennacchi (1996) for a study using Eurodollars. See Mishkin (1991), Hardouvelis (1994) and Jorion and Mishkin (1991) for research using assets denominated in other currencies.

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

• Estimated b for interest rates of long maturities (more than one or two years) appear to be significantly positive.

Most significant amongst these results is the failure of the null of $b = 1$. This implies that the forward rate is not an unbiased estimator of the future spot rate,[10] which is inconsistent with the expectations hypothesis.

In addition to these standard estimations, many other studies look at 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 b 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 standard results.

There are three major possible explanations for the failure of the null of $b = 1$: (1) a failure of the rational expectations hypothesis, (2) the expected future spot rate not being equal to the forward rate and (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. 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 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 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.

BBF propose another possibility for how monetary policy affects the predictability failure. They state, "the bias in tests of the expectation hypothesis, that we and others document, can be mainly attributed to erroneous anticipation about the change in monetary policy" (BBF, p.224). To support their claim, BBF formulate two test equations for the future spot interest rate and for the future federal funds target rate set by the Fed, and compare the predictive power across the two equations. They show that the predictive power for the federal funds target rate is significantly smaller than the predictive power for the federal funds rate. Therefore, the more pronounced bias in the target component of overnight federal funds rate dynamics supports their view that the erroneous expectations of market participants lead to predictability failure.

3. Data Description

In this paper we study very short spot and forward interest rates in both Eurocurrency and domestic money markets.[11] 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

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[10] The "predictability smile" outlined by the last three points is also a concern of economists. See Roberds and Whiteman (1999) and Rudebusch (1995) for attempts to explain the pattern.

[11] Eurodollars, Eurosterling, domestic Italian Lire and domestic Japanese Yen are actively traded examples of these instruments. For the first three assets, data is available through Datastream, while Tokyo Tanshi provides

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 the same across ON, TN and SN transactions. In our regressions we use the medium quotes, i.e. the averages of the bid and ask, of the ON and TN interest rates for Eurodollars and Eurosterling.[12] 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, which are the entire periods for which data is available.

Short-term instruments in the Japanese and the Italian domestic money market are interbank funds with maturities including the very short spot (ON) and forward (TN and SN) rates. All of 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. 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

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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).

[12] Currently these currencies comprise the only available set of data for which both the ON and TN rates are actively traded.

[13] The suggestion to use the data for Japan was made by Shigenori Shiratsuka.

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. The Very Short-term Money Market: The Case of Japan[15]

While it is meaningful to introduce a new set of interest rates and run regressions, upon closer examination we find 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, when investing for longer terms many substitutes, such as bank deposits, stocks and real estate, for bonds exist. 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 basically limited to financial institutions, and there does not exist 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

[14] For Japan, periods with a series of financial institution bankruptcies, and near zero interest rates are omitted from the sample.
[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).

are easier to observe. By closely examining the activities in this market, we are able to gain better insights into possible reasons for the predictability failure.

In this section, we touch upon what kind of parties raise and invest funds in these markets, how those participants act in response to changes in the investment environment and what sort of role financial authorities play. 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. However, we are able to make inferences about other markets based on the information gathered.

It is also important to note that in the case of Japan, factors, such as market participants and their attitudes 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. Participants in Japan's Very Short-term Money Market

Our primary focus in this section 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. Although the repo market differs from the others in that funds are invested and raised by putting up collateral, such as government bonds, 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: 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	---------[17]	Japanese banks (overseas branches), foreign banks	Japanese banks (domestic branches)
Forex swap	---------[17]	Foreign banks,[18] Japanese banks	Japanese banks
Repo	---------[17]	Securities firms, city banks	Investment trusts, foreign banks

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

From table 4.1 it is clear that there are not many procurers of funds. The main players are limited to city banks, foreign banks and securities firms that need to raise funds to hold bonds. The investment side is more diverse, and in contrast to the procurement side, players are fixed to particular markets. For example, investment trusts invest at the overnight (ON) rate because a portion of their funds must be within the day due to the nature of their investments. Also, 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, and 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 why investors are fixed in certain markets as opposed to procurers is most likely because for investors, the opportunity cost of being unable to lend is much smaller than the various penalties incurred in the event of an

[16] Annotations are added to our explanations whenever it is believed a certain observation something is a phenomenon unique to the current situation, in which the overall trust in domestic banks has been shaken.
[17] Due to time differences with overseas markets, practically no funds are raised at the overnight rate in the Euroyen and forex swap markets. Also, there are customarily no overnight rate transactions in the repo market.
[18] 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.

overdraft. Based on these observations, we focus on the procurers and outline their behavior in the ON and TN markets.

4.2. The Main Players on the Procurement Side

(i) Securities companies

While 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, should they need very short-term funds they will go to the TN or later market, but will rarely go to the ON market. At most, some of the major brokerages will obtain ON funds on the unsecured call market, although this is not a common occurrence.

Participants on the investment side of the very short-term money market are well aware of the situation, and therefore, credit lines for securities firms on the ON unsecured call market are either non-existent or very small. This fact, coupled with concerns over whether clerical procedures for ON market procurements will go smoothly provides securities firms with even less incentive to raise funds in the ON market. Due to these circumstances, it may be said that securities companies take part in the TN market, but not in the ON market.[20]

(ii) City banks and foreign banks

[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 idea will materialize soon as critics argue that t+0 transactions are already conducted on the secured call market. These critics also point out that the creation of the t+0 market would only serve to complicate mark to market clerical work.

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

In contrast to securities firms, both city banks and foreign banks are required to hold a certain amount of reserves. Also, on a given day these banks are often faced with the sudden need for a large amount of funds. Because banks usually calculate the amount of funds that they predict they will need in about two days time, they usually, with a decent degree of accuracy, know the amount of money that they will need to have on hand. Therefore, it is possible for 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 can raise funds from both the ON and TN or later markets.

However, if and when the necessary amount of funds on a particular day is large, these players would rather not wait until the next day to raise the funds on the ON market, but will instead raise a portion of the amount needed from the TN day market, even if they must pay a higher rate. Most likely, this is because those in charge of fund procurement believe that the possibility of overdraft stemming from unforeseeable circumstances, such as clerical errors, rise sharply with the amount of funds needed.

Through experience market participants have also 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 reserves maintenance period, or the last day of the quarter. This is due to the fact that heavier than normal penalties are levied when it becomes clear that reserve requirements were not met, and account statements show a deficit in the financial institution's Bank of Japan (BOJ) current account.

City banks mainly procure funds from the ON market because of the low rate made possible by the fixed players on the investment side.[21] However, when they are faced with the task of raising a large amount of funds they tend not to wait, but to quickly procure funds in the forward market. In addition, city banks often have separate sections in charge of the ON (unsecured call) market and the TN or later (repo, Euroyen and foreign exchange swap) markets. Moreover, there are implicit restrictions to the amount of funds that each section can extend to the other. Thus, it is extremely difficult for those in charge of the TN market, when they are unable to raise the necessary amount of funds, to ask another section for the funds necessary to procure a large amount from the ON market. At times, a section will be unable to meet its fund demands, or will be forced to pay an interest rate higher than the usual internal transaction rate. Because of such limitations, at times city banks will raise more funds than needed at the higher TN rate.

In the case of some foreign banks, while there are sizable shocks to their reserves level, they hold a smaller amount of required reserves than city banks do.[22] Hence, it is relatively easy for their reserves position to be negative at the end of day, which will incur substantial penalties. To avoid this situation, foreign banks have an incentive to procure funds in the forward market. In addition, the head office sets a credit line for the Japanese market.[23] As a result, even if ON or TN rates become unnecessarily high, these banks will at times be unable to hold a position for arbitrage.

[21] Especially true before 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 and often borrowed at the overnight rate, which was the lowest rate, and extended long-term loans.
[22] 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.
[23] It appears that even though they are risk-free, there is a maximum ceiling for Bank of Japan current accounts.

City banks and foreign banks can raise funds from both the ON and TN markets. However, 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, even if they must pay a higher rate, out of fears of an unexpected overdraft. At the same time, market players are aware that market rates rise when this occurs.

4.3. The Relationship between Monetary Control and Procurement

At present, in Japan, there is a significant amount of excess reserves, and there is absolutely no need for the BOJ to ensure that the market has an adequate supply of funds. However, when interest rates were much higher, the degree of accuracy of the BOJ's fund supply to the reserves market is said to have been greater than in other industrialized countries. This was characterized by the BOJ's accuracy in forecasting fund demand, and the banks' precision in putting up reserves with no lack or excess up to the million-yen mark. This sort of accurate fund supply had two conflicting influences on banks' fund demand.

First, BOJ pressure to ensure that legal reserve levels were accurately met was very strong, and it is said that the central bank took a very stern attitude in the event of unforeseen accidents 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 got the needed reserves, and as mentioned above, 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.

On the other hand, it is also true that because the BOJ supplied the market with liquidity with a great deal of accuracy, those seeking to raise funds had a sense of security. Some banks did not try to procure funds at higher rates, to maintain their reserves, until the last minute of the final day out of the belief that the BOJ would supply funds to the market and push interest rates down.[24] It is likely that these banks will not change their traditional stance of procuring at the ON rate on the day rather than swiftly securing money at the TN rate, unless they feel pressured to secure a large amount of funds.

The impression gained through 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 arbitrage between the TN and ON rates, and it is difficult to say which is stronger.

4.4. Implications for Other Very Short-term Money Markets

The Eurocurrency market for 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 thus it is likely that arbitrage between the two markets is easier.

But at the same time, 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.[25] Because of this, in the event that foreign banks need a large amounts of funds, they most likely will obtain funds

[24] It is said 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.

swiftly, including through forward rates such as the TN rate, and it is therefore possible that there is no complete arbitrage between the ON and TN rates.

5. Estimations of Predictability

In the previous section, we discussed several factors preventing market participants from exploiting arbitrage opportunities. Examples are market practices that limit overnight fund procurement by securities companies, a "Chinese wall" for intra-company fund transactions, and the central bank's commitment to supply funds accurately to the market. In addition, the degree of arbitrage between the ON and TN interest rates varies according to the amount of transactions in the market. Common knowledge among participants is that the interest rate tends to rise with larger transaction amounts, which is substantiated by Furfine (2000) for the US federal funds market. 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 expectation hypothesis, we have

$$ON_{t+1} = E_t(ON_{t+1}) + e_{t+1}, \qquad (5.1)$$

where e_{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 have

[25] Money center banks continue to procure funds into the evening, but it is said that foreign banks, with the

$$ON_{t+1} = TN_t + e_{t+1}. \qquad (5.2)$$

Note that this assumption may be violated if market participants have asymmetric loss functions and constraints, whose possibility is discussed in the previous section. We follow general convention and assume the interest rate process is a unit root. Therefore, we take differences and the test equation becomes:

$$ON_{t+1} - ON_t = a + b(TN_t - ON_t) + e_{t+1}, \qquad (5.3)$$

with the null of $a = 0$ and $b = 1$. Estimation results are reported in Table 5.1.

We find that while the coefficient of b is significantly different from zero for every currency except for the Japanese yen, we reject the null of $b = 1$ at the 1% level except for the UK Euro-sterling. These results are consistent with the existing literature on longer interest rates. Euro-sterling and Italian domestic Lire have high estimates for b 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 $b = 0.17$ and $b = 0.09$, respectively.[26]

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 b separately for each. We obtain an estimate of the predictability coefficient, b_1, when the forward rate is

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exception of some creditworthy European banks, do not procure funds after 5 p.m.

[26] We also observe a negative a for Italian Lire. A negative a 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 a. However, since the non-pure version of the expectations hypothesis does allow for non-zero a we do not pay much attention to the significance of a.

larger than the current spot rate, and an estimate of the predictability coefficient, b_2, when the forward rate is smaller than the current spot rate. Hence, equation (5.3) becomes

$$\begin{aligned} ON_{t+1} - ON_t = {} & a_1 I(TN_t - ON_t > 0) + a_2 I(TN_t - ON_t < 0) \\ & + b_1 (TN_t - ON_t) I(TN_t - ON_t > 0) \\ & + b_2 (TN_t - ON_t) I(TN_t - ON_t < 0) + e_{t+1} \end{aligned} \qquad (5.4)$$

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

• For every currency, b_2 is significantly different from (higher than) b_1.

• For UK eurosterling, Italian Lire and Japanese Yen, b_2 is not significantly different from 1 at the 10% level, and for Eurodollars and Japanese yen, b_1 is not significantly different from 0 at the 10% level.

• a_1 and a_2 are sometimes significantly different from zero.

The third result is understandable 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 both sides. Moreover the 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}.

However, the key result is the first point; that for every currency b_2 is significantly higher than b_1. This finding seems to be quite robust since we obtain very high t-statistics to reject $b_1 = b_2$ across all currencies. Following from the institutional discussion of section 4 we expect that the extent of arbitrage will depend on the sign of the forward-spot spread. The estimation results here are clearly consistent, not only with the Japanese market, but also, with other foreign markets since b_1 is not necessarily significant and that b_1 is always smaller than b_2.

To analyze the liquidity demand in the Japanese very short money market at the end of a quarter, a month or a reserve maintenance period, Saito et al. (2001) introduced several dummy variables. Our concern here is to know if we still maintain the property of $b_1 \neq b_2$ even after isolating the end-of-term effect on the predictive power. The estimation results with these dummies are shown in Table 5.3. There is not much conspicuous difference from Table 5.2 in rejecting $b_1 = b_2$. Rather, what is striking is the not significant but negative g s across currencies. Especially, the coefficients for end-of-quarter dummies are negative except for the U.S. Eurodollars, which may imply that the realized ON rate on day t+1 is smaller than the TN rate on day t.

In order to see the extent that the current forward-spot spread affects the future interest rates, we examine longer maturity bonds. In these 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

$$\frac{ON_{t+2} + ON_{t+1}}{2} - ON_t = a + b\left(\frac{SN_t + TN_t}{2} - ON_t\right) + e_{t+1}, \qquad (5.5)$$

$$\frac{1}{6}\sum_{i=1}^{6} ON_{t+i} - ON_t = a + b\left(\frac{7}{6}1W_t - \frac{1}{6}ON_t\right) + e_{t+1}, \qquad (5.6)$$

$$\frac{1}{13}\sum_{i=1}^{13} ON_{t+i} - ON_t = a + b\left(\frac{14}{13}2W_t - \frac{1}{13}ON_t\right) + e_{t+1}, \qquad (5.7)$$

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:

$$\frac{ON_{t+2} + ON_{t+1}}{2} - ON_t = \boldsymbol{a}_1 I(\bullet > 0) + \boldsymbol{a}_2 I(\bullet < 0)$$
$$+ b_1 I(\bullet > 0) + b_2 I(\bullet < 0) + e_{t+1} \qquad (5.8)$$

$$\frac{1}{6}\sum_{i=1}^{6} ON_{t+i} - ON_t = \boldsymbol{a}_1 I(\bullet > 0) + \boldsymbol{a}_2 I(\bullet < 0)$$
$$+ b_1 I(\bullet > 0) + b_2 I(\bullet < 0) + e_{t+1} \qquad (5.9)$$

$$\frac{1}{13}\sum_{i=1}^{13} ON_{t+i} - ON_t = \boldsymbol{a}_1 I(\bullet > 0) + \boldsymbol{a}_2 I(\bullet < 0)$$
$$+ b_1 I(\bullet > 0) + b_2 I(\bullet < 0) + e_{t+1} \qquad (5.10)$$

The results of the estimation are displayed in Table 5.4. Sample periods differ from Table 5.2 due to the availability of data. Again we have a few common results across currencies:

• With longer maturities, b is unchanged or sometimes significantly larger in size.

• Except for Italy, as the maturity becomes longer, we tend not to reject the null hypothesis of $\boldsymbol{b}_1 = \boldsymbol{b}_2$.

The degree of arbitrage between the very short-term spot (ON) and forward (TN or SN) rates are seriously affected by the current forward-spot spread, while arbitrage between the 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 a certain amount of 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 be 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 want to isolate factors especially relevant for the very short-term money markets. In this section we develop a three period model that combines an asymmetric loss function with institutional constraints to explain the estimated asymmetry. There are two crucial market institutions embodied in the model:

• There exists a penalty for overnight overdrafts,[27]

• Even if a bank needs to borrow funds in the current period, there are limitations. Banks must therefore, prepare one period ahead.

The second assumption, in particular, is based on our observation that securities firms in Japan procure only in the TN market and not in the ON market, and that banks tend to obtain a certain amount of TN funds because of the implicit barrier among procurement sections and the fear of the overdraft.[28]

6.2. The Bond and Reserves Market

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.

6.3. Bank's 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 generally regarded as costly, we assume that banks attempt to reduce their holdings of excess reserves to zero. Banks, however, are faced with possible exogenous shocks to their level of reserves. If reserves do

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

[28] This assumption is also adopted in Holmstrom and Tirole (2001). However, their justification of the assumption is different from ours.

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 the day. Considering this trade-off, a bank determines the amount of bonds purchased and reserves held, to minimize its expected cost. For simplicity, shocks to reserves occur only on day *t+1*, and no reserve shocks occur on either day *t* or day *t+2*. We assume the shock is normally distributed with mean zero and variance one. Therefore, the expected cost minimization of a bank can be written as follows:

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

$$\text{where } C_{t+1} = \begin{cases} 0 & ; x_{t+1} \geq -b_t - aB_t \\ -q(b_t + aB_t + x_{t+1}) & ; otherwise \end{cases}$$

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

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 a 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

$$\begin{aligned} E_t(C_{t+1}) &= \int_{-\infty}^{\infty} h(a) \int_{-\infty}^{\infty} C_{t+1} f(x_{t+1}) dx_{t+1} da \\ &= -q \int_{-\infty}^{\infty} h(a)\left[(b_t + aB_t)\Phi(-b_t - aB_t) - f(-b_t - aB_t)\right] da \end{aligned} \tag{6.2}$$

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

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

$$Q_t = 1 + q \int_{-\infty}^{\infty} a\Phi(-b_t - aB_t) h(a) da \tag{6.4}$$

and $\mathrm{cov}(a, \Phi(-b_t - aB_t)) < 0$, 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, $\boldsymbol{b}_1 = 1$, will be rejected. In contrast, when there is no shock to reserves,

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

and there will be no deviation of the forward rate from the expected future spot rate. In this case, the efficient market hypothesis of $\boldsymbol{b}_2 = 1$ 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 our observation 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. Alternative Explanations for the Predictability Failure

In previous sections, the reasons we have focused on for the predictability failure are constraints to arbitrage between $E_t(i_{t+1})$ and $f_{t,t+1}$. We also find that varying degrees of arbitrage leads to the asymmetry in predictability. Of course, there are other possible reasons for the failure and asymmetry. Nevertheless, not all the possible factors can be covered in this article, and thus, we limit our focus to one additional factor, which is the erroneous anticipation of future monetary policy. This factor can be classified as a deviation from the rational expectation hypothesis, one of the three possible major causes for the predictability failure. The basic idea is that if predictions of future monetary policy by market participants are poor, then the predictive power of the future rate will differ depending on whether we are looking at the period immediately following a policy change or the next period up to the next policy change.

As our measure of monetary policy we use the federal funds target rate, not only because it is the primary monetary policy tool used by the Fed, but also because it is changed infrequently. Since 1995, on average, more than 50 days elapse between federal funds target rate changes by the Fed, with the shortest interval between changes being 12 days. Thus, market participants are less likely to anticipate future monetary policy changes during the period immediately following the most recent policy change. Hence, by comparing the two sub-samples, the sample following a change in the target rate and the sample leading up to the next change, in terms of their predictability performance, we can check whether the correct expectation of the future federal funds target rate change is embodied in the TN rate.

Our objective is to investigate whether erroneous anticipation about future monetary policy can cause the unsatisfactory predictability of the forward interest rate. While this objective is the same as BBF's, our methodology differs. BBF formulate an equation for the future federal funds target rate change that allows continuous changes in the target rate. Their model, however, ignores an important aspect of target rate changes—the minimum change in the target rate is by 0.25%. This is large enough to be called a discrete jump. As a result the methodology we propose is much simpler and more straightforward than what BBF do, in that we do not have to undertake the arduous task of formulating the federal funds target rate process.

Based on the estimation methodology of section 5, we further divide the sample into two periods: days right after a FF target change and the days up to the next target change. If BBF are correct, predictability following a change must be significantly higher than for the period leading up to the next policy change. We also maintain the division of the sample into two components according to the sign of the forward rate minus the current spot rate. Hence, in each of the estimation results, b is estimated separately for four sub-samples. We therefore obtain estimates of the predictability coefficient, b_{ij}, where $i=1, (2)$ indicates whether the forward rate is larger (smaller) than the current spot rate and $j=1, 2$, indicates if it is the period right after the policy change, $j=1$, or the period leading up to the next policy change, $j=2$. We also vary the length of the period in days, represented by X, after a policy change. For our estimations we vary X from 10 to 60. Results using Eurodollars are shown in Table 7.1 and Figure 7.1.[29] The main observations are summarized as follows:

- For every value of X, b_{21} is significantly larger than b_{22}, and b_{11} is larger than b_{12}, although the difference is not significant.

- As X increases, the gap between b_{21} and b_{22} shrinks and becomes less significant.

[29] Our measure of policy changes is, as discussed, represented by changes in the federal funds target rate.

These results are consistent with our prediction based on BBF. In particular, when the forward rate is lower than the current spot rate, predictability right after the FF rate change is significantly higher than predictability for the following period leading up to the next policy change. In contrast, when the forward rate is higher than the current spot rate, predictability does not differ significantly between the two sub-samples.

8. 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 market constraints. These constraints include overdraft penalties, and the inability of securities firms to procure funds in the ON market. Furthermore, these constraints are found to be binding on some occasions, but not others. Based on these institutional accounts, 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 larger when the spread is negative. We also develop a simple theoretical framework, which may explain this asymmetry. Both the estimation results and the theoretical model are consistent with our institutional findings. Surely, this aspect of market behavior accounts for only a limited portion of the entire predictability failure, and so there must be other causes. One possibility is the erroneous anticipation of the monetary policy.

Although we have proposed several explanations 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 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 5.1: Estimates of Predictability

$$ON_{t+1} - ON_t = a + b(TN_t - ON_t) + e_{t+1} \quad (5.3)$$

	α	β	For β=0	For β=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

$$\begin{aligned} ON_{t+1} - ON_t &= a_1 I(TN_t - ON_t > 0) + a_2 I(TN_t - ON_t < 0) \\ &+ b_1(TN_t - ON_t) I(TN_t - ON_t > 0) \\ &+ b_2(TN_t - ON_t) I(TN_t - ON_t < 0) + e_{t+1} \end{aligned} \quad (5.4)$$

where $I(\cdot)$ is an indicator function equal to 1 if the condition in the parentheses is satisfied, and is equal to 0 otherwise.

	TN-ON>0			
	α1	β1	For β1=0	For β1=1
U.S. Eurodollars: 1/9/95-12/31/99 (1299 observations)	0.028 (4.684)	-0.002 (-0.036)		***
UK Eurosterling: 1/9/95-8/9/2002 (1970 observations)	0.070 (1.457)	0.469 (4.611)	***	***
Italy domestic Lire: 4/4/88-8/7/2002 (3742 observations)	-0.178 (-5.975)	0.609 (15.932)	***	***
Japanese domestic Yen:5/19/94-11/14/97(864 observations)	0.009 (1.646)	-0.098 (-0.444)		***

	TN-ON<0				For β1= β2
	α2	β2	For β2=0	For β2=1	
U.S. Eurodollars: 1/9/95-12/31/99 (1299 observations)	0.006 (0.338)	0.252 (2.018)	**	***	*
UK Eurosterling: 1/9/95-8/9/2002 (1970 observations)	0.095 (4.041)	0. 976 (48.85)	***		***
Italy domestic Lire: 4/4/88-8/7/2002 (3742 observations)	-0.154 (-3.023)	1.121 (6.927)	***		***
Japanese domestic Yen:5/19/94-11/14/97(864 observations)	-0.008 (-2.621)	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

$$
\begin{aligned}
ON_{t+1} - ON_t = {} & a_1 I(TN_t - ON_t > 0) + a_2 I(TN_t - ON_t < 0) \\
& + b_1 (TN_t - ON_t) I(TN_t - ON_t > 0) \\
& + b_2 (TN_t - ON_t) I(TN_t - ON_t < 0) \\
& + g_1 QF_{t+1} + g_2 OTMF_{t+1} + g_3 MPL_{t+1} \\
& + d_i (MonetaryPolicyChange_i) + e_{t+1}
\end{aligned}
$$

where $I(\cdot)$ 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.

	TN-ON>0			
	α1	*β1*	*For β1=0*	*For β1=1*
U.S. Eurodollars: 1/9/95-12/31/99 (1299 observations)	0.030 (4.862)	-0.081 (-1.557)		***
UK Eurosterling: 1/9/95-8/9/2002 (1970 observations)	0.069 (1.435)	0.469 (4.608)	***	***
Italy domestic Lire: 4/4/88-8/7/2002 (3742 observations)	-0.174 (-5.815)	0.609 (15.921)	***	***
Japanese domestic Yen:5/19/94-11/14/97(864 observations)	-0.001 (-0.492)	0.377 (3.072)	***	***

(continued from the above)	*TN-ON<0*				*For β1= β2*
	α2	*β2*	*For β2=0*	*For β2=1*	
U.S. Eurodollars	0.006 (0.359)	0.264 (2.110)	**	***	**
UK Eurosterling	0.095 (3.928)	0. 976 (48.76)	***		***
Italy domestic Lire	-0.152 (-3.002)	1.121 (6.928)	***		***
Japanese domestic Yen	-0.008 (-2.562)	0.980 (12.68)	***		***

(continued from the above)	*γ1*	*γ2*	*γ3*
U.S. Eurodollars	0.141 (2.324)	0.035 (1.477)	-0.003 (-0.324)
UK Eurosterling	-0.080 (-1.269)	0. 055 (0.565)	
Italy domestic Lire	-0.065 (-0.371)	-0.079 (-0.658)	
Japanese domestic Yen	-0.007 (-0.461)	0.003 (0.990)	-0.006 (-0.848)

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

$$ON_{t+1} - ON_t = a + b\,(TN_t - ON_t) + e_{t+1} \qquad (5.3)$$

$$ON_{t+1} - ON_t = a_1 I(TN_t - ON_t > 0) + a_2 I(TN_t - ON_t < 0) \qquad (5.4)$$
$$+\, b_1 (TN_t - ON_t) I(TN_t - ON_t > 0) + b_2 (TN_t - ON_t) I(TN_t - ON_t < 0) + e_{t+1}$$

$$\frac{ON_{t+2} + ON_{t+1}}{2} - ON_t = a + b\left(\frac{SN_t + TN_t}{2} - ON_t\right) + e_{t+1} \qquad (5.5)$$

$$\frac{1}{6}\sum_{i=1}^{6} ON_{t+i} - ON_t = a + b\left(\frac{7}{6}1W_t - \frac{1}{6}ON_t\right) + e_{t+1}, \qquad (5.6)$$

$$\frac{1}{13}\sum_{i=1}^{13} ON_{t+i} - ON_t = a + b\left(\frac{14}{13}2W_t - \frac{1}{13}ON_t\right) + e_{t+1}, \qquad (5.7)$$

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.

Table 7.1: Evidence on the Balduzzi, Bertola and Foresi Hypothesis

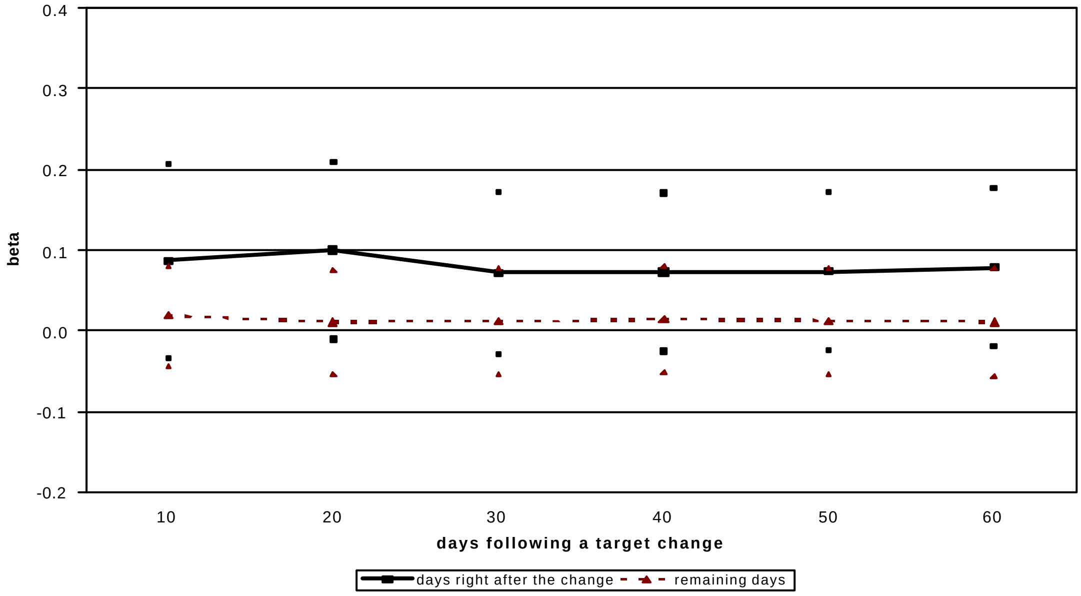
$$ON_{t+1} - ON_t = a + b_{11}(TN_t - ON_t)I(TN_t - ON_t > 0 \;\&\; \text{First Xdays after target change})$$
$$+ b_{21}(TN_t - ON_t)I(TN_t - ON_t < 0 \;\&\; \text{First Xdays})$$
$$+ b_{12}(TN_t - ON_t)I(TN_t - ON_t > 0 \;\&\; \text{Rest of days})$$
$$+ b_{22}(TN_t - ON_t)I(TN_t - ON_t < 0 \;\&\; \text{Rest of days}) + e_{t+1}, \quad (5.5)$$

where X varies (taking the values from 10 to 60, increasing by 10).

U.S. Eurodollars: 1/9/95-12/31/99 (1300 observations)					
	TN-ON>0		*TN-ON<0*		*For* $\beta 21=\beta 22$
	First X days	*Remaining days*	*First X days*	*Remaining days*	
X	$\beta 11$	$\beta 12$	$\beta 21$	$\beta 22$	
10	0.087 (0.705)	0.019 (0.406)	0.682 (4.860)	0.259 (2.576)	***(6.839)
20	0.100 (0.897)	0.011 (0.238)	0.703 (5.187)	0.256 (2.555)	***(8.286)
30	0.072 (0.748)	0.012 (0.252)	0.712 (6.220)	0.249 (2.478)	***(11.52)
40	0.073 (0.771)	0.014 (0.292)	0.489 (2.839)	0.252 (2.425)	(1.561)
50	0.074 (0.794)	0.013 (0.271)	0.450 (3.066)	0.249 (2.343)	(1.420)
60	0.079 (0.854)	0.011 (0.239)	0.385 (2.991)	0.255 (2.350)	(0.698)

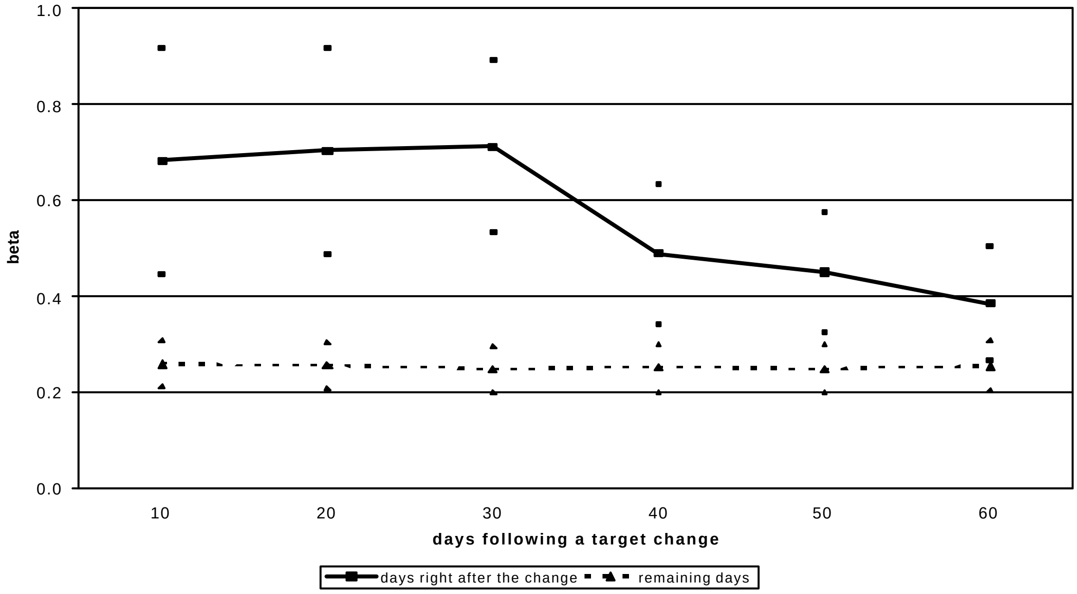
Note: t-values in parentheses. The rightmost parentheses are for F-values. ***,**,* denote significance level of 1%, 5%, 10% respectively.
Heteroskedasticity and autocorrelation consistent covariance is employed for standard errors.

Figure 7.1a: Change in Predictability (*TN-ON<0*)



Note: This figure plots the changes in b across different estima tes (from Table 5.2). The small squares and small triangles provide a two standard deviation band for the days after the change and the remaining days respectively.

Figure 7.1b: Change in Predictability (*TN-ON>0*)



Note: This figure plots the changes in b across different estimates (from Table 5.2). The small squares and small triangles provide a two standard deviation band for the days after the change and the remaining days respectively.

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