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**Failed Delivery and
Daily Treasury Bill Returns**

by Ramon P. DeGennaro and James T. Moser

Ramon P. DeGennaro is a visiting scholar at the Federal Reserve Bank of Cleveland and James T. Moser is a visiting scholar at the Federal Reserve Bank of Chicago. The authors thank Warren Bailey, David Barson, David Buckmaster, Doug Evanoff, James Hilliard, Chris McLay, Edward Ozark, James Thomson, and two anonymous reviewers for helpful comments and for providing institutional details. They also gratefully acknowledge the research assistance of Ralph Day, Chris Pike, and Dawn Sechler.

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ABSTRACT

If the seller of a Treasury bill does not provide timely and correct delivery instructions to the clearing bank, the bank does not deliver the security. Further, the seller is not paid until this "failed delivery" is rectified. Since the purchase price is not changed, these "fails" generate interest-free loans from the seller to the buyer.

This paper studies the effect of failed delivery on Treasury-bill prices. We find that investors bid prices to a premium to reflect the possibility of obtaining the interest-free loans that fails represent. This premium is a function of the opportunity cost of the fail. We also find that the bid-ask spread varies directly with the length of the fail. We rule out the possibility that our results are due to liquidity premiums, or to a general weekly pattern in short-term interest rates or the bid-ask spread.

Failed Delivery and Daily Treasury Bill Returns

This paper studies the impact of failed delivery on Treasury bill prices. Failed delivery occurs if the seller does not give timely and correct delivery instructions to the clearing bank. If the instructions are late, incorrect, or incomplete, the clearing bank does not make the transfer as scheduled.¹ This constitutes failed delivery, or a "fail."

Since it is the seller's responsibility to instruct the clearing bank to deliver the security to the buyer's account, the buyer need not make payment until the fail is corrected. Yet, despite having made no payment, he owns the security as of the promised delivery date; when the fail is rectified, the price is not renegotiated. In essence, the buyer obtains a zero-interest loan for at least one business day if the seller fails to deliver, but pays only the agreed-upon price if the seller does deliver. He may be forced to fail on a subsequent delivery of that same security, but if so, the zero-interest loan he must make is offset by the zero-interest loan he receives. If the dealer correctly anticipates the fail, he wins, but even if he did not expect to be failed, he is (approximately) even. Buyers may be willing to pay extra for this possibility. If so, observed prices are bid up to reflect the possibility of fails.

The effect of failed delivery is not trivial. For example, if financing costs are at an annual rate of 10 percent, a seller who fails to deliver a \$10 million Treasury bill loses more than \$2,700. If the fail is over a three-day weekend, it cannot be rectified for four calendar days, costing the seller over \$11,000. If the buyer anticipates the fail, he gains a like amount. The prospect of earning such large sums leads many dealers to play various forms of the "fails

game." For example, Stigum (1983) reports that dealers often finance less than the value of their Treasury bill purchases, relying on fails to cover the difference.

We will argue that the length of the fail, should it occur, is variable and known at the time the order is placed. This lets us conduct regression tests of its significance using the opportunity cost of the fail as an explanatory variable. Since the delivery mechanism operates only when markets are open, fails can be corrected only when markets are open. Market closings, therefore, take on a special importance for our work.

Although the United States Treasury's change to a book-entry system for government securities has reduced the probability of fails, the large sums involved with delivery failures remain an important issue among market participants. However, fails have not yet generated much interest in the literature. This might be due to the relative lack of daily return data on debt securities. The issue is still important for several reasons, both from the perspective of regulatory policy and for our understanding of financial markets. First, as noted above, fails generate transfers from losers of the fails game to winners. Dealers in total neither win nor lose, but very large transfers could conceivably wipe out a dealer's capital, causing bankruptcy and market disruptions.

Second, Gilbert (1989) shows that fails contribute to the problem of daylight overdrafts, which are intraday deficits incurred by a customer at his clearing bank, or by a bank with the Federal Reserve. To see how fails lead to daylight overdrafts, consider a dealer who must make delivery on two orders by the end of the day, one for \$5 million and one for \$25 million. Suppose that at noon he has \$10 million worth

of the security in inventory. He can fill the smaller order immediately, but instead will choose to wait until the last moment. This is because he may take delivery of other bills later that day. If these deliveries amount to \$15 million, he can add it to the \$10 million already in inventory and fill the \$25 million order. At worst, he fails on the smaller trade. If, however, he fills the \$5 million trade early in the day, receiving the \$15 million order does him no good -- he still must fail on the \$25 million order.

Other market procedures combine with this practice to generate daylight overdrafts. Securities financed via repurchase agreements (repos) are returned early in the day, and the clearing bank must transfer funds to the repo investor at that time. Because funds are transferred from the dealers' accounts early in the day and because dealers deliver securities late in the day, dealers must overdraw their accounts with their clearing banks by large amounts in the interim. Banks protect themselves by obtaining liens on the securities. If the dealer becomes insolvent, the bank takes the collateral.

Because it involves only the clearing bank and the dealer, such an insolvency does not necessarily pose a problem for the Federal Reserve. However, Gilbert (1989) points out that when the repo investor returns securities to the dealer early in the day and the clearing bank returns funds to that investor on behalf of the dealer, the clearing bank's account with the Federal Reserve is overdrawn; a daylight overdraft is created at the Federal Reserve. Further, the funds transfer is final and cannot be reversed. If the bank suffers large losses on its other assets and becomes insolvent, the Federal Reserve has no claim on the securities transferred to the dealer in the morning, and loses on the

daylight overdraft. The danger of large losses by the Federal Reserve (and ultimately, by taxpayers) is magnified by the dealer's efforts to build inventory to avoid fails.

A third reason fails are important is that daily return data using securities subject to failed delivery can show a systematic return pattern, because the value of being failed varies systematically with the length of market closings. If fails are ignored, tests using these data may be biased. Fourth, if fails are priced, they contribute to the more general weekly pattern identified by Gibbons and Hess (1981) and Flannery and Protopapadakis (1988). This also means tests of the importance of fails must control for a more general weekly pattern.

Finally, fails can conceivably contribute to variation in the bid-ask spread because they represent another source of risk for market makers: dealers often buy from one trader and sell the same security to another. The dealer may receive delivery on time, but too late in the day to deliver the security to the second trader, causing an expensive fail. Under such circumstances, dealers may not make a trade without a larger bid-ask spread. Because the cost of a fail is a function of its length, we conjecture that the bid-ask spread widens as the length of the potential fail increases. Consistent with the view that fails are important, the Federal Reserve has taken preliminary steps toward gathering data on delivery fails.

This paper models Treasury-bill holding-period returns as a function of the expected return on an investment in federal funds during the holding period (an important alternative interest rate that is not subject to fails), and the expected opportunity cost during the length of time before a fail can be corrected.² Use of the federal funds rate

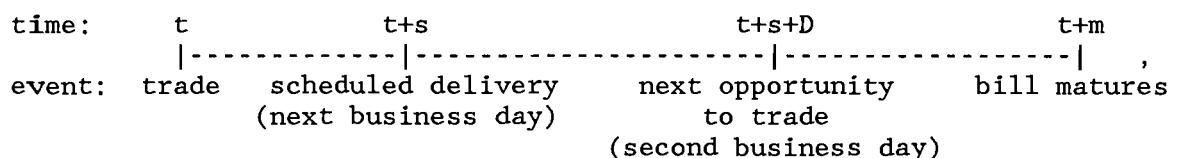
simplifies the time series specification for our empirical work and helps control for a possible common state variable that might induce a general weekly pattern in short-term rates. The results do not, however, depend on the use of the federal funds rate. Modeling bill returns as a function of the holding period and the length of the potential fail yields substantially similar results.

Our results support the hypothesis that the marginal trader considers failed delivery. Our estimate of the premium for fails is always significant, even after controlling for differences in the weekly seasonal return pattern between Treasury bills and federal funds. In addition, we find that the bid-ask spread does indeed widen when the dealer faces the prospect of a longer fail.

The paper is organized as follows. Section I develops our hypotheses. Section II develops the model, linking the effect of failed delivery to market closings. Section III describes the data and examines several empirical issues important to our tests. Section IV reports the results. Section V studies variation in the probability of fails, while Section VI studies the effect of fails on the bid-ask spread. Section VII provides a summary.

I. The Importance of Market Closings on the Day after Delivery

Although investors who purchase securities for next-day delivery obtain conditional title to those securities on the trade date, payment in interest-bearing funds does not occur until delivery. These payment delays may be diagrammed as follows:



where s is the number of calendar days from the trade date, t , until delivery on the next business day; D is the number of calendar days between the scheduled delivery date ($t+s$) and the business day following that date; and m is the maturity of the bill on the trade date.

Our empirical tests use discount-rate quotations obtained from Data Resources, Incorporated. During the period we study, a sample of dealers supplied these quotes to the Federal Reserve between 3:00 p.m. and 3:30 p.m. Although an increasing proportion of Treasury-bill trades are for cash, or same-day delivery, Fedwire closes for book-entry transfers before the quotes are collected. Therefore, securities traded at these rates are delivered the next business day.³ In the time diagram above, the bill is delivered and payment is due at $t+s$. A fail at $t+s$ cannot be corrected until $t+s+D$. Therefore, D represents the minimum term of the potential interest-free loan. It is, therefore, crucial in identifying any possible impact of failed delivery.

If delivery at $t+s$ were certain, Treasury bill prices would be unaffected by the value of D . However, delivery is not certain. This gives D an appealing economic implication. The seller must provide instructions to the clearing bank so that it can deliver the security to the buyer. If the instructions are late or in any way unclear, the clearing bank does not make the transfer. This means that the buyer of the security need not make payment until the fail is corrected. Nevertheless, payment procedures specify that he owns the security as of the promised settlement date. In essence, he obtains a zero-interest loan for at least one business day, or D calendar days. Clearly, the possibility of correctly anticipating and collecting fails must be valuable to a dealer. There is no penalty if he receives delivery on

time, but he need not finance the purchase if he is failed. Rational buyers bid up observed prices to reflect this possibility.

Dealers report that fails are a significant issue. We contacted several dealers; each claimed fails were important. Most focused primarily on their efforts to avoid the cost of failing to make delivery, but noted that the ability to correctly anticipate their customers' failures to deliver was a valuable skill. And, although the proportion of failed trades is now (thanks to book-entry) only 1 or 2 percent, the sheer volume of trade makes the total impact substantial and worthy of study. Stigum (1988) reports total fails to receive for one large dealer average \$225 million per day, while his fails to deliver average \$200 million per day.

Even if a dealer is not absolutely certain that he will be failed, it can be advantageous for him to take the risk of misguessing his position. For example, a dealer may have purchased 10 blocks of bills of a given maturity, each worth \$5 million. Perhaps the dealer is reasonably sure that one of the blocks will fail; he need not know which of the 10. He arranges financing for only nine blocks in the relatively low-cost repo market. If he is correct, he need not finance the tenth block, effectively saving the entire cost of the tenth loan. If, however, he is incorrect and all 10 blocks are delivered, the dealer must finance the tenth block at the bank's loan rate, which typically runs 100 basis points above the repo rate.

Depending on the dealer's confidence in predicting fails, this may be an acceptable risk. For example, at rates of 10 percent, the dealer can be incorrect nine times out of 10 and still be ahead. He loses 100 basis points nine times, but earns the entire financing rate -- 10

percent -- the tenth time. Stigum (1988) reports that some top-tier dealers enjoy still better odds. Such dealers may have lines of credit at foreign banks that permit uncollateralized borrowing. These dealers can typically obtain overnight funds late in the day for a smaller spread, increasing the likelihood of winning their gamble. Further, if two of the 10 blocks in the example fail rather than one, the dealer still wins the same amount. He may be forced, in turn, to fail on one of his nine repos, but his loss on this is offset by his gain in being failed. In addition, he still saves the entire financing cost of the tenth block.

In terms of the time diagram above, D represents the minimum time before markets reopen and a fail can be corrected. Clearly, a buyer prefers to be failed on Friday deliveries. In this case, a fail cannot be corrected for at least three calendar days; he receives two extra days' worth of free financing. Since the benefit of being failed is about three times as large on trades for Friday delivery, it follows that the premium, if any, is about three times as large.⁴ Similar forces operate if $t+s$ falls before a holiday. If the probability of collecting a fail is the same, then the longer the time before a fail can be corrected, the more valuable that potential fail becomes: Treasury bill prices increase with D .

In summary, if fails are not priced or are too trivial to matter, the delay D has no effect on bill prices. If, however, fails are important, then prices are an increasing function of D .

II. The Model

This section derives a pricing model that explicitly controls for the possibility that delivery may not be made on time. We do this by

incorporating the opportunity cost during the D calendar days from the scheduled delivery date until the next business day into the return-generating equation for Treasury bills.

We begin by defining P'_t as the observed price at t of a bill paying one dollar at maturity, if payment and delivery were certain to be made on the delivery date, $t+s$. Note that although the bill is default-free, P'_t is not par since the bill does not mature until $t+m$. P'_t may be expressed as:

$$P'_t = P'_{t-n} \times \exp[\gamma \times E_{t-n}(\text{ffn}_t) + \epsilon_t], \quad (1)$$

where E_{t-n} is the expectations operator conditioned on information at $t-n$, ffn_t is the continuously compounded return on federal funds during the n days in the holding period observed at t , γ is a constant (we relax this assumption later), and ϵ is an error that incorporates information realized at time t . Consistent with the time of our quotes, n is defined in terms of delivery dates. For example, buying on Thursday and selling on Friday generates a cash outflow on Friday and an inflow on Monday, so n equals three. Although n depends on t , we suppress the subscript t to simplify notation. Also, while observations are separated by varying numbers of calendar days, they represent consecutive trading days. We use the federal funds rate because it responds rapidly to changes in economic conditions, is not subject to fails, and is readily available. Both P'_t and P'_{t-n} in equation (1) are observed prices if late-afternoon quotes are directed at traders who deliver as scheduled with probability one -- with no chance of failed delivery.

But if the probability of fails is positive, it may well influence prices. To capture the effect of delivery failures, we write P'_t as a function of the observed price at time t , P_t :

$$P'_t = P_t \times \exp(-\delta \times \text{ffD}_t), \quad (2)$$

where ffD_t is the continuously compounded return on federal funds during the D calendar days from $t+s$ to $t+s+D$, and δ is a proportion. The product $(\delta \times \text{ffD}_t)$ is interpreted as the premium or rate of price adjustment for fails during those D days. We call this the fail premium.

D is important because it represents the number of days before a fail can be corrected. In turn, the variable ffD_t is the value, per dollar, of a fail generated by trades made at time t . The parameter δ represents the proportion of this value that a buyer pays as a premium for the possibility of obtaining an interest-free loan for D days. Intuitively, equation (2) removes this quantity from the observed price by discounting at the market-determined fail premium during the term of the loan.

In Section V we study the possibility that the proportion of the return on federal funds during the D days in the potential fail period, δ , varies, but here we assume it is constant. Equation (2) then holds for any t and we can write:

$$P'_{t-n} = P_{t-n} \times \exp(-\delta \times \text{ffD}_{t-n}). \quad (3)$$

Substituting equations (2) and (3) into equation (1) yields:

$$P_t \times \exp(-\delta \times \text{ffD}_t) = P_{t-n} \times \exp(-\delta \times \text{ffD}_{t-n}) \times \exp[\gamma \times E_{t-n}(\text{ffn}_t) + \epsilon_t]. \quad (4)$$

Taking logs and rearranging, we obtain:

$$\log(P_t/P_{t-n}) = \gamma \times E_{t-n}(\text{ffn}_t) + \delta \times \Delta \text{ffD}_t + \epsilon_t, \quad (5)$$

where ΔffD_t is the difference or change in ffD from $t-n$ to t . With the exception of γ , δ , and ϵ , all variables are observable. Equation (5) says that the observed Treasury bill return depends on the return on an asset not subject to fails, plus an adjustment for fails. More precisely, it is a proportion of the expected return on an investment in federal funds during the holding period, plus the difference in adjustments for potential fails, $(\delta \times \Delta \text{ffD}_t)$, plus an error term.

Our primary regression test equation is, therefore:

$$\log(P_t/P_{t-n}) = b_1 \text{ffn}_t + b_2 \Delta \text{ffD}_t + e_t. \quad (6)$$

In this formulation, b_1 estimates γ , the average proportion of the federal funds rate earned by Treasury bill investors over the holding period in the absence of fails. The coefficient b_2 estimates δ , the average proportion of the federal funds return during the potential fail period that buyers pay sellers for the chance to collect fails.

We expect b_1 to be positive: if the federal funds rate is high, bill returns tend to be high. The null hypothesis that investors consider fails in pricing Treasury bills restricts the coefficient b_2 to be positive: if the opportunity cost of today's potential fail is larger than yesterday's, prices are bid up more than yesterday's. Measured returns tend to be high.

III. Data, Preliminary Tests, and Empirical Issues

A. Data

The appendix contains a detailed description of the data. The sample period extends from August 26, 1977 to September 28, 1989, and includes 3,013 observations. Quotes used in our tests are from Data Resources, Incorporated. Maturities range from 27 to 35 days. In the absence of holidays, this uses the longest-maturity bill when the fail

period is shortest. Thus, any liquidity premium tends to increase measured holding-period returns when fails tend to decrease them, and to decrease holding-period returns when fails tend to increase them. This insures that any liquidity premium biases our tests against finding that fails are important.

B. Preliminary Tests

An important empirical issue can be traced to a common problem bond researchers face: we cannot be sure whether variation in the bid-ask spread affects our results. If the spread is not constant by day of the week, the use of ask, bid, or mean of bid-ask quotes may not yield similar results. To study this, we estimate:

$$\text{Bid}_t - \text{Ask}_t = b_0 + b_1 d_{1t} + b_2 d_{2t} + b_3 d_{3t} + b_4 d_{4t} + e_t, \quad (7)$$

where Bid_t and Ask_t are discount quotes in percent and the dummy variables d_{1t} through d_{4t} control for the days of the week, excluding Tuesday.⁵ In this specification, the intercept estimates the spread on Tuesday, while the coefficients b_1 through b_4 estimate deviations from Tuesday's spread on the other four days of the week. We test the restriction that each coefficient on the dummy variables is zero using the heteroskedasticity-consistent estimator due to White (1980). Table 1 shows that none of the coefficients differ statistically from zero. Therefore, we use the mean of the bid and ask quotes in all empirical work.⁶

Table 2 reports sample statistics. Panel A gives the number of observations, mean and variance for the variables in equation (6), as well as for the length of the fail period itself, D , and the opportunity cost of a fail during D , ffD . Panel B gives the same statistics for the center-of-market discount quote, $(\text{bid}+\text{ask})/2$, according the length of

the fail period. If investors do bid bill prices to a premium to reflect the possibility of collecting fails, mean discount quotes decrease as D increases. Although the rankings do not decrease monotonically, much of the deviation from the expected rankings can be traced to the case in which D equals five. This should have the lowest mean quote; in fact, it is the highest. However, one cannot have much confidence in this case because there are only two observations. Omitting these two observations, the only deviation from the expected rankings is that the mean quote for the days on which D equals one is larger than when it equals two. We interpret this as providing some evidence that investors consider fails in pricing bills.

C. Empirical Issues

A potential problem with equation (6) is that the dependent and independent variables are simultaneously determined. One solution is to use predicted values of the dependent variables. The estimates below use this procedure. We obtain predicted values of the continuously compounded daily federal funds rate by regressing them on the five most recent values of the rate available at time t ; we then apply the predicted rate during, respectively, the n days in the holding period and the D days in the potential fail period.

Another important empirical question relates to the time-series properties of the variables in equation (6). Specifically, we need to determine whether or not the variables are stationary. If they are not, we must use models such as the error-correction model of Engle and Granger (1987). To study this we use the unit-root tests of Perron (1988), Phillips (1987), and Phillips and Perron (1988). To conduct

these tests we estimate three equations using ordinary least squares:

$$y_t = \hat{\alpha} y_{t-1} + \hat{u}_t, \quad (8)$$

$$y_t = \mu_t^* + \alpha^* y_{t-1} + u_t^*, \quad (9)$$

$$y_t = \tilde{\mu}_t + \tilde{\beta}(t - T/2) + \tilde{\alpha} y_{t-1} + \tilde{u}_t. \quad (10)$$

Equation (8) models the series without drift or time trend. Equation (9) allows for drift, and equation (10) permits both drift and time trend. The tests for a unit root use the adjusted t-statistics given in Perron (1988) for the parameters $\hat{\alpha}$, α^* , and $\tilde{\alpha}$, denoted as $Z(t_{\alpha}^{\hat{\alpha}})$, $Z(t_{\alpha}^{\alpha^*})$, and $Z(t_{\alpha}^{\tilde{\alpha}})$, respectively, rejecting the null hypothesis of a unit root for sufficiently small values of Z. These tests require a consistent variance estimator; we use the method of Newey and West (1987). The estimates reported in Table 3 are for a truncation lag of five, but the results are unchanged for other values of the truncation lag. Critical values for the t-statistics are given in Fuller (1976). For the 1 percent level, these are -2.58, -3.43, and -3.96, respectively. For all three variables, the adjusted t-statistics are far below the critical values; we reject a unit root for all three series.

Table 3 also reports the results of three joint tests for a unit root. Z(1) tests the joint hypothesis of $\mu^* = 0$, $\alpha^* = 1$. Z(2) tests the joint hypothesis of $\tilde{\mu} = 0$, $\tilde{\beta} = 0$, $\tilde{\alpha} = 1$. Z(3) tests the joint hypothesis of $\tilde{\beta} = 0$, $\tilde{\alpha} = 1$. The critical 1 percent levels given by Dickey and Fuller (1981) are 6.43, 6.09, and 8.27, respectively. All estimated values are well in excess of these levels, confirming that the series are stationary. This means we can use autoregressive

specifications in lieu of the more complex error correction models of Engle and Granger (1987).

IV. Results

The results in Table 3 imply that the ordinary least squares residuals from equation (6) are stationary. Simple autoregressive specifications can, therefore, adequately capture the residual processes. A parsimonious specification that proves successful is an AR(6) process with the second-, third-, and fourth-order parameters constrained to equal zero. Table 4 presents the results obtained by estimating equation (6), along with the Box-Pierce $Q(j)$ statistics and a test of the intercept restriction embodied in equation (6). The $Q(j)$ statistics test for an autoregressive or moving-average process of order j in the residuals. These statistics are distributed chi-square with j degrees of freedom. For the $Q(5)$, $Q(10)$, and $Q(15)$, the 5 percent critical values are 11.07, 18.31, and 25.00, respectively. None are significant. In addition, none of the autocorrelations through lag 15 are more than two standard errors from zero. The intercept restriction implied by equation (6) holds.

As expected, the coefficient on the federal funds variable, \hat{ffn}_t , is positive and highly significant. The estimated coefficient is 0.883. This implies that investors in one-month Treasury bills earned an average of 88.3 percent of the federal funds rate during the sample period.

Table 4 also provides support for the hypothesis that buyers raise their bids to reflect the possibility of collecting fails. We have argued that this should be more pronounced if scheduled delivery occurs before a market closing, because then the fail could not be corrected as

rapidly, extending the term of the zero-interest loan. The coefficient b_2 , which controls for changes in the opportunity cost of a potential fail, is positive and significant, with a t-statistic of 7.39.

This coefficient estimates the proportion of the federal funds rate built into the bill return for the possibility of collecting fails. This estimate is 0.0708. This implies that investors bid up bill prices by 7.08 percent of the predicted federal funds rate. Taking the funds rate as the financing cost, this suggests a failure rate of about 7.08 percent. Conversations with dealers suggest that this is too high; the most common figure mentioned is 1 or 2 percent during our sample period. This suggests that the model expressed by equation (6) omits an important factor.

In particular, we conjecture that Treasury bill holding-period returns are not a constant proportion of the federal funds rate. Weekly return seasonality has been found in many assets; it is worth testing to see if the relationship between bill returns and returns on federal funds differs on any other days of the week. To formally test this, we regress the log of the price ratio on the return on an investment in federal funds during the holding period and interactive terms for Mondays, Wednesdays, Thursdays, and Fridays. The coefficient on the federal funds investment measures the proportion of the funds rate that bill investors earn on Tuesdays. The four interactive terms measure the deviation from Tuesday's proportion earned by bill investors on those four days. We then test the restriction that these coefficients are zero with a chi-square test using White's (1980) heteroskedasticity-consistent variance estimator.

The results of the four chi-square tests are: 1.81 for Monday, 23.06 for Wednesday, 14.00 for Thursday, and 0.01 for Friday. The tests for Monday and Friday are not significant at even the 15 percent level, but the other two are significant at the 1 percent level. The results are the same using the usual t-tests. Therefore, we include interactive terms for Wednesdays and Thursdays and estimate:

$$\log(P_t/P_{t-n}) = b_1 \hat{ffn}_t + b_2 \hat{\Delta ffD}_t + b_3 (d_{3t} \times \hat{ffn}_t) + b_4 (d_{4t} \times \hat{ffn}_t) + e_t, \quad (11)$$

where d_{3t} is unity on Wednesdays and zero otherwise and d_{4t} is unity on Thursdays and zero otherwise. As in equation (6), bill returns are a function of fails and the return on federal funds, but equation (11) permits the proportion of the return on funds earned by bill investors to differ on Wednesdays and Thursdays.

Table 5 reports the results. All Q-statistics are insignificant, and all autocorrelations (not shown) are within two standard errors of zero. The intercept restriction holds. As expected, given the results of the chi-square tests, the coefficients on the interactive terms for Wednesdays and Thursdays are significant. The proportion of the federal funds rate that Treasury bill investors earn differs on Wednesdays and Thursdays. The coefficient b_2 , measuring the proportion of the federal funds rate paid as compensation for fails, is smaller. The point estimate of 0.0364 implies a delivery failure rate of about 3.64 percent. As noted above, dealers report a failure rate of 1 or 2 percent on bills during our sample. Given that the standard error of the estimate of b_2 is 0.0118, a formal t-test fails to reject that our estimate falls well within this range.

The implied rate of failed delivery for the model using a constant is even closer to the failure rate that market participants report. The estimated coefficient b_2 is 0.0297, for an implied failure rate of about 2.97 percent.

Our results do not depend on the use of the federal funds rate as a proxy for the opportunity cost of a fail. We also estimate equation (6) without incorporating an interest rate proxy:

$$\log(P_t/P_{t-n}) = b_1 n_t + b_2 \Delta D_t + e_t. \quad (6')$$

In this model, b_1 estimates the daily holding-period return on Treasury bills, and b_2 estimates the rate of compensation for fails. Both are positive and significant, implying delivery failure rates about the same as the regressions using an interest-rate proxy. These results are not shown for reasons of space, but are available on request.

V. Variation in the Probability of Fails

The tests above assume that the probability of a fail is constant. This assumption may not be valid, because rational sellers realize that multiday fails are more costly than single-day fails. Because they invest more resources in preventing multiday fails, the probability of fails should decline as the length of the potential fail increases. If preventing fails is progressively more costly, the probability of fails should decline at a decreasing rate. Although two-day fails are twice as costly as one-day fails, one-day fails are somewhat less than twice as likely as two-day fails. Treasury bill prices should be bid up at a progressively decreasing rate.

One way to test this is to write:

$$P_t = \exp[\gamma_1 \hat{ffm}_t + \gamma_2 (d_{3t} \times \hat{ffm}_t) + \gamma_3 (d_{4t} \times \hat{ffm}_t) + \delta_1 \hat{ffd1}_t + \delta_2 \hat{ffd2}_t + \delta_3 \hat{ffd3}_t + \delta_4 \hat{ffd4}_t + \epsilon_t], \quad (12)$$

where \hat{ffm}_t is the predicted return on federal funds during the remaining maturity of the bill, d_{3t} and d_{4t} are dummy variables for Wednesdays and Thursdays, and $\hat{ffd1}_t$ through $\hat{ffd4}_t$ are the predicted opportunity costs for one-day fails through four-day fails, respectively, measured as the predicted return on federal funds during the fail. For example, if P_t is subject to a one-day fail, $\hat{ffd1}_t$ is the predicted return during the one-day fail period and $\hat{ffd2}_t$ through $\hat{ffd4}_t$ are zero. The variables $(d_{3t} \times \hat{ffm}_t)$ and $(d_{4t} \times \hat{ffm}_t)$ are included based on the results in Table 5; we expect γ_2 and γ_3 to be positive.

Taking logs, we obtain the regression equation:

$$\log(P_t) = b_1 \hat{ffm}_t + b_2 (d_{3t} \times \hat{ffm}_t) + b_3 (d_{4t} \times \hat{ffm}_t) + b_4 \hat{ffd1}_t + b_5 \hat{ffd2}_t + b_6 \hat{ffd3}_t + b_7 \hat{ffd4}_t + e_t, \quad (13)$$

where the b estimate the corresponding γ or δ .

In this regression, b_1 should be negative, as increases in interest rates or the maturity of the bill lowers its price. If fails are important, investors bid up bill prices at a decreasing rate as the opportunity cost of fails increases. This means $b_4 > b_5 > b_6 > b_7 > 0$. Because we have only two observations with fails of five days, we include them with four-day fails.

Table 6 contains the results. As expected, b_1 is negative and both b_2 and b_3 are positive. The evidence concerning b_4 through b_7 is mixed. The estimates have large standard errors and none approach conventional significance levels. Also, b_5 and b_6 are too high. However, given the

large standard errors, it is not possible to reject the hypothesis that the coefficients are between, say, 0.01 and 0.02. In addition, the rankings of b_4 through b_7 are almost exactly as predicted by the model: only b_4 deviates from the expected rankings. In addition, all four coefficients are positive. For independent coefficients, the likelihood of this occurring is only $1/(2^4)$, or 0.0625.

One reason these results are inconclusive could be that buyers, as well as sellers, alter their behavior as the opportunity cost of fails increases. While sellers invest extra resources in attempts to prevent fails, buyers may invest extra resources in attempts to cause fails. Dealers report that several factors contribute to the likelihood of fails occurring. For example, although the Treasury bill market is among the most liquid in the world, some issues are less liquid than others. Less-liquid maturities are more likely to fail. A buyer might attempt to generate a fail by purchasing a less-liquid bill for same-day delivery shortly before Fedwire closes for securities transfers, or perhaps late in the day for next-day delivery. He may also place several small orders for a security. Small deliveries are made last, and are more likely to miss the cutoff time for Fedwire. The more valuable the fail, the more likely dealers engage in such behavior. If sellers invest increasing effort to prevent fails but buyers invest increasing effort to generate them, the net effect on the probability of fails depends on the relative costs of preventing and generating fails.

Other factors also influence the failure rate. For example, more fails occur if Fedwire closes on time, both because dealers have less time to fix errors and because more deliveries miss the cutoff time. Although more liquid issues are less likely to fail, heavy total trading

volume (for all issues) leads to more delivery failures. Dealers have more work to do but no more time in which to do it, leading to more errors and congestion on Fedwire. Finally, improvements in technology should lead to fewer fails. Given that trading volume increased dramatically during our sample while technology also advanced, it is not possible to determine the net effect a priori. We note, though, that the Federal Reserve has taken preliminary steps to obtain information on delivery failure rates, indicating that problems remain.

VI. The Effect of Fails on the Bid-Ask Spread

We have seen that dealers build inventory throughout the day to avoid fails on large trades. What other aspects of dealer behavior might fails influence? Consider a dealer who can simultaneously buy from trader A at a discount of, say, 8.25 percent and sell to B at a discount of 8.00 percent. If delivery were certain, this guarantees a profit for the dealer. However, suppose the dealer knows that A will deliver the security only moments before Fedwire closes for securities deliveries. The dealer runs the risk of being unable to deliver the security to B on time. The result could be a costly fail, wiping out the profit on the transaction. Although the dealer appears to enjoy the elements of a perfect arbitrage -- buying and selling simultaneously at different prices -- he may not make the trades because the deliveries, although perhaps occurring within minutes, are not simultaneous, adding risk to the transaction.

We conjecture that this has two effects. First, it may affect trading volume. The data do not permit testing this. Second, dealers may require larger expected profits on transactions if the potential

fail is longer. To test this, we regress the bid-ask spread on a constant and the length of the potential fail:

$$\text{Bid}_t - \text{Ask}_t = b_0 + b_1 D_t + e_t. \quad (14)$$

If the scenario above is true and dealers do require larger profits when the risk of fails is larger, the spread should widen as D increases.

The coefficient b_1 should be positive. Since failing to make delivery amounts to making an interest-free loan to the buyer, the spread should also be a function of the level of rates. Therefore, we also estimate:

$$\text{Bid}_t - \text{Ask}_t = b_0 + b_1 D_t + b_2 q_t + e_t, \quad (15)$$

where q_t is the average of the bid and ask discounts at time t . Table 7 contains the results. Consistent with our conjecture, b_1 in equation (14) is indeed positive and significantly different from zero. The t -ratio is 2.06; using a chi-square test with White's (1980) heteroskedasticity-consistent estimator, the statistic equals 4.00, which is also significant at the 5 percent level. Equation (15) also supports the conjecture that dealers require larger spreads as the length of a potential fail increases. Both b_1 and b_2 are positive and significant. This evidence in favor of fails is more persuasive when one recalls Table 1; the variation in the spread cannot be attributed to some general weekly pattern, because the spread does not depend on the day of the week in our sample.

VII. Summary

This paper studies the effect of failed delivery on Treasury bill prices. We find that Treasury bill prices reflect the value of being failed. Prices increase if the scheduled delivery date falls before a market closing, lengthening the time before a fail can be corrected. We interpret this result as supporting the hypothesis that buyers compete

for the possibility of collecting fails, bidding up the prices of bills to be delivered before market closings. Because sellers should invest progressively more resources to prevent fails as the opportunity cost of fails increases, the probability of fails should fall as the opportunity cost rises. Tests of this are inconclusive: the four coefficients for the different opportunity costs of fails are not statistically significant, but the ranks of their magnitudes are almost exactly as predicted, and all four are positive, as required by the theory. Finally, we find that the bid-ask spread widens as the length of a potential fail increases. This is consistent with the interpretation that fails add another source of risk to a transaction.

Footnotes

1. These procedures are from Stigum (1983, 1988).
2. Fails in physical securities are much more common than in book-entry securities. However, it is much less reasonable to expect fails in physical securities to be corrected in one business day. Therefore, we are unable to test for the effect of fails in such assets.
3. We discuss this and the construction of our data in the appendix.
4. Sellers may well take extra care to avoid fails before weekends, reducing the premium to less than three times the usual amount. However, if progressively lowering the fail rate is increasingly costly, the multiday premium must exceed the one-day premium. The comments of dealers were mixed: most reported that their employees were especially concerned with multiday fails, but a few were compelled to constantly remind employees of the potential cost.
5. The sample for this test extends from June 2, 1978 because DRI did not supply bid and ask quotes until then. Prior to that date, DRI reported only the average of the bid and ask quotes.
6. We also conducted tests using bid-to-bid and ask-to-ask returns on different Treasury bill data from another source. Although not reported here, the results are consistent with those reported below using the mean of the bid and ask quotes.

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TABLE 1

Estimates obtained by regressing the spread between the bid and ask discount rates on an intercept and four dummy variables for the days of the week (Tuesday excluded).

$$\text{Bid}_t - \text{Ask}_t = b_0 + b_1 d_{1t} + b_2 d_{2t} + b_3 d_{3t} + b_4 d_{4t} + e_t. \quad (7)$$

Full Sample: June 2, 1978 - September 28, 1989.

Number of observations: 2,825

Parameter	Estimate (t-statistic)	χ^2
b_0	0.158 (24.4) **	
b_1 (Monday)	0.0047 (0.50)	0.253
b_2 (Wednesday)	0.0078 (0.85)	0.769
b_3 (Thursday)	0.016 (1.73)	2.950
b_4 (Friday)	-0.001 (-0.10)	0.012

Bid_t = the bid discount on day t , in percent.

Ask_t = the ask discount on day t , in percent.

d_{it} = dummy variables for the four business days of the week, excluding Tuesday.

The χ^2 tests the restriction that the dummy variables are zero using White's (1980) heteroskedasticity-consistent estimator. The test has one degree of freedom. None of the values is significant at the 5 percent level.

** Significant at the 1 percent level.

The sample period begins on June 2, 1978 because DRI does not report bid and ask discount quotes until then.

Source: Authors' computations.

TABLE 2
Sample statistics

Panel A: Sample statistics for Treasury bill holding-period returns, returns on an investment in federal funds during the holding period, the length of the fail period, returns on an investment in federal funds during the fail period, and the change in returns on an investment in federal funds during the fail period.

Full Sample: August 26, 1977 - September 28, 1989.

	$\log(P_t/P_{t-n})$	ffn_t	D_t	ffd_t	ΔffD_t
Mean	3.5665×10^{-4}	4.0022×10^{-4}	1.466	4.01×10^{-4}	2.0×10^{-7}
Variance	9×10^{-8}	8×10^{-8}	0.799	8×10^{-8}	1.7×10^{-7}
Number of observations	3,013	3,013	3,013	3,013	3,012

Panel B: Sample statistics for the average of the bid and ask discount quotes (percent) on Treasury bills for each length of the fail period.

Number of days in the fail period, D	1	2	3	4	5
Mean	8.258	8.576	8.167	7.936	9.635
Variance	7.616	7.563	7.682	7.210	23.052
Number of observations	2,338	44	535	94	2
Ranking by mean	3	2	4	5	1
Ranking by mean, excluding D=5	2	1	3	4	---

P_t = the price of the Treasury bill at time t.

n = the number of calendar days in the holding period.

ffn_t = the return on an investment in federal funds during the holding period at time t.

D_t = the length of the fail period at time t.

ffd_t = the opportunity cost of a fail at t.

ΔffD_t = the change in the opportunity cost of a fail from t-n to t.

Source: Authors' computations.

TABLE 3

Phillips-Perron tests for a unit root.
Full Sample: August 26, 1977 - September 28, 1989.
Number of observations: 3,013

For $y_t = \log(P_t/P_{t-n})$	For $y_t = \hat{ffn}_t$	For $y_t = \hat{\Delta ffD}_t$
	$y_t = \hat{\alpha}y_{t-1} + \hat{u}_t$	(8)
$Z(t_{\hat{\alpha}}) = -16.7 **$	$Z(t_{\hat{\alpha}}) = -14.6 **$	$Z(t_{\hat{\alpha}}) = -137.3 **$
	$y_t = \mu_t^* + \alpha^*y_{t-1} + u_t^*$	(9)
$Z(t_{\alpha^*}) = -47.8 **$	$Z(t_{\alpha^*}) = -53.2 **$	$Z(t_{\alpha^*}) = -137.3 **$
$Z(1) = 3429.7 **$	$Z(1) = 4337.4 **$	$Z(1) = 21726 **$
	$y_t = \tilde{\mu}_t + \tilde{\beta}(t - T/2) + \tilde{\alpha}y_{t-1} + \tilde{u}_t$	(10)
$Z(t_{\tilde{\alpha}}) = -117.2 **$	$Z(t_{\tilde{\alpha}}) = -131.3 **$	$Z(t_{\tilde{\alpha}}) = -235.2 **$
$Z(2) = 2399.5 **$	$Z(2) = 3190.0 **$	$Z(2) = 14485 **$
$Z(3) = 3599.2 **$	$Z(3) = 4785.0 **$	$Z(3) = 21727 **$

P_t = the price of the Treasury bill at time t .

n = the number of calendar days in the holding period.

\hat{ffn}_t = the predicted value of the return on an investment in federal funds during the holding period.

$\hat{\Delta ffD}_t$ = the predicted value of the change in the opportunity cost of a fail from $t-n$ to t .

The $Z(t)$ statistics test the hypothesis that the corresponding adjusted t -ratio differs from unity. These adjusted statistics are given in Perron (1988). The critical one percent values given by Fuller (1976) are -2.58, -3.43, and -3.96 for $Z(t_{\hat{\alpha}})$, $Z(t_{\alpha^*})$, and $Z(t_{\tilde{\alpha}})$, respectively. $Z(1)$ tests the

joint hypothesis of $\mu^* = 0$, $\alpha^* = 1$. $Z(2)$ tests the joint hypothesis of $\tilde{\mu} = 0$, $\tilde{\beta} = 0$, $\tilde{\alpha} = 1$. $Z(3)$ tests the joint hypothesis of $\tilde{\beta} = 0$, $\tilde{\alpha} = 1$. The critical one percent values given by Dickey and Fuller (1981) for these tests are 6.43, 6.09, and 8.27, respectively. All statistics use the variance estimator given by Newey and West (1987). The truncation lag is 5 for the estimates given, but other values for the truncation lag give similar results.

** Significant at the 1 percent level.

Source: Authors' computations.

TABLE 4

Estimates obtained by regressing Treasury bill holding-period returns on the predicted return on federal funds over the holding period and the change in the predicted value of the opportunity cost of a fail from t-n to t, corrected for autocorrelation.
(Average of bid and ask rates)

Full Sample: August 26, 1977 - September 28, 1989.
Number of observations: 3,013

$$\log(P_t/P_{t-n}) = b_1 \hat{ffn}_t + b_2 \hat{\Delta ffD}_t + e_t. \quad (6)$$

	Parameter estimate (t-statistic)	Test of the intercept restriction
b_0	---	1.30×10^{-5} (1.55)
b_1	0.883 (100.2) **	0.857 (46.4) **
b_2	0.0708 (7.39) **	0.0581 (4.60) **
Q(5)	7.90	8.45
Q(10)	13.67	14.12
Q(15)	18.26	19.24

P_t = the price of the Treasury bill at time t.

n = the number of calendar days in the holding period.

\hat{ffn}_t = the predicted return on federal funds during the holding period at t.

$\hat{\Delta ffD}_t$ = the predicted value of the change in the opportunity cost of a fail from t-n to t.

The Q(j) statistics are the Box-Pierce (1970) statistics for an autoregressive or moving average process of order j. These statistics are distributed chi-square with j degrees of freedom.

** Significant at the 1 percent level.

Source: Authors' computations.

TABLE 5

Estimates obtained by regressing Treasury bill holding-period returns on the predicted return on federal funds over the holding period, the change in the predicted value of the opportunity cost of a fail from t-n to t, and interactive variables controlling for the divergence between the proportion of the federal funds rate earned by Treasury-bill investors on Wednesdays and Thursdays compared to other days of the week, corrected for autocorrelation. (Average of bid and ask rates)

Full Sample: August 26, 1977 - September 28, 1989.

Number of observations: 3,013

$$\log(P_t/P_{t-n}) = b_1 \hat{ffn}_t + b_2 \hat{\Delta ffD}_t + b_3 (d_{3t} \times \hat{ffn}_t) + b_4 (d_{4t} \times \hat{ffn}_t) + e_t. \quad (11)$$

	Parameter estimate (t-statistic)	Test of the intercept restriction
b_0	---	6.14×10^{-6} (0.70)
b_1	0.844 (76.5) **	0.831 (40.1) **
b_2	0.0364 (3.08) **	0.0297 (1.95)
b_3	0.182 (6.56) **	0.177 (6.21) **
b_4	0.106 (3.91) **	0.110 (3.97) **
Q(5)	4.54	4.70
Q(10)	9.23	9.23
Q(15)	12.84	13.02

P_t = the price of the Treasury bill at time t.

n = the number of calendar days in the holding period.

\hat{ffn}_t = the predicted return on federal funds during the holding period at t.

$\hat{\Delta ffD}_t$ = the predicted change in the opportunity cost of a fail from t-n to t.

d_{3t} = unity on Wednesdays and zero otherwise.

d_{4t} = unity on Thursdays and zero otherwise.

The Q(j) statistics are the Box-Pierce (1970) statistics for an autoregressive or moving average process of order j. These statistics are distributed chi-square with j degrees of freedom.

** Significant at the 1 percent level.

Source: Authors' computations.

TABLE 6

Estimates obtained by regressing the log of Treasury bill prices on the predicted return on federal funds over the maturity of the bill, interactive terms for Wednesdays and Thursdays, and the predicted return on an investment in federal funds during the length of the potential fail, corrected for autocorrelation.
(Average of bid and ask rates)

Full Sample: August 26, 1977 - September 28, 1989.
Total number of observations: 3,013

$$\log(P_t) = b_1 \hat{ffm}_t + b_2 (d_{3t} \times \hat{ffm}_t) + b_3 (d_{4t} \times \hat{ffm}_t) + b_4 \hat{ffd1}_t + b_5 \hat{ffd2}_t + b_6 \hat{ffd3}_t + b_7 \hat{ffd4}_t + e_t \quad (13)$$

Parameter	Estimate (t-statistic)
b_1	-0.788 (-39.8) **
b_2	0.007 (3.64) **
b_3	0.007 (1.26)
b_4	0.046 (0.08)
b_5	0.132 (0.42)
b_6	0.086 (0.40)
b_7	0.007 (0.05)

P_t = the price of the Treasury bill at time t .

\hat{ffm}_t = the predicted return on federal funds during the maturity of the bill at time t .

d_{3t} , d_{4t} = dummy variables for Wednesdays and Thursdays, respectively.

$\hat{ffd1}_t$, $\hat{ffd2}_t$, $\hat{ffd3}_t$, $\hat{ffd4}_t$ = the predicted return on federal funds during the length of a fail at time t (fails of five days are included with fails of four days because only two exist in the sample).

** Significant at the 1 percent level.

Source: Authors' computations.

TABLE 7

Tests for variation in the bid-ask spread:

$$\text{Bid}_t - \text{Ask}_t = b_0 + b_1 D_t + e_t. \quad (14)$$

$$\text{Bid}_t - \text{Ask}_t = b_0 + b_1 D_t + b_2 q_t + e_t. \quad (15)$$

Full Sample: June 2, 1978 - September 28, 1989.
Number of observations: 2,825

Parameter	Estimate (t-statistic)	χ^2	Estimate (t-statistic)	χ^2
b_0	0.153 (27.3) **		-0.107 (-12.2) **	
b_1	0.0067 (2.06) *	4.00 *	0.0084 (3.75) **	8.72 *
b_2			0.031 (35.1) **	968.62 **

Bid_t = the bid discount on day t , in percent.

Ask_t = the ask discount on day t , in percent.

D_t = the number of days in the fail period on day t .

q_t = the average of the bid and ask discount rates on day t , in percent.

The χ^2 tests the restriction that the dummy variables are zero using White's (1980) heteroskedasticity-consistent estimator. The test has one degree of freedom.

* Significant at the 5 percent level.

** Significant at the 1 percent level.

The sample period begins on June 2, 1978 because DRI does not report bid and ask discount quotes until then.

Source: Authors' computations.

Appendix

This appendix describes the data. The first important issue is the proper delivery procedure for our sample. Regular delivery is the next business day. Nevertheless, an increasing portion of Treasury bill trades are for same-day delivery. Further clouding the matter is that reported yields (not the quotes used in this paper) can be considered to be for skip-day delivery, two business days from the quote date. To resolve this problem we contacted several traders. All agreed that although delivery is negotiable and extremely flexible, quotes collected between 3:00 and 3:30 p.m. are much too late in the day to be for same-day delivery. Despite the common practice of reporting yields based on skip-day delivery, not one trader considered the quoted discount rates themselves to be for skip-day delivery.

To confirm this, we contacted the Federal Reserve Bank of New York, which supplies the quotes to DRI. The bank reported that it first collects the discount quotes from dealers, which are for next-day delivery at the time they are collected. However, the bank assumes skip-day delivery to compute the reported yield. This convention likely evolved to meet the needs of the print media, which obtain the data the evening they are collected and publish them the following morning. Investors purchasing bills that day (for next-day delivery) would therefore receive the bill the second day after the data were originally collected. The important point is that the delivery date assumed in the yield calculation (skip-day) does not reflect the actual delivery date (next-day).

We convert quoted rates to prices using the usual formula,

$$P_t = 1 - [q_t * (m_t - s_t)/36000],$$

where P_t is the price at t , q is the quoted discount rate in percent, and $(m-s)$ is the number of days from the promised delivery date until maturity. These prices are then used to compute log-price ratios for the test equations. Maturities range from 27 to 35 days. We choose this maturity range for several reasons. First, it approximates one month, the maturity often used as the proxy for the riskless rate. In addition, this minimizes problems with differential seasoning, causes Monday's maturity to be as near the mean as possible, and causes any term premium to bias our tests against finding an effect due to fails. To verify that the time series of Treasury bill prices is as accurate as is possible, we use numerous manual and computer procedures. A complete listing of these is available from the authors.

We illustrate the construction of the data by describing a week unaffected by holidays. Monday's holding-period return is computed using Friday's price on a 34-day bill and Monday's price on that same bill, which has 31 days until maturity on Monday. Tuesday's return uses Monday's and Tuesday's prices on the same bill (which has 30 days until maturity on Tuesday), and Wednesday's return uses Tuesday's and Wednesday's prices on the same bill. Thursday's return is the last one using this same bill, representing the return on a bill with 28 days until maturity at the end of the holding period. Friday's return uses a new bill (maturing a week later), with 35 days until maturity on Thursday and 34 on Friday. Thus, any liquidity premium would cause Thursday's average return to be the lowest and Friday's to be the highest. Since fails would cause exactly the opposite result in the absence of holidays, constructing the data in this way biases our tests against finding that fails are important.

This approach offers two advantages over assuming a locally flat term structure and using yields to compute implied prices. First, our method need not impose any specific shape on the yield curve. More important, our method obtains returns that actually could have been earned by investors. This is not the case using implied prices, which sometimes use yields on two different securities to calculate returns. Flannery and Protopapadakis (1988) discuss these return measures.