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Year-End Seasonality in One-Month LIBOR Derivatives

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Abstract: We examine the markets for one-month LIBOR futures contracts and options on those futures for a year-end price effect consistent with the previously identified year-end rate increase in one-month LIBOR. The cash market rate increase appears in forward rates and derivative prices, which allows the derivatives to properly hedge year-end interest rate risk. However, while the year-end effect appears in the derivative contract, these derivative contracts provide biased forecasts of both future interest rates and their volatility. The bias appears to be different at year's end for the LIBOR futures contract, but not for the options contract. The information in the derivatives almost always subsumes simple benchmark forecasts.

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1. Introduction

We examine seasonal patterns in one-month LIBOR (London InterBank Offer Rate) futures and options on those futures. Specifically, we are interested in whether the recently identified year-end effect in one-month LIBOR passes through to the derivative securities. The seasonal pattern in the cash market must pass through to the derivative securities for the derivatives to be able to properly hedge risk and for the derivatives to provide unbiased predictions of future interest rates and volatility. While we expect that a seasonal pattern in the underlying asset will pass through into the related derivative securities, empirical evidence suggests that such seasonal patterns are not always common among related securities.

A large body of research studies seasonal patterns across stocks, bonds, money markets, and derivatives. [1] The empirical evidence finds that the patterns vary across related securities. Flannery and Protopapadakis [1988], for example, compare day-of-the-week patterns in Treasuries bills, notes, and bonds and three stock indices. The patterns in the stock indices differ from those in Treasuries securities, which, in turn, vary by maturity. They conclude that there appears to be no one explanation for seasonal patterns across securities. Similarly, Jordan and Jordan [1991] examine the Dow Jones Composite Bond Index and a stock index created to mirror the composition of the bond index for seasonal patterns. They find different seasonal patterns in the indices. Johnston, Kracaw and McConnell [1991] find day-of-the-week effects in GMNA, T-note, and T-bond futures, but not in T-bill futures. The lack of such day-of-the-week effects in T-bill futures suggests a divergence between the spot market and the futures market since Flannery and Protopapadakis previously identified a day-of-the-week effect in T-bills. This suggests that spot market seasonalities may not always pass through to derivative securities.

Yadav and Pope [1992] find mostly similar day-of-the-week patterns in the FTSE 100 index and LIFFE (London International Financial Futures Exchange) FTSE 100 index futures contract. There are, however, a few notable exceptions that show that cash and futures markets can diverge. Griffiths and Winters [1996] examine fed funds futures and provide another example where the cash and futures markets diverge. The fed funds cash market has an identified biweekly increase in the mean and variance of the fed funds rate on settlement Wednesdays.[2] Griffiths and Winters find that the fed funds settlement effect does not pass through to fed funds futures prices. The divergence occurs because the payoff to fed funds futures contracts is based on the average monthly funds rate, rather than the rate on a single day.

Jones and Singh [1997] discover some divergence in the implied volatilities from sets of winner and loser stocks at the turn of the year. They find different implied volatilities for call and put options on loser stocks at the turn-of-the-year and increased implied volatility on both calls and puts for winner stocks at the turn of the year. The different implied volatilities between calls and puts on the same stock suggests a pricing divergence between the cash and options market.

Griffiths and Winters [2005a] examine various one-month money market securities—including one-month LIBOR—at the year-end and find a common effect across money market securities. Specifically, one-month rates increase dramatically at the beginning of December, remain high during December, and decrease back to normal at the turn-of-the-year, with the decline in rates beginning a few days before the year-end.[3] The year-end increase in one-month LIBOR is important to cash market participants because of the popularity of LIBOR as an interest-rate index. The pricing of this year-end effect in the LIBOR derivatives is important if market participants are to use these derivatives to hedge the year-end increase in the cost of funds and infer unbiased predictions of future interest rates and volatilities.

The evidence of divergence between the cash market and the derivatives markets—especially that of the money markets—prompts us to test one-month LIBOR futures and options on one-month LIBOR futures for the presence of the recently identified year-end rate increase in one-month LIBOR.

LIBOR has become a popular reference rate for many interest-bearing financial products, such as variable rate commercial lines of credit. In addition, with the daily benchmarking of LIBOR by the British Bankers' Association (BBA), the LIBOR-based interest-rate derivatives offered by the Chicago Mercantile Exchange (CME) have become a popular interest-rate management tool.[4] For example, financial institutions use options on financial futures contracts to create caps and floors to limit their exposure to changing interest rates. The CME offers LIBOR-based futures contracts and options on those futures.

The popularity of LIBOR-based financial products makes it important to understand their price behavior in light of the new evidence that a year-end regularity exists in one-month LIBOR. Specifically, this paper examines the pricing of LIBOR-based derivative contracts in three ways: 1) Are the year-end spot LIBOR market effects also present in the LIBOR futures and LIBOR options markets? 2) Are implied interest rates from LIBOR-based futures contracts unbiased predictors of future interest rates? Does the predictive bias differ at the year-end? and 3) Are implied volatilities (IV) for options on LIBOR-based futures contracts unbiased predictors of future daily volatilities (DV)? Does the predictive bias differ at the year-end?

The paper begins by reviewing the year-end effect in one-month LIBOR and its implications for pricing call options for interest-rate caps. We show that failing to recognize the year-end increase in LIBOR would result in underpricing the option by as much as $300 per million for December interest rate caps. We then analyze the LIBOR-based futures contracts to determine if the futures price provides an unbiased predictor of future LIBOR rates and properly prices the year-end cash market effect. The year-end effect in LIBOR does pass through to the LIBOR futures contract. In addition, the LIBOR future is a biased predictor of future interest rates, but the bias appears to be different at year's end. Finally, we analyze the predictive power of IV for the DVof LIBOR futures. The utility of these options as risk management tools depends on whether they reflect the year-end rate behavior of the underlying markets. The cash market year-end rate increase does pass through to the price of the option contract through higher volatility. In addition, the option contract provides biased estimates of daily volatility but the volatility bias is *not* related to the year-end.

2. Background

This section discusses the background necessary for empirical tests conducted in this paper. This section details three specific issues. First, we explain the reasons for, and timing of, the year-end effect in short-term interest rates. A large body of research has investigated turn-of-the-year/year-end effects in financial markets. We review the *year-end* effect in short-term interest rates to differentiate it from the better known *turn-of-the-year* effect in equities. Understanding the timing of this year-end effect in one-month interest rates is important because it provides the timeframe reference necessary for using the derivative contracts to hedge at the year-end. Second, we illustrate how the year-end effect in short-term interests rates affects the price of an interest rate option. This motivates our tests to determine if the year-end effect in short-term interest rates passes through to the derivative securities. Third, we discuss the arbitrage between the derivative contracts and their underlying assets to explain why we expect the cash market year-end effect to pass through to the derivative contracts.

2.1. The Timing of the Year-End Effect in Short-Term Interest Rates

The year-end effect in the stock market is referred to as a turn-of-the-year effect. Keim [1983] finds abnormal stock returns during January and, in particular, during the first week of January. Roll [1983] shows that stock re-purchases following December sales begins on the last day of December. Ariel [1987] shows that almost all of the cumulative returns in stock indices occur over a 10-day trading period commencing on the second to last trading day of each month. Thus, the *turn-of-the-year* effect in equities starts at the end of December and continues into the beginning of January. The *year-end* effect in short-term interest rates follows a very different pattern. Short-term interest rates exhibit abnormally high rates during most of December, before declining to normal levels across the turn-of-the-year. Thus, the short-term interest rate effect is a year-end effect instead of a turn-of-the-year effect.

We now discuss the year-end pattern expected for one-month instruments under a year-end preferred habitat for liquidity and some of the empirical results related to this pattern. Griffiths and Winters [1997, 2005a, 2005b] hypothesize that the year-end effect in short-term interest rates is consistent with a year-end preferred habitat for liquidity. To meet short-term cash obligations, investors (lenders in the money markets) exit short-term securities during the last few trading days of November, when the term to maturity of the one-month instrument begins to span the lenders' end of December cash obligation dates. This preference for liquidity drives up one-month interest rates for most of December.[5] As the end of December liquidity demand passes, investors repurchase short-term instruments, returning interest rates back to normal levels. The result is that one-month interest rates rise in very late November and return to normal across the turn-of-the-year.[6]

Exhibit 1 illustrates the December pattern in one-month LIBOR and euro-dollar rates found by Griffiths and Winters [2005a].[7] Exhibit 1 shows the average spread between the interest rate on a one-month instrument and the yield on three-month T-bills from 25 days before year end to five days after year end. The average spread is demeaned; a value of 0 in the plot means that the average spread on that trading day equals the average spread for all trading days not in the plot. Because there are approximately 20 trading days in December, days -25 to -21 represent the trading days at the end of November. The LIBOR and euro-dollar spreads are near normal on days -25 and -24 and then increase dramatically over the next three trading days. From trading day -20 through trading day -5 the spreads remain steady and abnormally high (20 to 40 basis points above normal). From trading day -5 through trading day -1 spreads spike and then decline dramatically to near normal levels. In the new year (trading days +1 to +5) spreads are about normal; spread differences are about 0. This pattern suggests a year-end preferred habitat for liquidity. It clearly differs from the turn-of-the-year pattern in equities.

Musto [1997] suggests that an increase in the price of risk at the year-end might produce the interest rate pattern reported in Exhibit 1. Griffiths and Winters [2005b] find that the price of risk increases at the year-end, in a pattern that follows Exhibit 1. Interest rates on high risk commercial paper increase substantially more than the rates on lower risk commercial paper. Rates on the lower risk commercial paper also follow the pattern in Exhibit 1, however, leading Griffiths and Winters [2005b] to conclude that the year-end increase in the price of risk is in addition to a general year-end increase in interest rates because of the year-end preferred habitat for liquidity.

Having detailed the year-end pattern in one-month interest rates, we need to relate this pattern to the instruments examined in this paper, one-month LIBOR derivative contracts (futures and options-on-futures) from the CME. Both the futures contract and the option on the futures contract expire on the second London bank business day immediately preceding the third Wednesday of the contract month. This means that the December LIBOR futures contracts expire in the middle of the time spanned by the increase in one-month rates. Accordingly, the settlement price of the futures contract, which is defined as 100 – rate, clearly should be affected by the year-end rate increase in one-month securities. Equally clear, is that a trader wanting to hedge interest rates in the latter half of December cannot fully hedge using the December LIBOR contracts because the contract expires too soon. For example, assume in November a borrower wants to hedge LIBOR-based cost of debt at the end of December and the borrower is aware of the year-end rate increase. If the borrower believes that the year-end seasonal effect has a different rate generating process than the general level of interest rate then the borrower would want a position in both the December LIBOR futures contracts and the January LIBOR futures contract. The December contract would hedge unexpected deviations from the year-end rate pattern (as shown in Exhibit 1) until its expiration, while the January contract would hedge general movements in market interest rates until the borrower acquired the needed funds. There are several alternative interest rate futures contracts, but most also expire in the middle of the month like the LIBOR futures contract. We are aware of two interest rate futures contracts that expire on the last trading day of the month. These contracts are the CME turn futures contract and the CBOT fed funds futures contract. However, both use fed funds rates to determine the settlement price and the fed funds rate does not exhibit the December rate increase of the one-month instruments.[8]

2.2. An Example of Pricing Interest-Rate Caps in a Cash Market with a Year-End Rate Effect

The one-month LIBOR, used by Griffiths and Winters [2005a], averages 6.02 percent during the months of January through November, and 6.38 percent during December. In addition, the annualized standard deviation of the daily rate changes is 22.26 percent for January through November and 44.85 percent during December.[9] To illustrate the potential importance of these end-of-year effects on options prices—and interest caps—we consider a simple example in which call options on interest rates are priced using historical data as inputs into the Black/Scholes formula. Specifically, we use one-month cash market LIBOR to demonstrate the difference that accounting for seasonal patterns makes in one-month call prices, for a sequence of strike prices from 5.20 percent to 6.70 percent.[10] We use three sets of parameters to price the set of options, as follows:

1. A parameter set calibrated from data from January through November data {S = 6.02, σ = 22.26 percent}.
2. A parameter set calibrated from December data {S = 6.38, σ = 44.85 percent}.
3. A parameter set calibrated with the December mean rate and January-to-November volatility {S = 6.38, σ = 22.26 percent}.

The hybrid (third) parameter set represents the "flat" implied volatilities for interest rate caps and floors that are provided by brokers. The flat volatilities are similar to cumulative averages of spot volatilities and therefore exhibit less variability than spot rates. Accordingly, the hybrid set of parameters provides an example of the pricing error possible in December if flat volatilities are used instead of the higher spot volatility.[11]

The solid line in Exhibit 2 displays the <u>difference</u> between the call prices for the January-November call prices (set #1) and the December call prices (set #2) for a notional value of $1,000,000. In other words, the solid line shows that a call option on interest rates with a strike price of 6 percent and a notional value of $1,000,000 would cost about $315 more with the December mean and standard deviation as inputs {S = 6.38, σ=44.85 percent} than with the January-November statistics as inputs {S = 6.02, σ=22.26 percent}.

To show the marginal difference that the higher mean rate makes, the dashed line in Exhibit 2—labeled "constant volatility"—shows the difference between the January-November call prices (set #1) and the December prices using the January-November volatility (set #3). The marginal effect of the higher mean rate in December adds about $208 to the price of an interest-rate call option with a strike price of 6 percent. For lower strike prices, the higher mean interest rate in December adds as much as $300 per million to December interest rate caps. Falsely assuming constant volatility can lead to underpricing the interest-rate Cap option in December by as much as $150 per million—the difference between the solid and dashed lines in Exhibit 2.

This brief example illustrates that the year-end rate increase must pass through into the derivatives to properly price the options on LIBOR-based futures. This is particularly important for the writers of calls on interest-rate caps who will be exposed to increases in interest rates and volatility.

2.3. Arbitrage

In the previous section we provide an example of why it is important for the cash market year-end effect to pass through to the derivative security. However, previous research shows that a cash market effect does not always pass through as expected to the derivative. Therefore, the logical next step is to demonstrate why we expect the effect in the underlying asset to pass through to the derivative in this case. In this section we discuss the arbitrage between the cash market and the LIBOR futures contract and between the LIBOR futures contract and the option on the LIBOR futures contract.

The LIBOR futures contract is a contract on a one-month $3 million euro-dollar time deposit. The contract settlement price is (100 – rate), where rate is defined as the British Bankers' Association interest settlement rate for one-month euro-dollar interbank time deposits, which is known as BBA LIBOR. The CME notes that LIBOR futures contract is analogous to the euro-dollar futures contract with the underlying asset for the euro-dollar futures contract being a three-month $1 million euro-dollar time deposit. The analogous nature of the contract is important because the euro-dollar futures contract is a popular and well understood contract.

Chance [1998, p. 457-460] provides an example of the arbitrage between the cash and futures market for euro-dollar futures. The Chance example provides a situation where a bank wants to issue a 180-day euro-dollar time deposit but can achieve a lower rate by issuing a 90-day time deposit and selling a euro-dollar futures contract that expires in 90-days which creates a synthetic 180-day time deposit. The arbitrage opportunity will force the futures price to reflect interest rates in the underlying cash market. An analogous arbitrage using one-month and two-month LIBOR can be created for the LIBOR futures contract which requires that the LIBOR futures contract reflects market interest rates in the underlying cash market.

Since the arbitrage opportunity for the LIBOR futures contract involves one-month and two-month spot LIBOR, we need to verify that the implied forward rate in two-month LIBOR reflects the year-end rate increase in one-month LIBOR. We collect one-month and two-month spot LIBOR for the period 4/5/90 through 10/7/02 (the sample period for our futures data) and calculate the one-month forward rate implied in two-month spot LIBOR. We find that the implied one-month forward rate is generally greater than one-month spot LIBOR with the daily difference averaging about 7 basis points in January through October, inclusive. In November the difference jumps to about 46 basis point, while in December the difference becomes negative and averages about 15 basis points.[12] The 46 basis point difference in November between one-month spot LIBOR and the implied forward rate is similar in magnitude to the December rate increase in one-month LIBOR found in Griffiths and Winters [2005a] suggesting that the cash market anticipates the year-end rate increase. As further support Exhibit 3 shows the spread between implied 30-day forward rates and the 3-month LIBOR rate. The top panel displays 30-day forwards constructed from the 1- and 2-month rates, while the bottom panel shows those from 2- and 3-month rates. The top panel shows that 1-month ahead 30-day rate begins to rise in late October, remains high until late November and then declines to normal levels. The bottom panel likewise illustrates that the two-month ahead 30-day forward rate begins to rise in late September and to fall again before the start of October. Both 30-day forward rates appropriately embody the expected rise in the December rate.

Suppose that the futures market failed to properly price the December effect. How would one take advantage of this? To directly arbitrage a mispricing of the December effect in the futures market, one could take a 30-day forward position—as described above—approximately 30 days before the expiration of the December futures contract. For example, if the futures price implies a low rate for December, one can borrow through a futures contract (shorting the contract) and lend through the forward contract. Therefore, arbitrage should force the implied 30-day forward and the futures price to imply approximately the same LIBOR rate one month before the expiry of the futures contract.

Of course, three factors will prevent our observed forward and futures prices from being exactly equal in practice: 1) It is not generally possible to construct a forward contract to exactly match the length of the futures contract;[13] 2) daily settlement and interest rate uncertainty; 3) forward rates used here are collected at the London close while the futures prices are collected at 2:30 pm, central time.

Are the futures rates and 30-day forward rates equal, approximately one-month before expiry? The top panel of the Exhibit 4 shows a scatterplot of the rate implied by the futures prices versus the implied 30-day forward, calculated approximately 30-days before expiry of the futures contract.[14] The solid line indicates a line with unit slope through the origin. If the forwards and futures were exactly equal, all the pairs would lie on the 45 degree line. The figure shows that implied forward rates generally exceed the rate implied by the futures price. The bottom panel displays a histogram of the differences between the interest rates implied by these matched forward and future pairs. The mean difference is about 8 basis points; the 10^{th} and 90^{th} percentiles of the distribution are 0 and 17 basis points, respectively. The largest forward/future differences are associated with the Y2K liquidity problems in December 1999 and the start of the first Gulf War in January 1991.

Having established the expectations that market forces should cause interest rates in the cash market to be reflected in the price of the futures contract and having shown that implied forward rate is reflected in the futures price, the next step is to establish that the expected volatility and price of the futures contract is expected to be reflected in the price of the option on the futures contract. Under some assumptions that include risk-neutral pricing, the volatility implied by options should be approximately the conditional expectation of realized volatility in the underlying asset until expiry (Bates [1996]). If it were not, one could make excess returns by buying options whose IV was lower than expected realized volatility and selling options whose IV was higher than expected realized volatility. Even if there are priced risks associated with writing options, risk-arbitrage should still limit the extent to which IV diverges from expected volatility.

It is important to remember that the underlying asset for the LIBOR options market is the futures contract, so the price of the option is determined from the implied futures rate, not the spot rate. Because the arbitrage between the futures and options markets is fairly easy, we expect that the options market will properly price the futures market, even if the latter does not properly price important characteristics of the spot market.

In summary, arbitrages are available to force the prices of the LIBOR derivative contracts to reflect the interest rates in the cash market. Accordingly, our expectations are that interest rate pattern in LIBOR should pass through to the derivative contract, but that there is sufficient empirical evidence of segmentation between the cash market and derivatives markets in other instruments that whether the LIBOR regularity passes through to its derivative contract is an empirical question. The remainder of this paper attempts to answer this empirical question.

3. CME One-Month LIBOR Futures Contracts

This section discusses and analyzes CME one-month LIBOR futures contracts. First, we describe the CME contract and our data. Then we analyze the futures prices to determine if the December cash market interest rate increase appears in the futures data. We conclude our analysis of the futures contract by discussing the futures' predictive power for the year-end effect.

3.1. Institutional Details and Data Description

The CME one-month LIBOR futures contract is a contract for a one-month euro-dollar time deposit with a principal amount of $3,000,000.[15] Contracts are available for each month of the year, up to 12 months ahead. A rise of one basis point in one-month LIBOR translates into a loss of $25 for each long contract. The final settlement price is 100 minus the BBA one-month LIBOR. Contracts are cash settled on the second London business day immediately preceding the third Wednesday of the contract month. The CME has agreed with the BBA to use the BBA LIBOR benchmark rate as a basis for settling the CME one-month LIBOR futures contract.

Our data set consists of contract settlement month and year, opening price, closing price, high price, low price, total volume, and total open interest for each one-month LIBOR futures contract for the period 4/5/90 through 10/07/02. Following the usual practice in dealing with futures and options data, we use data from the month immediately preceding a contract's settlement month. In other words, our observations from December 1991 pertain to the futures contract that settles in January 1992. Johnston, Kracaw, and McConnell [1991] note this avoids any pricing problems associated with settling the contract and that this typically covers the period of highest volume in futures contracts.

Exhibit 5 shows the time series of LIBOR daily futures prices and the final settlement price associated with the expiry of the contract. The daily settlement prices appear to track the final settlement prices—the BBA one-month LIBOR on the expiration date—fairly closely. There has been substantial variation in interest rates and future prices during the sample.

Exhibit 6 shows summary statistics for futures price changes and absolute futures price changes in columns 1 and 2. Columns 3 and 4 show summary statistics for implied volatility (IV) until expiry and DV (daily volatility) until expiry, in percentage terms, for the options on LIBOR futures, which we will visit later during our discussion of the options. Mean futures price changes are very small, less than ½ basis point per day. There is a modest amount of positive autocorrelation in the prices, indicating that futures positions are probably not priced by a risk neutral measure. There is more positive autocorrelation in the absolute futures price changes, as one might expect from a financial time series.

3.2. The December Effect in One-Month LIBOR Futures Prices

We begin our analysis of one-month LIBOR futures contracts by searching for evidence of the year-end increase in one-month cash market LIBOR.[16] To do this, we regress the futures-price implied

LIBOR ($R_t = 100 - F_t$) on monthly indicator variables (12 indicator variables):[17]

$$R_t = \sum_{x=1}^{12} b_x \, I(month(t) = x)_t + \varepsilon_t \tag{1}$$

where R_t is the implied one-month LIBOR interest rate for the settlement date in the following month, using the day t futures contract closing prices ($R_t = 100 - F_t$), and $I(month(t) = x)_t$ is an indicator variable that takes the value one when date t occurs during month x.[18]

We estimate equation (1) by OLS and calculate Wald statistics for the null hypothesis that each coefficient differed from the average coefficient. The Wald statistics use Newey-West covariance matrices with a window of length 33. Exhibit 7 plots the coefficients in temporal order $\{b_1, b_2, ...b_{12}\}$ along with the p-values from heteroskedastic-consistent Wald tests (Newey and West [1987]) that each coefficient is equal to the mean of the rest of the coefficient vector. The only coefficient that is statistically significantly different from zero at the five percent level is that on the November indicator. The fact that the coefficient on November was significantly greater than the mean coefficient indicates that the year-end effect in LIBOR is priced in the futures market.[19] The effect appears in November rather than in December because the November data is for the contract that settles in December. These regression results show that rates increase when the series switches to the December contract and declines when the series switches to the January contract. In other words, the December contract (November trading dates) has higher implied rates than the surrounding contracts. This effect is consistent with the year-end effect found by Griffith and Winters [2005a] in the cash market.

3.3 Do LIBOR Futures Prices Predict the December Increase in Spot LIBOR?

The preceding analysis makes it clear that the December futures contract price contains a higher implied LIBOR to accommodate the year-end rate increase in the cash market. So, the futures market anticipates the December rate increase in the cash market. The next question is how well futures prices predict spot rates, particularly the December rate in the cash market?

To examine the predictive ability of the futures market, we first estimate the following regression model for the entire sample using OLS:

$$Settle_t = \alpha + \beta \cdot Close_t + \varepsilon_t \quad (2)$$

where $Settle_t$ is the final settlement price for a contract trading on day *t* and $Close_t$ is the daily closing price on day *t* for the contract during the month preceding settlement. If the futures market is a conditionally *unbiased* predictor of the cash market, then $\alpha = 0$ and $\beta = 1$. A predictor is said to be conditionally unbiased if its conditional expectation is equal to the predicted variable. Of course, futures prices need not provide unbiased forecasts of the future asset price. Nevertheless, the special case of unbiased predictions is a useful benchmark with which to compare the actual behavior of the data.

Because closing prices at dates *t* and *t+1* will both be used to forecast the final settlement price at *T*, the *t* and *t+1* error terms in regression (2) will be correlated because they are both influenced by shocks from *t+2* to *T*. In fact, all adjacent elements in the error vector will be correlated with each other and the degree of correlation will be higher for contracts with longer times to expiry. Such a data set is described as "telescoping" because the degree of correlation between adjacent errors declines linearly and then jumps up at the point at which contracts are spliced. To correctly measure parameter uncertainty, this paper uses a covariance estimator that corrects for overlapping forecast errors (Jorion [1995]):

$$\hat{\Sigma} = (X'X)^{-1}\hat{\Omega}(X'X)^{-1} \quad (3)$$

where $\hat{\Omega} = \sum_{t=1}^{T} \hat{\varepsilon}_t^2 X_t' X_t + \sum_{s=1}^{T} \sum_{t=s}^{T} I(s,t)\hat{\varepsilon}_t \hat{\varepsilon}_s (X_t' X_s + X_s' X_t)$, X is the *T* by *K* matrix of regressors, X_t is the *t*th row of *X*, $\hat{\varepsilon}_t$ is the residual at time *t*, and *I(s,t)* is an indicator variable that takes the value 1 if the forecast from period *s* overlaps with the forecast from period *t* in equation (2).

We present the results of the regression in the first row of Exhibit 8. The first row shows that α is estimated to be 0.536 with a standard error of 0.899 and β is estimated to be 0.995 with a standard error of 0.009. The univariate coefficients and standard errors indicate that the data are consistent with the unbiasedness hypothesis. For example, the β estimate suggests that a \$1 increase in the daily closing price ($Close_t$) would produce a \$0.995 expected increase in the settlement price ($Settle_t$). A Wald test, however, reveals that $\{\hat{\alpha}, \hat{\beta}\}$ are in fact significantly different from $\{0,1\}$ when the very strong negative correlation between the parameter estimates is taken into account in a multivariate test. The column in Exhibit 8 labeled "PV1" shows that the p-value from the Wald test is essentially zero. This bias is consistent with the existence of some priced risk associated with holding the futures contract.

The preceding test shows that the implied interest rate from the futures price is not a conditionally unbiased predictor of the future one-month LIBOR interest rate. It does not tell us, however, whether the predictions of the futures market are different at year-end. That is, does the futures market predict the future interest rate in the same way in November as it does in the other months of the year? To investigate this question we estimated 12 versions of the following regression—one for each month of the year—allowing the coefficients for each month to change, one at a time:

$$Settle_t = \alpha + \beta \cdot Close_t + I(month(t) = x) \cdot (\alpha_x + \beta_x \cdot Close_t) + \varepsilon_t \tag{4}$$

where $I(month(t) = x)$ is an indicator variable that takes on the value one for days on which date t occurs during month x, zero otherwise.

For each of the 12 regressions (4), we calculated Wald statistics for three null hypotheses:

1) The predictions of the other 11 months are unbiased when we treat one month differently, $\{\alpha, \beta\}$ = {0, 1}.

2) The particular month should be treated the same as the other 11 months: $\{\alpha_x, \beta_x\}$ = {0, 0}.

3) Closing prices are unbiased predictors in the particular month: $\{\alpha + \alpha_x, \beta + \beta_x\}$ = {0, 1}.

These Wald statistics and their p-values are displayed in Exhibit 8 in columns labeled "Stat 1," "PV1," "Stat 2," "PV2," "Stat 3," and "PV3." Rows labeled "1" through "12" indicate the results using each of the 12 months of the year, January, February,...December.

The low p-values in the column labeled PV1 indicate that the Wald tests for the first hypothesis, that $\{\alpha, \beta\}$ = {0, 1}, reject the null in each case, despite the fact that the coefficients are typically very close to their values under the null of unbiasedness. It is certainly possible that even a small amount of measurement error—perhaps due to bid-ask spreads or small effects from illiquidity—in the regressors could generate sufficient bias in the coefficients to explain the very small but statistically significant bias.

The tests of whether the monthly coefficients are zero—$\{\alpha_x, \beta_x\}$ = {0, 0}—fail to reject the null hypothesis at the five percent level for any month (see the column labeled PV2). The November-specific coefficients—$\{\alpha_x, \beta_x\}$—have the smallest p-value (p = 0.059), however. Thus, the futures price appears to deviate more from its usual predictive behavior in November than in any other month.

The third hypothesis asks if closing prices are unbiased for a selected month when its forecasting ability is examined individually. That is, is $\{\alpha + \alpha_x, \beta + \beta_x\}$ = {0, 1}? When one month is treated differently from the other 11 months, we can reject unbiasedness at the 5 percent level in 3 months: June, July, and December (see the column PV3).

November appears to be unusual in three ways: 1) The value of $\hat{\beta} + \hat{\beta}_x$ is greater in November than in any other month, $\{\hat{\alpha} + \hat{\alpha}_x, \hat{\beta} + \hat{\beta}_x\}$= {-6.395, 1.069} and is on the opposite side of 1 from the unconditional $\hat{\beta}$, which is 0.995;[20] 2) the p-values for the tests that November should be treated differently (PV2) are the lowest of all months and marginally significant (p = 0.059); 3) p-values for unbiasedness (PV3) when November is treated differently are marginally significant (p = 0.07). In short, the predictive properties of futures prices in November appear to be more different—with statistical evidence of bias in an unusual direction—than in any other month.

3.4 Do Futures Prices Predict Future Interest Rates?

One might wonder about the information content of futures prices versus a naïve benchmark such as the current LIBOR rate. That is, does the futures price subsume the information in the current rate? To investigate this issue, we added a transformation of the current LIBOR rate to equation (4).

$$Settle_t = \alpha + \beta \cdot Close_t + I(month(t) = x) \cdot (\alpha_x + \beta_x \cdot Close_t) + \gamma(100 - LIBOR_t) + \varepsilon_t \qquad (5)$$

where $LIBOR_t$ is, of course, the LIBOR rate at time t. If interest rates are a martingale, the conditional expectation of final settlement should be the current LIBOR rate.

Exhibit 9 shows the results of estimating equation (5) with robust standard errors for all the data ($\{\alpha_x, \beta_x\} = \{0,0\}$) and permitting the month of November to be treated differently (x = 11). The t statistics implied by the figures in the column denoted γ are not able to reject the null that the coefficient on current LIBOR equals zero. Therefore, the futures price subsumes the naïve forecast.

The results from equation (5) above suggest that the futures price subsumes the naïve forecast while the results in the previous section suggest a bias in the futures prices. However, a biased forecast can be useful if it is not noisy. Accordingly, we examine the accuracy of three forecasts of the final settlement price of 1-month LIBOR futures with the root-mean-squared error (RMSE) criterion. Exhibit 10 shows the RMSEs and their standard error for the prediction of the rate implied by the final settlement price for three predictors: 1) the rate implied by the futures price in the previous month; 2) spot rates in the previous month; and 3) the 30-day forward rates in the previous month. The first row of the table shows the overall results, pooling over all final settlement prices for all months. The futures price is the best predictor by the RMSE criterion, but not by a statistically significant margin. The second row shows results for the November trading days (December final settlement). Again, the futures price is the best predictor, its margin increasing over the other predictors, especially the naïve spot rate, which does not embody the December rise. Note that the November RMSE is higher for all three predictors. This is unsurprising, given the documented higher implied volatility for the December contract.

3.5. Discussion of Results on One-Month LIBOR Futures Pricing

Our results suggest that the December one-month LIBOR futures contract prices include an expectation of higher cash market LIBOR in December and the magnitude of the effect in futures prices is similar to the magnitude in the cash market. This is particularly important because the higher December futures-implied rate allows these contracts to properly hedge the increased interest rates in December and to pass the December cash market effect through to the LIBOR options contract. The ability of futures prices to subsume the naïve forecast (current LIBOR) is undiminished by the seasonal factors. The next section of the paper examines whether options are priced correctly for the December cash market effect.

Exhibit 8 suggests that the futures market is, overall, a very slightly biased predictor of the future cash market spot rate, but it is our best predictor by the RMSE criterion (see Exhibit 10). However, we feel that not much should be made of the bias because (1) it is economically small; (2) it appears to be focused around the year-end; and (3) it might be due simply to econometric problems.

From an economic perspective, the central issue is why we should care about the predictive ability of this futures market. There are many financial contexts where having an unbiased predictor (or a biased predictor with limited noise) of future interest rates would be very useful. One situation central to the mission of the Federal Reserve is the implementation of monetary policy. The FOMC open market trading desk ("the Desk") implements monetary policy by trading in the money markets to manage interest rates around the policy target interest rate. It is easy to see how having an unbiased predictor (or a low noise biased predictor) of future interest rates could aid the in the Desk's decision process for its daily market intervention to manage interest rates relative to the policy target rate.

LIBOR futures prices subsume a naïve benchmark and provide reasonable forecasts of future interest rates but care should be exercised in using these forecasts around the year-end. While specific information about bank system reserves and projected system needs likely dominate any information about general market trends for Desk open market operations, reasonable forecasts of future interest rates would still be a valuable tool for the Desk in managing interest rates.

4. Options on One-Month LIBOR Futures Contracts

Through the intimate connection between volatility and options pricing models, any year-end effects in the volatility of the underlying asset should carry through to the options market. As discussed in section 2, the price of an option depends on the volatility of the underlying asset (among other factors), so a year-end effect in the price of the underlying asset that changes the volatility of the underlying asset should change the price of the option. In this case, the November price spike in the December LIBOR futures contract (which follows from the December rate spike in LIBOR) might change the DV for the December contract and thus should also change the implied volatility (IV) of the December contract. This paper extends previous research by examining whether the prices of options on LIBOR futures contracts contain unbiased forecasts of the volatility of LIBOR futures prices and whether they reflect any year-end volatility effects that are seen in the market for the underlying asset.

To determine the ability of markets to forecast conditional variance in LIBOR futures contracts, we obtained data on call and put options on one-month LIBOR futures contracts for the period 6/12/91 through 6/26/01. The price of an option is quoted in International Money Market (IMM) one-month LIBOR basis points. The actual price of an option is 25 times the quoted price. Options can be exercised by the holder on any business day that the option is traded until the expiry of the futures contract, until 7:00 p.m., the second London bank business day immediately preceding the third Wednesday of the contract month. In-the-money options that have not been exercised previously are exercised automatically at the termination of trading, in the absence of contrary instructions.

Options pricing models depend on the volatility of the return to the asset underlying the options contract. Latane and Rendleman [1976] pioneered the technique of inverting an options pricing model—using the option premium and known arguments of the model: asset price, strike, interest rates, and time to expiry—to obtain volatility of the underlying asset until expiry. If the option pricing model is correct, IV should be an unbiased and informationally efficient forecast of DV, or one could generate excess returns by buying and selling options on the basis of a better volatility forecasting procedure.

4.1 The Options Data

As discussed earlier, to construct a series of the most liquid contracts, the futures and options contract data are spliced in the usual way at the beginning of each month. That is, on each trading day of

January, the settlement price for the February futures and the strikes and settlement prices for the two nearest-the-money puts and two nearest-the-money calls on the February options contracts are collected. Unfortunately, there are many days, especially after the beginning of 1996, in which the options market was not sufficiently liquid to provide at least one put and one call with positive volume.

We use IVs computed by the CME, rather than our own estimates, because the CME IVs were grossly similar to the latter and have fewer missing values. The CME supplies Barone-Adesi and Whaley [1987] IV on the futures contracts that we transformed to obtain the volatility on the futures price for the one-month LIBOR contract. We used the average of the IVs on the two nearest-the-money calls and two nearest-the-money puts. Cases for which fewer than two IVs were available were discarded.

Bates [1996] reports that using at-the-money options has become increasingly popular. There are three reasons to estimate IV from at-the-money options: 1) at-the-money options prices are most sensitive to changes in IV, meaning that changes in IV should be reflected in those options; 2) at-the-money options are usually the most heavily traded, resulting in fewer pricing errors due to illiquidity; and 3) research suggests that at-the-money IV provides the best estimates of future DV (e.g., Beckers [1981]). Therefore, choosing the two nearest calls and puts to estimate IV seems to be a reasonable procedure.

4.2 Options Summary Statistics

The third and fourth columns of Exhibit 6 display the summary statistics for the annualized statistics for IV and DV until expiration, on the days for which IV is available. Mean IV is 0.606 percent, and mean DV until expiry is a bit lower at 0.551 percent per annum. (See columns 3 and 4, row 3 of Exhibit 6 for those figures.) The finding that IV exceeds volatility until expiry is consistent with findings in other option markets and might be due to a price of volatility risk that "overprices" options compared to the price implied by the risk-neutral distribution. Note that both these figures are consistent with the standard deviation of log futures price changes ($\sigma = 0.038$) shown in the fourth row, first column of Exhibit 6. The annualized standard deviation of log futures price changes is ($0.038 \cdot \sqrt{255} =$) 0.607.[21]

The autocorrelation statistics should be viewed with some caution because of the many missing observations in the series. Nevertheless, first-order autocorrelations exceeding 0.9 for both series are consistent with the known persistence of IV and DV in other asset markets.

Exhibit 11 illustrates the time series behavior of DV until the next option expiration ($\sigma_{t,T}^{DV}$) and IV ($\sigma_{t,T}^{IV}$) from 1991 through 1997. The figure is truncated at the beginning of 1998 because there were few valid observations after January 1, 1998.[22] IV appears to be fairly volatile but to weakly track the DV series. There is some tendency for both series to covary positively with the overall level of interest rates.

To study whether there is a seasonal component in the level of interest rate volatility, Exhibit 12 shows the annualized monthly means of DV and IV, with associated 2-standard error confidence intervals, in percentage terms. The January figures, for example, refer to the DV and IV of the futures contract expiring in February. It is difficult to discern from the figure but mean IV is higher than DV in most months. And there is a seasonal component associated with the December rise in interest rates shown in Exhibit 12.[23] Mean IV and DV in November (0.98 and 0.79 percent) are significantly higher than the unconditional means of IV and DV. It appears that the year-end effect makes DV higher than normal in November and the market more than fully anticipates this increase. That is, it appears that the options market understands that volatility rises at the year-end and might over-compensate for the increased volatility of the underlying futures price.

4.3 How Well Does IV Predict DV Until Expiry?

Whether IV from LIBOR options on futures prices is an unbiased predictor of volatility is investigated by estimating variants of the following predictive equation:

$$\sigma_{t,T}^{DV} = \alpha + \beta_1 \sigma_{t,T}^{IV} + \varepsilon_t \tag{6}$$

where $\sigma_{t,T}^{DV}$ is the DV from t to the expiration of the option at T, and $\sigma_{t,T}^{IV}$ is the IV estimated from options prices from t to T. The annualized root mean squared log returns of daily futures prices measures volatility until expiry.

We are also interested, however, in the predictive ability of IV at the year-end. Specifically, does IV predict DV differently for the December contract? Recall from section 2 that the volatility of one-month LIBOR increases dramatically in December and the cash market effect passes through to the LIBOR futures contract; so, for the option contract to properly hedge the increased volatility in the cash market, the IV of the December options must also increase. Because of that, we estimate the following variant of the predictive equation (6) with monthly indicator variables.

$$\sigma_{t,T}^{DV} = \alpha + \beta\,\sigma_{t,T}^{IV} + I(month(t) = x)\cdot\left(\alpha_x + \beta_x \cdot \sigma_{t,T}^{IV}\right) + \varepsilon_t \tag{7}$$

Robust standard errors are constructed for the telescoping data set, as in (3).

Exhibit 13 shows this paper's estimates of (6) and (7) for LIBOR options-on-futures and DV in the LIBOR futures market from 1991 through July 2001, with robust standard errors (see equation (3)). As in previous research—e.g., Jorion [1995]; Canina and Figlewski [1993]; Lamoureux and Lastrapes [1993]; Fleming [1998]; Christensen and Prabhala [1998] and Neely [2004a, 2004b]—when all the data are used with no seasonal effects, the $\hat{\beta}$ coefficient is positive and statistically significant but far less than the hypothesized value of one under the null that the IV is unbiased (first row of Exhibit 13).

Hypotheses similar to those investigated for closing/settlement prices from Exhibit 8 are also considered for IV/DV in Exhibit 13. For the November estimation of the IV/DV regression (equation (7)) with the monthly dummies, we calculated Wald statistics for three null hypotheses:

1) IV from the other 11 months is unbiased when we treat November differently, $\left\{\hat{\alpha}, \hat{\beta}\right\}$ = {0, 1}.

2) IV from November should be treated the same as the other 11 months: $\left\{\hat{\alpha}_x, \hat{\beta}_x\right\}$ = {0, 0}.

3) IV is an unbiased predictor of DV in November: $\left\{\hat{\alpha} + \hat{\alpha}_x, \hat{\beta} + \hat{\beta}_x\right\}$ = {0, 1}.

We estimate equation (7) for each month but only report the results for November to keep the focus here on the year-end effects identified in the cash and futures markets. The full seasonal results are available upon request.

First, it is clear that IV is a conditionally biased predictor of DV. The column labeled PV1 shows that one can reject the hypothesis that $\{\hat{\alpha}, \hat{\beta}\}$ = {0, 1}, even when other months are treated differently. Second, we cannot reject the hypothesis that IV from November should be treated the same as the other 11 months, $\{\hat{\alpha}_x, \hat{\beta}_x\}$ = {0, 0}. Third, we also reject unbiasedness—$\{\alpha + \alpha_x, \beta + \beta_x\}$ = {0, 1}—for November. There is no evidence of a year-end effect on the predictive properties of IV.

In summary, DV is higher for the December option contract than for the contracts in any other month and the high level of IV in November shows that the market anticipates this increase. IV is an apparently conditionally biased forecast of future volatility, but there is nothing unusual in the predictive properties of November IV for DV.[24] We note, but omit the results for brevity, that October IV, which predicts the DV for the November futures contract, stands out as being different in our tests on IV and DV. We have no reason to think that this is related to the year-end effect, however.

4.4 Why Is IV a Biased Predictor of DV?

Recent research has found that IV is apparently a biased predictor of DV in a variety of markets. If IV appears to be biased then either there is some significant deviation from the efficient markets hypothesis (EMH) or inappropriate testing procedures—including the possibility that volatility risk is priced—provide misleading inference. We follow most studies in attributing IV's forecasting bias to one or more of the possible flaws with the testing procedures. We briefly discuss possible problems below.

A very popular explanation is that the simple option pricing models used here don't account for important aspects of option pricing such as the pricing of volatility risk or jump risk. Thus the regression of DV on IV would be misspecified because it would omit a price-of-volatility risk component. The volatility risk problem reflects the fact that there are two sources of uncertainty about the value of an option in a SV environment: the change in the price of the underlying asset and the change in its volatility. An option writer will have to take a position both in the underlying asset (delta hedging) and in another option (vega hedging) to hedge both sources of risk. If the investor only hedges with the underlying asset—not using another option too—then the return to the investor's portfolio is not certain. It depends on changes in volatility. If such volatility fluctuations represent a systematic risk, then investors must be compensated for exposure to them.

Finite-sample, persistent-regressor bias will surely exist with the overlapping data used here. Simulations in other markets suggest that this could be significant but would not explain the whole thing. Neither is there likely to be much error in IV estimation from illiquidity/high transactions costs. A third source of bias could be sample selection. If IV is available only when DV takes certain values, the estimate of β will be biased (Engel and Rosenberg [2004]). For example, if IV is missing when DV exceeds a certain threshold, a regression of DV on IV will produce a downward biased coefficient estimate.

4.5. Does IV Subsume Historical Volatility?

It is again of interest to compare IV's information content to a simple benchmark, the annualized root 20-day moving average of squared futures returns, usually called historical volatility. To investigate this issue, one can add historical volatility to (7):

$$\sigma_{t,T}^{DV} = \alpha + \beta\,\sigma_{t,T}^{IV} + I(month(t) = x)\cdot\left(\alpha_x + \beta_x \cdot \sigma_{t,T}^{IV}\right) + \gamma\,\sigma_{t,T}^{HV} + \varepsilon_t \tag{8}$$

If one rejects that the coefficient on historical volatility (γ) equals zero, then one also rejects the idea that IV subsumes this naïve benchmark forecast.

Exhibit 14 shows that the one cannot reject the hypothesis that γ equals zero for the entire sample and in November. Accordingly, we conclude that IV subsumes the benchmark historical volatility forecasts on average and in November.

5. Conclusion

We have three goals for this paper. First, we want to determine if the December rate increase in LIBOR passed through into the prices of LIBOR derivatives contracts. Second, we want to determine if the derivatives prices can provide unbiased and accurate predictions of their spot analogues. Third, we wish to evaluate whether there are year-end seasonals in the predictive properties of futures prices and IV.

With respect to the first goal, the December rate increase in LIBOR passes through to the December LIBOR futures contract price. In addition, the increased December volatility in LIBOR is reflected in higher IV from options-on-LIBOR futures. This is important because the appearance of the December effect in the derivatives contracts means that these contracts can potentially be used to hedge the interest rate risk from the December increase in LIBOR.

On the second goal, the futures contract is a slightly biased predictor of future interest rates and the evidence suggests that seasonal factors could contribute to this bias. In particular, November forecasts differ from those in other months and the futures price is a biased predictor in this month. The overall bias is economically very small, however, and could well be due to a small risk premium or minor measurement error. Consistent with the idea that the bias is not economically important, futures prices subsume a naïve forecast of future LIBOR rates, the current LIBOR rate. The futures price is the best predictor by the RMSE criterion, but not by a statistically significant margin. The margin of the futures price's RMSE superiority increases slightly for the December futures contract.

One reason for looking at the predictive ability of the LIBOR futures contract was to determine if the futures contract could be used to improve the forecasting ability of the FOMC trading Desk for managing interest rates. While we recognize that the FOMC trading Desk focuses on other information in determining their daily market interventions, our results suggest that using the LIBOR futures contract can provide useful forecasts of future interest rates with the caveat that extra care must be used to fully understand the behavior of interest rates at the year-end.

Third, we examine the IV and DV of the options of LIBOR futures. November IV (for the December contract) clearly anticipates the strong rise in end-of-the-year interest rate volatility. IV is also a significantly biased predictor of the DV of the futures contract. However, the data from the month of November is not the driver of the bias. IV almost always does, however, subsume historial volatility forecasts.

The goal of this project is to determine if the one-month LIBOR derivative contracts behave as expected, given the previous evidence on the divergence in seasonal patterns among related securities. Specifically, it is important that the year-end rate increase in one-month LIBOR pass through to the related derivative securities for these derivative securities to work properly in hedging and forecasting. The December increase in LIBOR and LIBOR volatility does pass through to the derivative contracts, which allows for hedging the underlying interest rate increase. In addition, both the futures contract and the option contract provide biased forecasts, but in both the futures and options the forecasts from the derivative contract subsume a naïve benchmark, suggesting the forecasts have economic value. There is marginal evidence of a year-end seasonal pattern in the futures' predictive bias but no evidence of a year-end bias in the predictive properties of IV.

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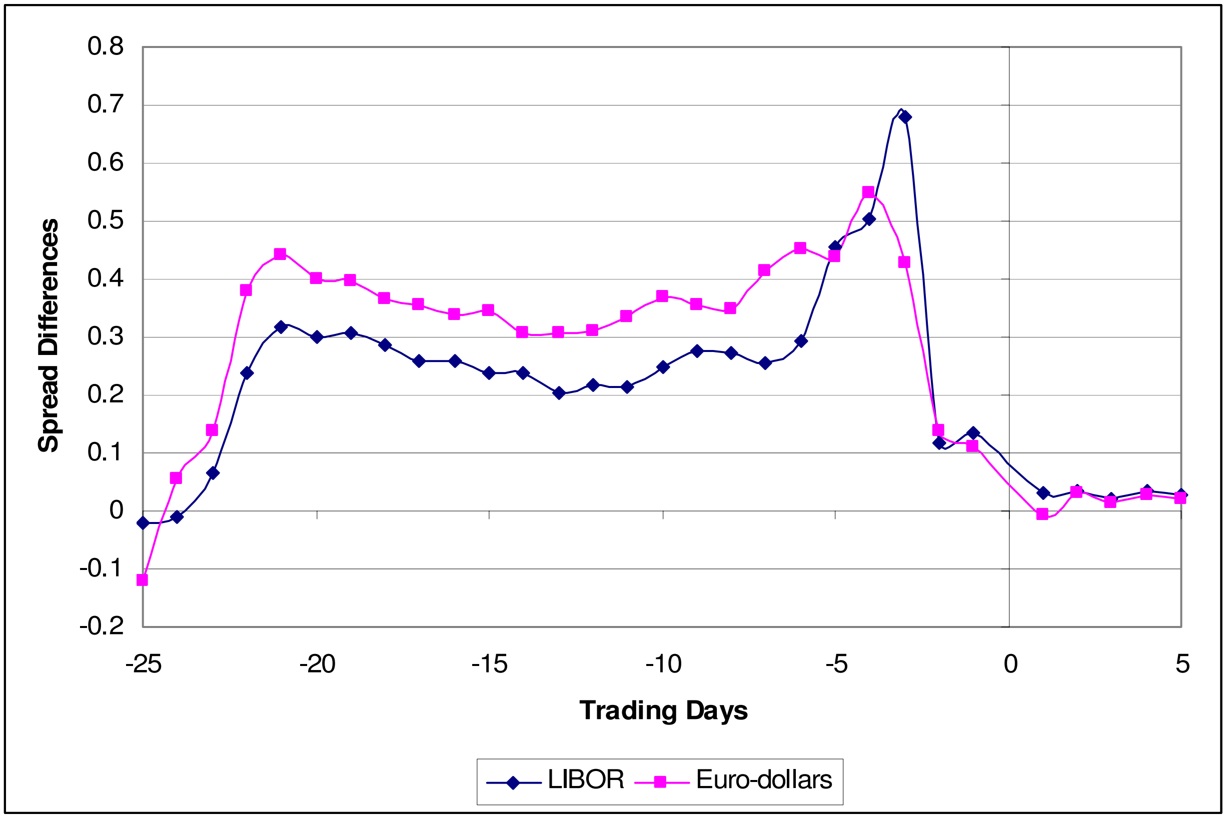
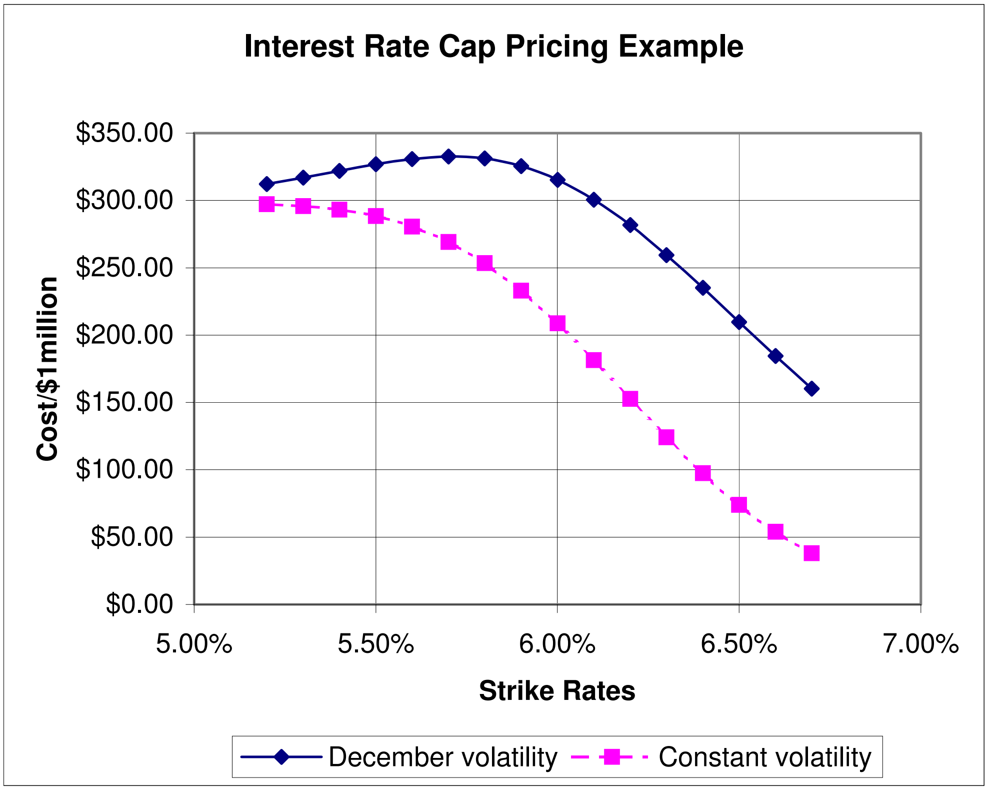
Exhibit 1: Year-end spread differences for one-month LIBOR and one-month Euro-dollar rates



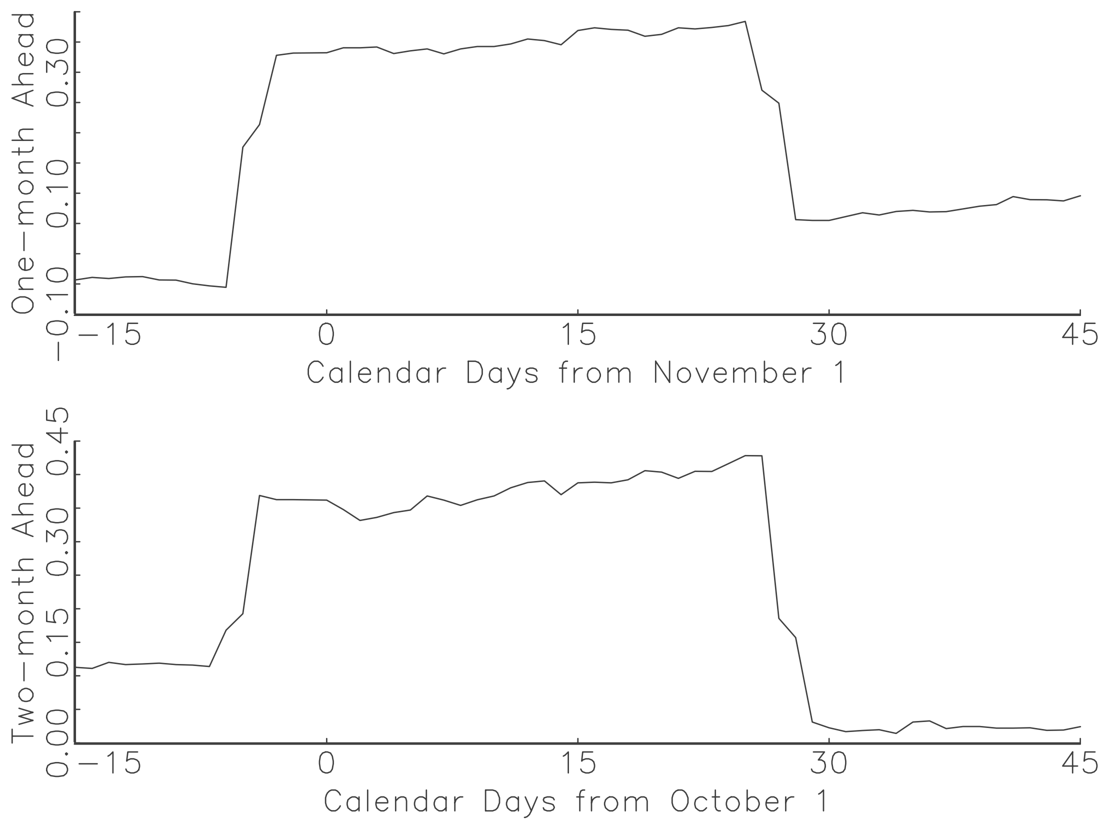
Notes: The plot is of spread differences. The spread is the one-month rate (LIBOR or euro-dollar) minus the yield on three-month T-bills and is calculated daily. The daily spreads are aligned relative to the turn-of-the-year and are averaged by trading day relative to the turn-of-the-year. Then, the average spread for all trading days not include in the plot are averaged and this average is subtracted from the average for each trading day in the plot to create spread differences for each day plotted. A zero spread difference means the average spread for that day equals the average spread for all trading days not in the plot. The 0 on the x-axis represent the switch from December to January. There is no trading day 0.

Exhibit 2: Interest rate cap pricing example



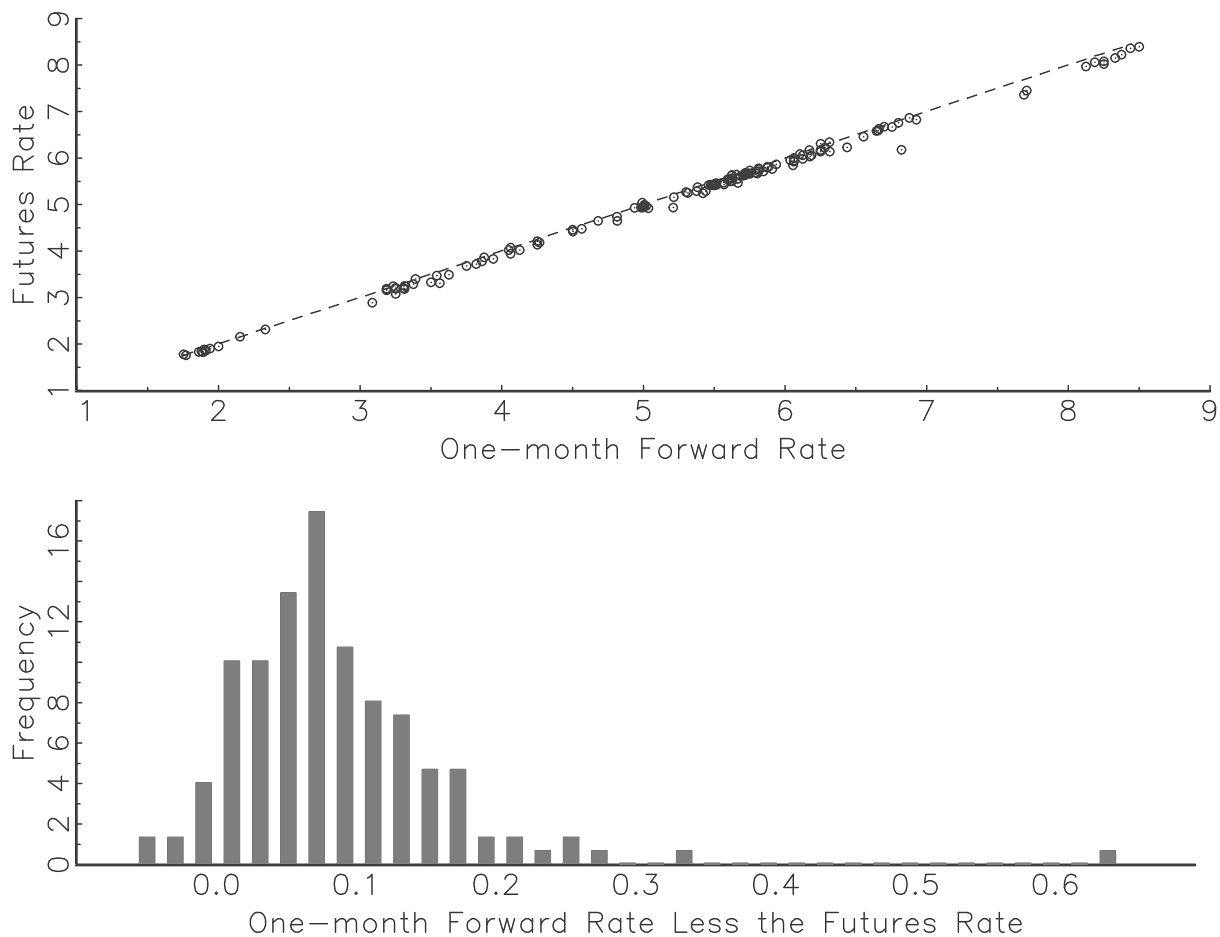
Notes**:** The solid line displays the <u>difference</u> between the call prices for the January-November call prices {S = 6.02, σ=22.26 percent} and the December call prices {S = 6.38, σ=44.85 percent} for an interest rate call option with notional value of $1,000,000. The dashed line—labeled "constant volatility"—shows the difference between the January-November call prices {S = 6.02, σ=22.26 percent} and the December prices using the January-November volatility {S = 6.38, σ=22.26 percent}.

Exhibit 3: Do the forward rates embody the expected rise in December spot rates?



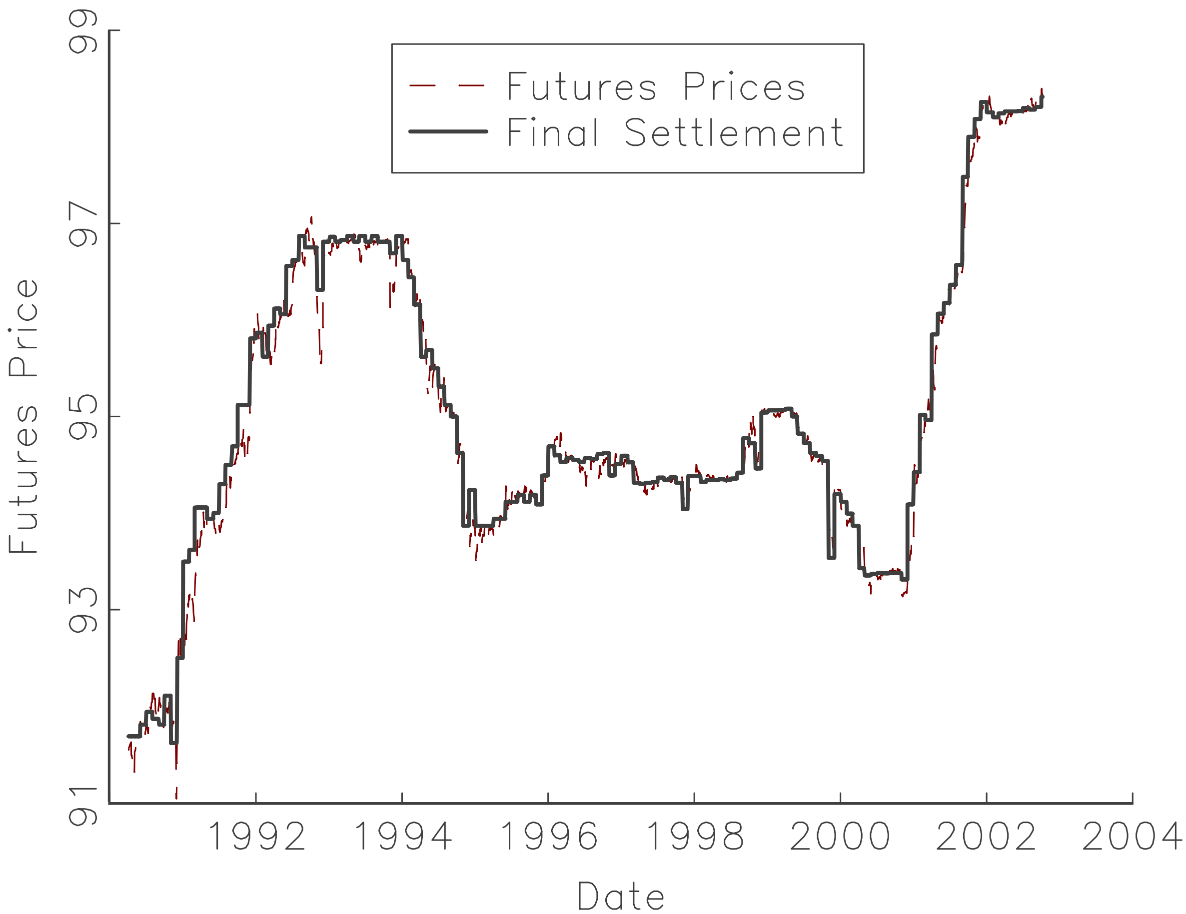
Notes: The upper panel shows the one-month ahead 30-day forward rate implied by 1-month and 2-month spot LIBOR, while the lower panel shows the two-month ahead 30-day forward rate implied by 2-month and 3-month spot LIBOR rates.

Exhibit 4: Comparing the Futures Price to the 30-Day Forward Rate, One Month From Expiry.



Notes: The upper panel of the figure shows a scatterplot of futures prices vs. implied 30-day forward prices, one month prior to contract expiry. The lower panel shows the histogram of the differences between the implied rates (forward less future).

Exhibit 5: LIBOR daily futures prices and final settlement prices



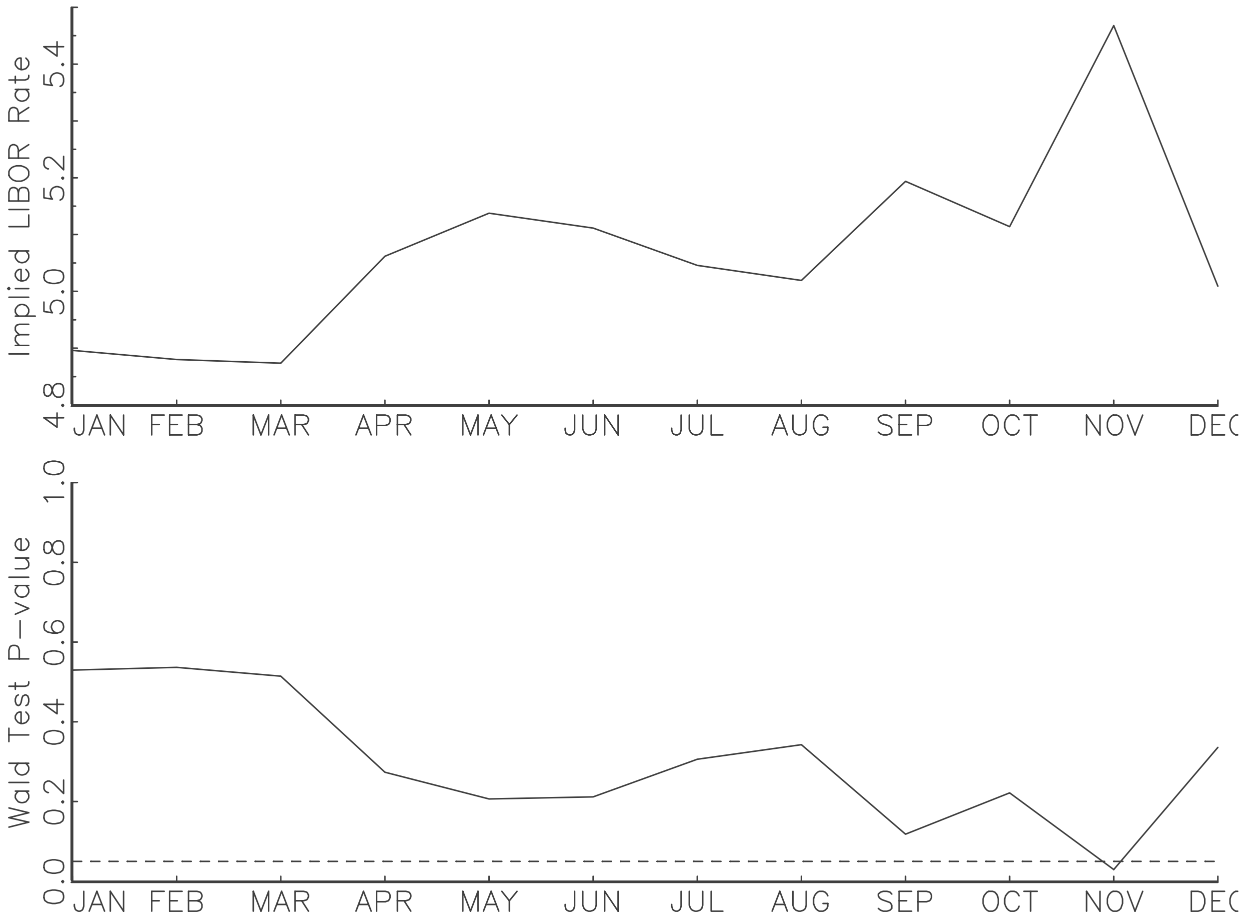
Notes: The figure plots the daily one-month LIBOR futures price rate as well as final settlement price at which that contract would eventually settle. The data start on April 5, 1990 and end in October 2002.

Exhibit 6: Summary statistics

	ln(F(t)/F(t-1))	249*|ln(F(t)/F(t-1))|	$\sigma_{IV,t,T}$	$\sigma_{DV,t,T}$
TotalObs	3130	3130	3130	3130
Nobs	2979	2979	793	854
μ	0.003	5.244	0.606	0.551
σ	0.038	7.808	0.291	0.307
max	0.375	126.990	2.111	1.708
min	-0.510	0.000	0.095	0.026
ρ_1	0.144	0.303	0.906	0.916
ρ_2	-0.026	0.240	0.862	0.841
ρ_3	-0.046	0.194	0.825	0.766
ρ_4	0.016	0.213	0.807	0.709
ρ_5	0.011	0.178	0.767	0.656

Notes: The table displays summary statistics for the changes in futures prices, absolute changes in futures prices, and daily volatility and IV data. Futures prices are quoted in percentage terms, e.g., 95.5. $\sigma^{RV}_{t,T}$ is DV until expiry, and $\sigma^{IV}_{t,T}$ is IV until expiry. TotalObs (Nobs) denotes total (valid) observations. Futures price changes have fewer valid observations because contract splicing points were removed. Mean, stddev, max and min denote the mean, standard deviation, maxima and minima of the series, respectively. ρ_1 through ρ_5 denote the first five autocorrelations of the series. Summary statistics for the futures prices are computed from April 4, 1990 to August 30, 2002. Those for the volatility are computed from June 12, 1991, through March 2001.

Exhibit 7: Seasonal factors in the change in the implied one-month LIBOR rate



Notes: The top panel of the figure plots the coefficients estimated in equation (1):

$$R_t = \sum_{x=1}^{12} b_x \, I(month(t) = x)_t + \varepsilon_t \tag{1}$$

in temporal order {b1,b2, ...b12 }. The bottom panel shows the p-values from heteroskedastic-consistent Wald-tests (Newey and West (1987)) that each coefficient is equal to the mean of the coefficient vector. A p-value less than 0.05 rejects the null that the corresponding coefficient in the top panel is equal to the mean of the 12 coefficients.

Exhibit 8: Is the futures price an unbiased predictor of the future LIBOR rate?

month	α	β	α_x	β_x	$\alpha + \alpha_x$	$\beta + \beta_x$	Stat 1	PV 1	Stat 2	PV 2	Stat 3	PV 3	R^2
All	0.536	0.995			0.536	0.995	16.8	**0.000**					0.987
	(0.899)	(0.009)											
1	-0.103	1.002	8.670	-0.091	8.566	0.911	16.700	**0.000**	5.048	0.080	5.640	0.060	0.988
	(0.811)	(0.009)	(3.950)	(0.041)									
2	0.118	0.999	6.639	-0.070	6.757	0.929	18.798	**0.000**	4.664	0.097	3.192	0.203	0.987
	(0.816)	(0.009)	(3.642)	(0.038)									
3	0.459	0.996	1.113	-0.012	1.572	0.984	17.020	**0.000**	0.503	0.778	0.812	0.666	0.987
	(0.893)	(0.009)	(3.427)	(0.036)									
4	0.527	0.995	0.104	-0.001	0.631	0.994	15.457	**0.000**	0.022	0.989	1.631	0.442	0.987
	(0.957)	(0.010)	(2.055)	(0.022)									
5	0.545	0.995	-0.023	0.000	0.522	0.995	14.883	**0.001**	0.783	0.676	3.029	0.220	0.987
	(1.001)	(0.010)	(1.266)	(0.013)									
6	0.720	0.993	-1.969	0.021	-1.248	1.014	13.964	**0.001**	0.888	0.642	7.874	**0.020**	0.987
	(0.983)	(0.010)	(2.126)	(0.023)									
7	0.467	0.996	0.705	-0.007	1.172	0.988	14.614	**0.001**	0.267	0.875	11.909	**0.003**	0.987
	(0.978)	(0.010)	(1.439)	(0.015)									
8	0.784	0.992	-2.453	0.026	-1.668	1.018	15.230	**0.000**	2.328	0.312	3.047	0.218	0.987
	(0.930)	(0.010)	(2.122)	(0.022)									
9	0.724	0.993	-2.659	0.028	-1.935	1.021	16.377	**0.000**	1.591	0.451	1.334	0.513	0.987
	(0.886)	(0.009)	(2.865)	(0.030)									
10	0.615	0.994	-0.917	0.009	-0.302	1.004	17.312	**0.000**	0.464	0.793	1.080	0.583	0.987
	(0.944)	(0.010)	(2.139)	(0.023)									
11	1.093	0.989	-7.488	0.079	-6.395	1.069	16.394	**0.000**	5.649	0.059	5.314	0.070	0.988
	(0.947)	(0.010)	(3.169)	(0.034)									
12	0.505	0.995	0.531	-0.005	1.037	0.990	13.569	**0.001**	3.489	0.175	16.336	**0.000**	0.987
	(0.944)	(0.010)	(3.055)	(0.032)									

Notes: This table presents the results of regression (4):

$$Settle_t = \alpha + \beta \cdot Close_t + I(month(t) = x) \cdot (\alpha_x + \beta_x \cdot Close_t) + \varepsilon_t \quad (4)$$

where *I(month(t) = x)* is an indicator variable that takes on the value one for days in which the date *t* occurs during month *x*, zero otherwise. Row 1 shows the results constraining the coefficients to be the same for all 12 months of the year (equation (3)). Rows (2-13), labeled 1-12 under the "month" column, shows the results permitting the January through December coefficients to differ from the coefficients in the other months of the year. The first four columns present the estimated coefficients from the regressions with Newey-West standard errors in parentheses. The last six columns present Wald test statistics and p-values for the nulls that = $\{\alpha, \beta\}$ = {0,1}, $\{\alpha_x, \beta_x\}$ = {0,0} and $\{\alpha + \alpha_x, \beta + \beta_x\}$ = {0,1}. Boldfaced type denotes p-values less than 0.05, which reject the given null hypothesis. The final column is the regression R^2.

Exhibit 9: Does the futures price subsume the current LIBOR rate predictions?

month	α	β	α_x	β_x	γ	$\alpha + \alpha_x$	$\beta + \beta_x$	R^2
All	0.578	0.962	0.000	0.000	0.033	0.578	0.962	0.987
	(0.912)	(0.053)	(0.000)	(0.000)	(0.052)			
11	1.170	0.956	-7.619	0.081	0.033	-6.449	1.036	0.987
	(0.974)	(0.047)	(3.100)	(0.033)	(0.044)			

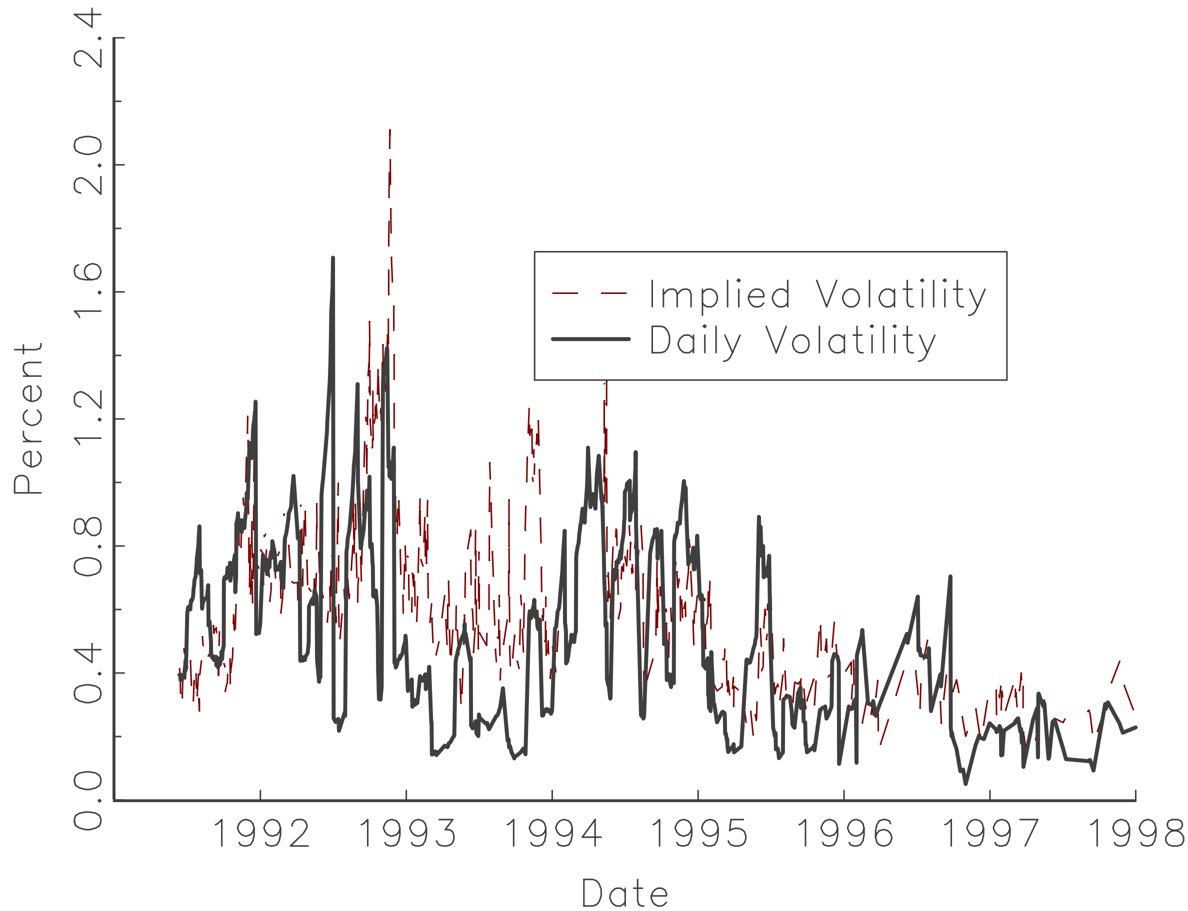
Notes: This table presents the results of estimating (5) by OLS and with Newey-West standard errors: $Settle_t = \alpha + \beta \cdot Close_t + I(month(t) = x) \cdot (\alpha_x + \beta_x \cdot Close_t) + \gamma(100 - LIBOR_t) + \varepsilon_t$. Row 1 shows the results constraining the coefficients to be the same for all 12 months of the year. Row 2, labeled 11 under the "month" column, shows the results permitting the November coefficients to differ from the coefficients in the other months of the year. The first four columns present the estimated coefficients from the regressions, with Newey-West standard errors in parentheses. The futures price subsumes the current LIBOR rate for the cases in which we fail to reject that γ equals 0.

Exhibit 10: Root-Mean-Squared Errors (RMSEs) of Several Forecasts of the Final Futures Price

	futures	(s.e.)	1-month spot	(s.e.)	forward	(s.e.)
Overall	0.183	(0.085)	0.266	(0.059)	0.247	(0.063)
November	0.273	(0.300)	0.426	(0.193)	0.357	(0.229)

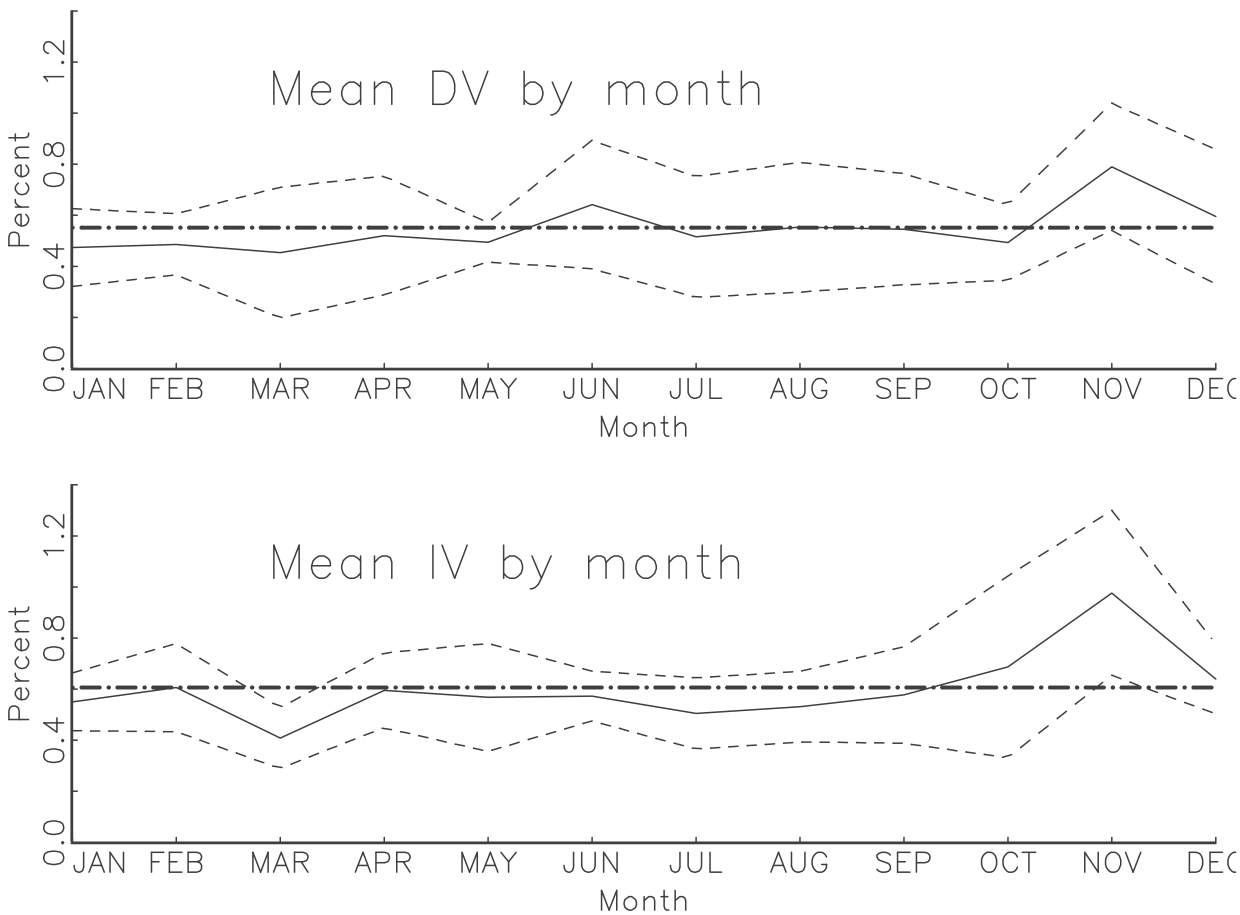
Notes: The first row of the table shows the overall RMSEs for three forecasts of final settlement prices, pooling over all months. The forecasts are the futures price, the 1-month LIBOR spot rate and the implied 30-day forward price from the previous month. The second row shows results for the November trading days (December final settlement). Standard errors were computed by the delta method.

Exhibit 11: DV and IV of the LIBOR futures contract



Notes: The figure plots daily volatility and IV of LIBOR futures until expiry from June 12, 1991, through 1997.

Exhibit 12: Mean DV and IV, by month



Notes: The figure shows mean annual DV and IV, by month, in percentage terms as well as a 2 standard-error band and the respective unconditional means.

Exhibit 13: Is IV an unbiased predictor of DV?

month	α	β	α_x	β_x	$\alpha + \alpha_x$	$\beta + \beta_x$	Stat 1	PV 1	Stat 2	PV 2	Stat 3	PV 3	R2
All	0.212	0.546			0.212	0.546	33.6	**0.000**					0.265
	(0.052)	(0.079)											
11	0.214	0.532	0.127	-0.068	0.341	0.464	11.970	**0.003**	0.564	0.754	22.215	**0.000**	0.269
	(0.072)	(0.136)	(0.195)	(0.210)	(0.000)	(0.000)							

Notes: This table presents the results of regression (7):

$$\sigma_{t,T}^{RV} = \alpha + \beta \sigma_{t,T}^{IV} + I(month(t) = x) \cdot \left(\alpha_x + \beta_x \cdot \sigma_{t,T}^{IV}\right) + \varepsilon_t \qquad (7)$$

where *I(month(t) = x)* is an indicator variable that takes on the value one for days in which the date *t* occurs during month *x*, zero otherwise. Row 1 shows the results constraining the coefficients to be the same for all 12 months of the year. Row 2, labeled 11 under the "month" column, shows the results permitting the November coefficients to differ from the coefficients in the other months of the year. The first four columns present the estimated coefficients from the regressions, with Newey-West standard errors in parentheses The last six columns present Wald test statistics and p-values for the nulls that = $\{\alpha, \beta\} = \{0,1\}$, $\{\alpha_x, \beta_x\} = \{0,0\}$ and $\{\alpha + \alpha_x, \beta + \beta_x\} = \{0,1\}$. Boldfaced type denotes p-values less than 0.05, which reject the null hypothesis.

Exhibit 14: Does IV subsume historical volatility forecasts?

month	α	β	α_x	β_x	γ	$\alpha + \alpha_x$	$\beta + \beta_x$	R^2
All	0.153	0.492			0.134	0.153	0.492	0.280
	(0.073)	(0.085)			(0.096)			
11	0.153	0.459	0.150	-0.063	0.150	0.303	0.395	0.287
	(0.085)	(0.144)	(0.190)	(0.199)	(0.098)			

Notes: This table presents the results of estimating (8) by OLS and with Newey-West standard errors:
$\sigma_{t,T}^{RV} = \alpha + \beta\,\sigma_{t,T}^{IV} + I(month(t) = x)\cdot\left(\alpha_x + \beta_x \cdot \sigma_{t,T}^{IV}\right) + \gamma\,\sigma_{t,T}^{HV} + \varepsilon_t$. Row 1 shows the results constraining the coefficients to be the same for all 12 months of the year. Row 2, labeled 11 under the "month" column, shows the results permitting the November coefficients to differ from the coefficients in the other months of the year. The first four columns present the estimated coefficients from the regressions, with Newey-West standard errors in parentheses. IV is said to subsume the information content of historical volatility— the annualized root 20-day moving average of futures returns—for the cases in which we fail to reject that γ equals 0. The final column is the regression R^2.

Endnotes:

[1] For example: see, Reinganum [1983] and Keim [1983] in stocks, Jordan and Jordan [1991] in bonds, Griffiths and Winters [2005a] in money markets, and Johnston, Kracaw, and McConnell [1991] and Fabozzi, Ma and Briley [1994] in derivatives.

[2] For example, see Spindt and Hoffmeister [1988], Griffiths and Winters [1995] and Hamilton [1996].

[3] The timing of the pattern suggests that money market investors plan their investment maturities to have cash available to meet year-end needs, which Griffiths and Winters describe as a year-end preferred habitat for liquidity (see Modigliani and Sutch [1966] for the development of the preferred habitat theory and Ogden [1987] for its application to T-bill yields).

[4] Crandell [2000] notes that the daily publishing of LIBOR by the BBA provides that necessary pricing transparency for a good benchmark rate and was crucial to the acceptance of LIBOR as a pricing standard. Crandell also notes that cash settlement of the CME LIBOR futures contract led to the contract's success.

[5] It is well known that demand for liquidity increases substantially in December (Ogden [1987]).

[6] Griffiths and Winters [2005a] examine one-month private-issue money market instruments and provide a detailed discussion of the expected pattern of interest rates across December. The year-end effect in one-month T-bills is also consistent with a preferred habitat for liquidity.

[7] The figure reproduces Figure 2 in Griffiths and Winters [2005a]. The data span June 1988 through June 2001. While the CME uses LIBOR rates to settle euro-dollar futures contracts, the LIBOR figures in Exhibit 1 are interbank rates, while the euro-dollar rates refer to retail deposit rates.

[8] Over the last two trading days of 1985 and 1986 the fed funds rate doubled. However, this year-end spike in the fed funds rate is not a common occurrence. For example, Kotomin and Winters [2005] find that for the years from 1994 through 2002 the fed funds rate declines on the last day of the year 8 of 9 years. Additionally, Demiralp, Preslopsky, and Whitesell [2004] note that the Fed has provided a generous supply of reserves at year-end in recent years. This is done to insure sufficient liquidity and thus prevent year-end rate spikes in the fed funds rate. We collected the monthly average fed funds rate from the Federal Reserve Bank of St. Louis FRED data base for our sample period and find that 11 of the 12 December averages is less than the preceding November average, which suggests that a lack of a rate increase across December in the fed funds rate.

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[9] Readers might be concerned about the size of the standard deviations cited. They are, however, the annualized standard deviation of daily rate changes relative to the interest rate in percentage terms. They are not directly comparable to the other Black/Scholes inputs, which are also described in percentage terms. For example, if the one-month-ahead interest rate is expected to be 6 percent, and the annualized standard deviation of interest rate changes is 22 percent, the normal approximation to the one-month ahead 95 percent confidence interval is $6 \pm 1.96 \cdot 0.22 \cdot 6/\sqrt{12} = \{5.25, 6.75\}$. While this confidence interval still appears wide, the normal approximation would probably be quite poor as rates frequently exhibit no change. For January through November the daily rate change is zero 50.49 percent of the time while during December the daily rate change is zero 31.64 percent of the time.

[10] This section examines the pricing of a generic interest rate option using the Black/Scholes formula, with LIBOR as the underlying interest rate. While the example prices options on interest rates, rather than the options on LIBOR futures contracts that we examine later in the paper, an example with the latter would make the same point. For example, the annualized daily volatility of the futures price for the contract underlying the option on LIBOR futures is about 50% larger for the contract that expires in December than the average for the contracts that expire in the other 11 months. And the mean rate rises over 40 basis points in December, relative to the rest of the year.

[11] We note that Jarrow and Turnbill [1996] discuss a volatility reduction factor for pricing options on Treasury bills. The reduction factor does not apply here because the LIBOR futures contract is for interest on a Euro-dollar time deposit, instead of a discount security, like a Treasury bill.

[12] We conduct a number of empirical tests that we do not report in the interest of brevity, but that are available upon request. The basic conclusion of these tests are that the year-end rate increase during December in one-month LIBOR is implied in November two-month LIBOR and, consistent with the unique nature of year-end one-month rate increase, the November difference between the implied forward rate and the one-month spot rate is significantly different from all other months.

[13] It is not generally possible to construct forward contracts that will provide an exact 30-day forward interval, starting at the future contract expiry. Consider constructing a one-month ahead forward rate to match the expiration of the December 2001, for example. The December futures contract expired on Monday, December 17, 2001. 30 days prior to that was Saturday November 17, 2001. A “30-day” contract expiring on December 17, 2001 would be entered into on Friday November 16, 2001 and would last 31 calendar days but the 60-day contract entered into on

November 16, 2001 would expire in exactly 60 days. Therefore the one-month ahead forward rate would be a 29-day forward rate. But the 30-day spot rate entered into on December 17, 2005 would be an exact 30-day rate.

[14] Futures contracts expire on Monday mornings in December so it is not usually possible to calculate the forward rate exactly 30-days ahead. The calculations were done with the closest forward/future pair to 30 days to expiry.

[15] The CME Eurodollar futures contract is similar in design to the CME LIBOR futures contract, but trades in significantly higher volume. Higher volume suggests more informative prices, which suggests that the Eurodollar futures contract might be a better choice of contract to study than the LIBOR futures contract. However, the Eurodollar futures contract is for a three-month time deposit instead of the one-month time deposit underlying the LIBOR contract. Griffiths and Winters [2005a] find a year-end rate increase across one-month private-issue money market securities and T-bills with one month until maturity, but do not find a year-end effect in T-bills with three-month until maturity. Griffiths and Winters [1997] find a year-end rate increase in one-month term repos, but not in three-month term repos. Accordingly, we believe it is more appropriate to examine the futures contract based on a one-month time deposit than a three-month time deposit. Thus, we chose to examine the LIBOR futures contract instead of the Eurodollar futures contract.

[16] The final settlement price for one-month LIBOR futures contracts is $F_t = 100 – R_t$, where R_t is the one-month LIBOR rate on the final settlement day. That allows us to back out the implied LIBOR from the futures price.

[17] This exercise was robust to an alternative specification in which the dependent variable was the difference between the one-month LIBOR rate and the federal funds target. Hamilton and Jorda [2002] discuss the behavior of the federal funds target rate. They show no evidence of a year-end effect in the target rate. Also, their Table 6 provides a complete history of the target rate from March 1, 1984, through April 1, 2001. Current target rates are available at http://www.federalreserve.gov/fomc/fundsrate.htm.

[18] Jordan and Jordan [1991] and Griffiths and Winters [2005a] also employ indicator variables for the first and last few days of the month.

[19] We note the November increase shown in Exhibit 7 is about 40 basis points (bp), which is similar in magnitude to the 36 bp (6.38 percent - 6.02 percent) difference between the December average LIBOR and the average LIBOR for the other eleven months found in the cash market data from Griffiths and Winters [2005a].

[20] We also note that the p-values for hypotheses 2 and 3 are low for January (0.08 and 0.06), though the tests are not strictly significant for that month at the usual 5 percent level.

[21] Mean DV until expiry does not equal the annualized standard deviation of log futures price changes because the former is a weighted sum of the latter, due to overlapping samples.

[22] We note that toward the end of our data period where the option contracts on LIBOR futures have very little volume there is substantial volume in the option contract on euro-dollar futures. While there are obvious differences between the LIBOR futures contract and euro-dollar futures contract (see endnote 14 for a discussion of the differences and why we chose the contract with less volume), both option contracts provide essentially that same hedging ability, so we inquired of the CME for a reason why the options volume has gone to the euro-dollar options and away from the LIBOR options. The CME knew of no structural or contractual reason why the euro-dollar option now receives the vast majority of the volume in interest rate options. The CME did suggest that, in interest-rate options, volume creates volume, so once the euro-dollar option created some volume it attracted more volume.

[23] Recall that the December rise in interest rates is associated with the fall in November futures prices.

[24] We note that one-month LIBOR begins its year-end rate increase at the end of November, but the rate increase occurs after the expiration of the November futures contracts.