Inverse maturity effects in short-term interest rate futures markets

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Abstract

This study examines the relation between futures volatility and contract's maturity. The negative covariance hypothesis predicts that the negative covariance between changes in carry costs and changes in spot prices is a key factor for observing the "maturity effect" (volatility increases as maturity approaches). In this framework, our study provides additional criteria to explain why, even when the negative covariance condition holds, an inverse maturity effect will be more likely to be observed. Moreover, when applied to the case of short term interest rate futures, it shows how changes in the futures volatility are linked with the term structure dynamics. To provide empirical evidence supporting our results, we analyze the behavior of the 3-month Eurodollar, Euribor, Short Sterling, and Euroyen futures contracts.

1 Introduction.

Understanding the dynamics of futures price volatility is important for several reasons. For example, clearinghouses set margin requirements on the basis of futures price volatility, so matching margins with volatility in an efficient way should be the aim of an adequate margin requirement policy. On the other hand, it is also important for hedging strategies, since such strategies seek to minimize price variability. Finally, volatility is a critical factor for pricing options and other derivatives.

This study investigates the relation between futures price volatility and the futures contract's time to expiration. Samuelson (1965) postulated that the volatility of futures prices should increase as the contract approaches expiration, a behavior which became known as the "maturity effect" or the Samuelson hypothesis. Numerous studies have investigated the Samuelson hypothesis empirically and, although the results are mixed, the hypothesis has been often supported in agricultural futures, but not in precious metals, energy or financial futures. Bessembinder, Coughenour, Seguin and Monroe Smoller (1996) attempted to provide an economic analysis that predicted why the maturity effect should be supported in some markets but not in others. Their hypothesis (negative covariance hypothesis, hereafter) states that the maturity effect is more likely to hold in markets that exhibit negative covariance between changes in spot prices and changes in net carry costs. Since such negative covariation will be more likely to hold for real assets but not for financial assets, they predict that the maturity effect is unlikely to hold in financial futures markets. The studies of Bessembinder et al. (1996) or Duong and Kalev (2008a), have provided empirical support to the negative covariance hypothesis, confirming that the negative covariance condition is a key factor for the maturity effect to hold. However, the results of Daal, Farhat and Wei (2006) provide weak evidence in favor of this hypothesis.

On the other hand, some studies have produced examples of financial futures presenting a significant inverse maturity effect (volatility decreasing as maturity approaches). In particular, this has been the case of the Nikkei index futures (Chen, Duan and Hung, 1999), the CME Eurodollar (Duong and Kalev, 2008a,b), and other short term interest rate futures (Daal, Farhat and Wei , 2006). Moreover, from the results of Daal, Farhat and Wei (2006), it follows that in many cases both the inverse maturity effect and the negative covariance condition hold at the same time. To the best of our knowledge, no explanation of this behavior has been given, despite the fact that, for negative covariance to have any predictive power at all, it is important to know how frequently negative covariance may hold when the inverse maturity effect has been observed.

The aim of this study is to reexamine the negative covariance hypothesis with the purpose of identifying additional information which may help to predict when, even under negative covariance, the inverse maturity effect would be more likely to hold. In particular, the study will focus on the the case of short-term interest rate (STIR's) futures and examine the link between futures volatility and the dynamics of the term structure.

To empirically test our results we will consider the four most actively traded STIR contracts: the 3-month Eurodollar futures contracts traded in the Chicago Mercantile Exchange (CME), the 3-month Euribor and the 3-month Short Sterling futures contracts, both traded in the London International Financial Futures and Options Exchange (LIFFE), and the Euroyen futures traded on the Tokio Financial Exchange (TFX).

Relative to the previous literature, the main contribution of this study is to identify the additional criteria needed to explain why, even when the negative covariance condition holds, the inverse maturity effect will be more likely to be observed. On the other hand, by focusing on the the particularities of interest rate futures, the analysis shows the relation between maturity effects and the dynamics of the term structure. More precisely, it explicitly provides a link between the maturity effect and the ratio between the spot volatility and the volatility at other points of the yield curve. Since this ratio changes depending on the behavior of the yield curve, the analysis explains why the same contract can show different volatility-to-maturity patterns when observed at different points in time. Finally, to empirically support the theoretical analysis, the study considers some futures contracts for which no studies of the presence of maturity effects have been previously reported.

Our findings show that, consistently with previous results, there is little evidence of maturity effects in most of the contracts. On the contrary, a significant inverse maturity effect prevails. However, in contracts maturing in 2008 and 2009, when the financial crisis was at its peak, this situation changed and the maturity effect was present in the Euribor, Eurodollar and Short Sterling contracts. With respect to the negative covariance hypothesis, almost all contracts in the sample exhibit negative covariance between changes in spot prices and changes in net carry costs. In particular, whenever the maturity effect is present, the negative covariance condition holds, as predicted by the negative covariance hypothesis. However, the negative covariance condition also holds when there is a significant inverse maturity effect, confirming that negative covariance is a poor predictor of when the maturity effect or its inverse will be observed. The results obtained provide support to the predicted relation between spot volatility and maturity effect. In particular, the coincidence between the presence of the maturity effect and an increase in the volatility of spot rates observed during the recent financial crisis is consistent with our analysis.

The rest of the article is organized as follows. The next section briefly reviews the existing literature. Section 3 describes the data and the methodology employed. Section 4 reports and discusses the results obtained, and concluding remarks are given in the last section.

2 Previous studies

The dynamics of futures price volatility has been studied in the literature from very different perspectives. Specifically, the relationship between the futures price volatility and time to maturity was first modeled by Samuelson (1965), who predicted that futures volatility should increase when contracts approach expiration. This relation is commonly referred to as the Samuelson hypothesis or the maturity effect. The intuition behind this prediction is that when there is a long time to the maturity date, little is known about the future spot price for the underlying. Therefore, futures prices react weakly to the arrival of new information (e.g. commodities supply and demand) since our view of the future will not change much with it. As time passes and the contract approaches maturity, the futures price is forced to converge to the spot price, so it tends to respond more strongly to new information.

The example used by Samuelson to present the hypothesis relies on the assumptions that futures price equals the expectation of the delivery date spot price, and that spot prices follow a stationary, first-order autoregressive process. However, Rutledge (1976) argued that alternative specifications of the generation of spot prices are equally plausible and may lead to predict that futures price variation decreases as maturity approaches (an "inverse" maturity effect). In response to this, Samuelson (1976) provides arguments on why volatility can momentarily reverse its direction in a general increasing pattern of price variability and obtains a weaker result: if delivery is sufficiently distant then the variance of the futures prices will necessary be less than the variance when contracts are near to maturity.

Anderson and Danthine (1983) contributed to the theoretical debate proposing that the increase or decrease of futures price volatility towards expiration depends on the pattern of information flow into the market. Their hypothesis, named the state variable hypothesis, establishes that the variability of futures prices is systematically higher in those periods when relatively large amounts of supply and demand uncertainty are resolved, i.e. during periods in which the resolution of uncertainty is high. Within this context, the Samuelson hypothesis would be a special case in which the resolution of uncertainty is systematically greater near contract maturity.

Bessembinder et al. (1996) introduced a different framework to explain the relation between volatility and time to maturity. According to their model, neither the clustering of information flow near delivery dates nor the assumption that each futures price is an unbiased forecast of the delivery date spot price is a necessary condition for the success of the hypothesis. Instead, the maturity effect requires negative covariation between spot returns and changes in futures cost of carry (the futures "term slope"). Since such negative covariation will be observed primarily in markets where there are convenience yields that display inter-temporal variation, they predict that the Samuelson hypothesis is unlikely to hold in financial futures markets. They test their predictions using data from agricultural, crude oil, metals and financial futures, and they obtain strong empirical supporting evidence for their model.

Empirical research came along with theoretical models, applying different methods to investigate the existence of the maturity effect and considering a wide range of futures contracts and markets. Results are mixed, but the most frequent outcome is that the maturity effect is strongly present in agricultural futures but it is statistical insignificant, or non-existent at all in metals and financial futures. See, for example, Milonas (1986), Grammatikos and Saunders (1986), Barnhill, Jordan and Seale (1987), Khoury and Yourougou (1993), Galloway and Kolb (1996), Hennessy and Wahl (1996), Han, Kling and Sell (1999), Chen, Duan and Hung (1999), Moosa and Bollen (2001), or Aragó and Fernández (2002). On the other hand, some results have also found evidence supporting the state variable hypothesis (Barnhill, Jordan and Seale, 1987), while others conclude that seasonality may be more important than maturity in explaining the patterns of the variances of futures price changes (Anderson, 1985).

Even if the research has mainly focused in detecting the presence of the maturity effect, the studies have also produced cases of volatility decreasing as the contract is closer to maturity. This inverse effect seems to be an exclusive behavior of financial futures. For example, Chen, Duan and Hung (1999) found that, contrary to Samuelson hypothesis, volatility of the Nikkei Index futures contracts decreased as maturity approached. More recently, Daal, Farhat and Wei (2006) examine 6,805 contracts from 61 commodities during the 80s and 90s, testing for the presence of maturity effect and for the negative covariance hypothesis. Their results show strong maturity effects in agricultural futures, but they also show significant inverse maturity effects in short term interest rate futures (Eurodollar and 1-month Libor) and other financial futures. Unfortunately, they test the negative covariance hypothesis only for currency futures as representatives of financial futures, so it is difficult to assess the relation between inverse maturity and negative covariance. Finally, Duong and Kalev (2008a,b), using intraday data from different futures markets, find strong support for the Samuelson hypothesis in agricultural futures and show that the hypothesis does not hold for other futures contracts. In particular, in Duong and Kalev (2008a) a significant inverse maturity effect is observed in three of the seven financial futures included in the sample (Eurodollar, E-mini S&P500 and E-mini Nasdaq), while in Duong and Kalev (2008b) the inverse effect is again observed in the only financial futures included in the sample (Eurodollar). By estimating the sign of the covariance between spot returns and net carry costs, Duong and Kalev (2008a) provide supporting evidence that the negative covariance hypothesis is the key factor for the empirical support of the Samuelson hypothesis.

3 Maturity effect in interest rate futures

3.1 The negative covariance hypothesis

Let F_t denote the price of the futures contract and let S_t be the price of the underlying asset at time t. If $E_t[-]$ denotes the conditional expectation at time t, then the unexpected rate of spot price appreciation v_t is defined as $v_t \equiv \ln(S_{t+1}) - \ln(E_t[S_{t+1}])$. Following Bessembinder et al. (1996), in the framework of the cost-of-carry model with variable cost of carry, the variance of futures price changes can be expressed as

$$\mathrm{Var}(\Delta F_t) = m_t^2 \mathrm{Var}(\Delta c_t) + 2m_t \mathrm{Cov}(v_t, \Delta c_t) + \mathrm{Var}(v_t) \tag{1}$$

where, for each contract, m_t is the time left to maturity at time t, v_τ is the unexpected rate of spot price appreciation, Var and Cov denote variance and covariance respectively, and $\Delta c_t = c_t - c_{t-1}$ is the change in the net carry cost

$$c_t = \frac{\ln(F_t) - \ln(S_t)}{m_t}. \tag{2}$$

Considering Equation (1), Bessembinder et al. (1996) argue that the maturity effect cannot rely on time variation of $\mathrm{Var}(v_t)$, because this would imply spot variance increasing every time a contract expiration date approaches. Hence, they conclude that the Samuelson hypothesis is more likely to be supported when $\mathrm{Cov}(v_\tau, \Delta c_\tau) < 0$ (negative covariance condition), since only when this condition holds it is reasonable to expect that the variance $\mathrm{Var}(\Delta F_t)$ may increase as m_t decreases.

3.2 Additional conditions

Recent studies like those of Duong and Kalev (2008a,b) have found that for those assets where maturity effects were observed the negative covariance condition holds, providing supporting evidence for the negative covariance hypothesis. However, from the results reported in Daal, Farhat and Wei (2006) and also from the results obtained in this study, it follows that the negative covariance hypothesis may equally hold when the inverse maturity effect is predominant. This implies that, although there is a high probability of observing negative covariance, conditional on the presence of the maturity effect (as implied by the negative covariance hypothesis), the probability of observing negative covariance conditional on the presence of an inverse maturity effect may also be high. This would mean that negative covariance is a poor predictor of when the maturity effect or its inverse will be observed. Thus, to increase the discriminatory power of the model, additional conditions should be introduced.

Assuming the negative covariance condition and considering $\mathrm{Var}(\Delta F_t)$ as a function of m_t, Equation (1) represents a parabola that attains its minimum value

$$\mathrm{Var}(\Delta F_t)_{\min} = \mathrm{Var}(v_t) - \frac{\mathrm{Cov}(v_t, \Delta c_t)^2}{\mathrm{Var}(\Delta c_t)} \tag{3}$$

at the point

$$\widehat{m} \equiv -\frac{\mathrm{Cov}(v_t, \Delta c_t)}{\mathrm{Var}(\Delta c_t)} > 0. \tag{4}$$

If we consider the distance

$$D \equiv \mathrm{Var}(v_t) - \mathrm{Var}(\Delta F_t)_{\min} \tag{5}$$

then the slope $-D/\widehat{m} = \mathrm{Cov}(v_t, \Delta c_t)$ is a measure of the rate of growth of $\mathrm{Var}(\Delta F_t)$ as maturity approaches. In principle, the larger the negative value of this ratio, the stronger the maturity effect will be. However, $\widehat{m}$ is also a key parameter in predicting whether the maturity effect or its inverse are more likely to be observed. It may be interpreted as the point in time when the relation between futures price volatility and time to maturity changes sign, with the volatility beginning to increase as maturity approaches. Hence, even when the slope $-D/\widehat{m}$ is (negatively) large, if $\widehat{m}$ is small then the inverse effect will be more likely to hold.

3.3 Maturity effect and term structure dynamics

We now explore the relation between $\widehat{m}$ and spot volatility. Let ρ_{vc} be the correlation coefficient between v_τ and Δc_t and denote by $\sigma(v_t)$ and $\sigma(\Delta c_t)$ the corresponding standard deviations. Then

$$\widehat{m} = -\rho_{vc}\frac{\sigma(v_t)}{\sigma(\Delta c_t)} \tag{6}$$

Hence, having a large $\widehat{m}$ will depend on having a spot volatility many times larger than the cost-of-carry volatility. This highlights some of the particularities of interest rate futures when considering maturity effect. In the case of commodities, for example, where the negative covariance condition usually holds, the cost-of-carry volatility tends to be of smaller magnitude, or even negligible, compared to the volatility of the underlying. As a consequence, $\widehat{m}$ can be large enough to allow the maturity effect to be observed. However, in the case of interest rate futures, both volatilities in Equation (6) are linked by the dynamics of the term structure, and they may be of similar magnitude. As a consequence, even when there is evidence of large negative covariance, the values of $\widehat{m}$ can be small enough so that the inverse maturity effect will be more likely to be observed.

4 Data and Methodology

To empirically test the previous arguments, the study considers four of the most traded short-term interest rate future contracts worldwide: 1) The 3-month Eurodollar futures contract, introduced by the Chicago Mercantile Exchange (CME) and currently the most actively traded interest rate futures contract in the world, 2) the 3-month Sterling (Short Sterling) and 3) the 3-month Euribor, which are the most liquid Sterling and Euro STIR futures contracts worldwide, and 4) The 3-month Euroyen futures contract traded in the Tokio Financial Exchange (TFX).

The four contracts have similar characteristics. All of them are cash settled to 100 minus their respective reference rate. In the case of the Eurodollar, the reference rate is the 3-month U.S. Dollar Libor published by the British Bankers Association (BBA). For the Euribor contract it is the European Bankers Federation Euribor Offered Rate (EBF Euribor) for 3-month Euro deposits. For the Sterling deposits it is the British Bankers Association London Interbank Offered Rate (BBA Libor), and for the Euroyen it is the 3-month Tokio Interbank Offered Rate (Tibor) determined by the Japanese Banking Association (JBA). Additionally, all four contracts have quarterly maturity months (March, June, September and December), extending for long periods (10 years in the case of Eurodollar). And finally, all contracts are traded electronically. The particular features of each contract are summarized in Table I.

For each of the four STIR futures contracts, the study considers daily settlement prices, daily highs and lows, and daily trading volume for the 30 contracts expiring quarterly between March 2002 and June 2009. These data, together with the spot 3-month USD Libor, Libor, Tibor and Euribor rates were obtained from Datastream. Since, for the majority of contracts, trading volume is thin in periods of more than 24 months before maturity, the sample used for each futures contract includes only the 24 months preceding its expiration. On the other hand, to avoid abnormal price variability, we will follow the usual practice of excluding the expiration month from the analysis. The result is a data set of 120 futures contracts with 500 daily settlement prices each.

The study considers the logarithmic returns

$$\Delta F_t = \ln(F_t/F_{t-1}) \tag{7}$$

where F_t denotes the futures settlement price on calendar day t.

Spot annual rates y_t will be converted to notional prices S_t as

$$S_t = 100 - y_t \tag{8}$$

where y_t is the corresponding 3-month reference rate at time t.

Tables II and III present summary statistics for the price changes ΔF_t. All contracts are leptokurtic and in all cases the Bera-Jarque statistic rejects the hypothesis of normality. There are clearly-defined periods where negative or positive skewness prevail. The Ljung-Box Q-statistic for autocorrelation (with 20 lags) shows little evidence of autocorrelation in the series. The tables also include the results for the Engle (1982) LM-test for an autoregressive conditional heteroscedasticity (ARCH) effect. With a 1% confidence level, only all contracts maturing before September 04 or after March 2008 show significant evidence of ARCH effects.

For each futures series there is a corresponding series of contemporaneous spot rates and, applying Equation (8), a series of contemporaneous notional spot prices.

As in Rutledge (1976) or Bessembinder et al. (1996), daily variability is measured using the absolute value of the logarithmic rate changes. That is,

$$\sigma(F)_t = |\ln(F_t/F_{t-1})| \tag{9}$$

for the case of futures contracts.[1] Analogous expressions hold for spot changes volatility $\sigma(S)_t$.

[1] The analysis was also performed using as a measure of daily volatility the realized daily range

$$\sigma(F)_t = \ln(H_t) - \ln(L_t)$$

where H_t and L_t are the high and low prices on day t. The results obtained were qualitatively the same.

5 Results and Discussion

5.1 Estimates of time-to-maturity effects on volatility

The first step in the analysis consists, for each individual contract, of a linear regression of the contract's daily volatility $\sigma(F)_t$ on the number of days m_t remaining to expiration, as specified by the model

$$\sigma(F)_t = \alpha + \beta m_t + u_t, \tag{10}$$

where u_t are the disturbances. If the maturity effect is present, the coefficient β should be negative and statistically significant.[2]

Table IV reports results of the above regressions (10).[3] In the case of the Eurodollar futures, only four of the contracts expiring in 2008 and 2009 show time to maturity coefficients which are negative and significantly different from zero, as predicted by the Samuelson hypothesis. On the other hand, from 2003 to the end of 2007, all the beta coefficients are positive and significant, providing evidence of an inverse maturity effect, i.e. volatility decreases as maturity approaches.

In the case of Euribor and Short Sterling, the similarities with the Eurodollar are remarkable. From 2003 to the end of 2007, both contracts show positive and significant beta coefficients, providing evidence of a strong inverse maturity effect. But in few individual contracts, most of them maturing in 2008 and 2009, there is evidence of the maturity effect. Finally, the Euroyen preents a different pattern, with almost all contracts showing positive and significant time to maturity coefficients through all the period under consideration and a one contract (Dec05) showing evidence of the maturity effect.

[2]A GARCH(1,1) model with time-to-maturity as an exogenous variable was also tested for each contract. However, in agreement with the results of the LM-test reported in Tables II and III, only in a few cases did the model appear to be appropriate.

[3]All the regression estimates in this study were obtained using using (Newey and West, 1987) heteroscedasticity consistent estimation.

5.2 Effect of controlling for variation in information flow

To test the effects of information flow, the above analysis was also performed including spot volatility as a regressor, following the procedure used in Bessembinder et al. (1996). If information flow is not the main explanation of the Samuelson hypothesis, the coefficient on the days to maturity variable should remain negative and significant.

Tables V and VI reports results of individual regressions of the daily volatility estimates on the days to maturity and on spot volatility. Compared with the results above, the inclusion of the spot price volatility has little effect on the estimates and significance of the coefficients of the time to maturity variable. Therefore, changes in the rate of information flow are not the main determinant for the empirical support of the maturity effect hypothesis, contrary to the suggestion of Anderson and Danthine (1983). Furthermore, the spot volatility is only statistically significant in very few cases, showing that, in general, it is not a relevant factor in explaining futures volatility.

5.3 Robustness tests

For the robustness of the results, it is convenient to examine the potential effects of volume trading on the relation between futures price volatility and time to maturity. In other words, the question remains of whether the finding of a decline in futures price volatility close to the expiration of the futures contract is not just reflecting the decline in trading volume. At first sight this should not be the case, since the last four weeks of the contract have been excluded from the analysis and also because volume patterns differ greatly between contracts with different expiration dates and also between the different contracts considered.

To test for the effects of volume we run the regression (10) including the daily trading volume for each of the contracts as control variable. The results, not included here but available from the authors, show that although volume is significant in many contracts in very few cases where an inverse maturity effect was previously observed the effect changes after including the volume variable. Thus, we conclude that the decline in futures price volatility as maturity approaches is not driven by the level of trading volume.

5.4 Negative covariance

We now examine the negative covariance hypothesis of Bessembinder et al. (1996), which states that the maturity effect is more likely to be supported in markets that exhibit negative covariance between spot price changes and changes in net carry costs.

Following Bessembinder, Coughenour, Seguin and Monroe Smoller (1995) and Duong and Kalev (2008a), the negative covariance condition is tested for each contract by performing the following regressions

$$\Delta c_t = \omega_0 + \omega_1 \Delta S_t + \varepsilon_t \tag{11}$$

where ΔS_t are the changes in the spot log-prices. The results on Table VII show that the ω_1 coefficients are negative always and significant for almost all of the contracts. In other words, the negative covariance condition ($\omega_1 < 0$) in itself has low power to predict if the maturity effect or its inverse will be observed. This confirms that additional criteria are needed to predict when the maturity effect or its inverse are more likely to hold. To empirically support this argument, Figures 1 and 2 show the estimated values of $\widehat{m}$ and of the slopes $-D/\widehat{m}$ for each of the contracts.[4] Since we have assumed that $m_t \geq 20$ (see Section 3.4), then we should expect that when $\widehat{m}$ is not sufficiently greater than 20, the inverse maturity effect should prevail. A comparison with the results summarized in Table IV confirms that low values of $\widehat{m}$ coincide with the dilution of the maturity effect or with the prevalence of the inverse effect. Even in those cases which exhibit large negative covariance (for example, in Dec 02 contract), there may be no evidence of a significant maturity effect, coinciding with a relatively low value of $\widehat{m}$ ($\widehat{m} = 18$ in the example).

The above analysis suggests that the sharp increase in the spot volatility observed from September 2007 onwards in the Libor, U.S. Dollar Libor, and Euribor rates (see Figure

[4] The values of $\text{Cov}(v_\tau, \Delta c_\tau)$ are estimated using the relation $\Delta S_\tau = c_\tau + \pi + v_\tau$, where π is a constant representing a risk premium (see Bessembinder et al. (1996)).

3) could be a key factor explaining the appearance of the maturity effect in 2008 and 2009 in the Eurodollar, Euribor and Short Sterling contracts. Indeed, this is supported by the fact that the Euroyen future is the only one of these contracts in which there is no maturity effect, coinciding with no significant increase in volatility in its reference rate.

6 Conclusion

This study examines the dynamics of volatility of interest rate futures as maturity approaches in the framework of the negative covariance hypothesis of Bessembinder et al. (1996). Based on the premises of this hypothesis, we introduce an additional parameter that explains why, even when the negative covariance condition holds, the maturity effect may not be observed or may even be replaced by the inverse effect. The theoretical analysis predicts that, even if the negative covariance condition holds, the inverse maturity effect will be more likely to be observed if spot volatility is not sufficiently larger than the cost-of-carry volatility. Since, in the case of interest rate futures, the cost of carry, the spot rate and the futures rate are all linked by the term structure, the analysis explicitly links the maturity effect with the dynamics of the term structure.

The theoretical arguments are tested empirically by considering four short term interest rate future contracts. Results of individual regressions show that the usual maturity effect, as defined by the Samuelson hypothesis, was present in some Eurodollar, Euribor and Sterling futures but almost only in 2008 and the first quarter of 2009, coinciding with the financial crisis. For the rest of the contracts, there is evidence of the inverse effect: volatility decreases as maturity approaches. These results are robust after controlling for trading volume and spot volatility.

The empirical evidence shows that, even if the negative covariance condition holds, the inverse maturity effect will be more likely to be observed if spot volatility is not sufficiently larger than the cost-of-carry volatility, as predicted by the model. In particular, the coincidence between the presence of the maturity effect and an increase in the volatility of spot rates observed during the recent financial crisis is consistent with our analysis.

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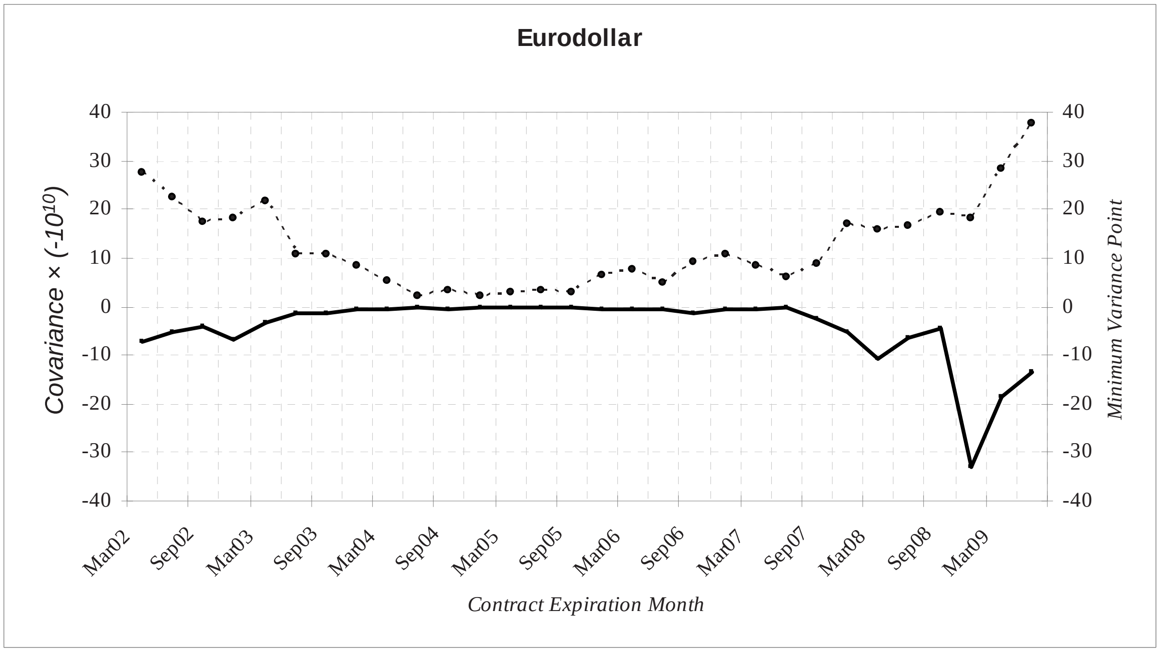
Table I: STIR futures contract characteristics

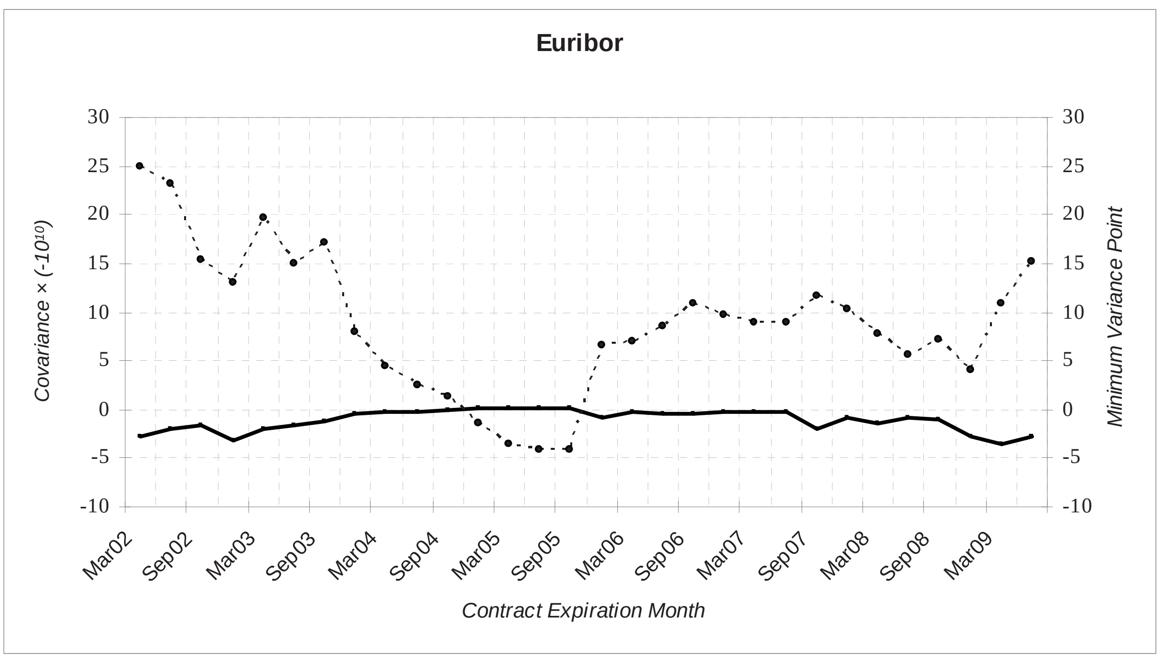
	CME Eurodollar	**NYSE Liffe Euribor**	**Liffe Short Sterling**	**TFX Euroyen**
Underlying instrument	Eurodollar three month deposit	Euro three month deposit	Sterling three month deposit	Euroyen three month deposit
Principal	USD $ 1,000,000	€1000000	£500,000	¥100,000,000
Price quote	100 - rate of interest	100 - rate of interest	100 - rate of interest	100 - rate of interest
1 basis point =	$25	€25	£12.50	¥2,500
Contract Months available for trading	40 quarterly months (Mar, Jun, Sep, Dec) and 4 nearest serial expirations	24 quarterly months (Mar,Jun, Sep, Dec) and 4 nearest serial expirations	24 quarterly months (Mar, Jun, Sep, Dec) and 2 and 2 nearest serial expirations	20 quarterly months (Mar, Jun, Sep, Dec) and 2 serial expirations
Last trading day	Two business days prior to the third Wednesday of the delivery month	Two business days prior to the third Wednesday of the delivery month	Third Wednesday of the delivery month	Two business days prior to the third Wednesday of the delivery month
Final settlement	Cash settled to 100 minus BBA three month U.S. Dollar Libor	Cash settled to 100 minus EBF three month Euribor	Cash settled to 100 minus BBA Libor for 3-month Sterling deposits	Cash settled to 100 minus JBA Tibor for 3-month Euroyen deposits
*Traded Volume in 2008**	596,974,081	228,487,462	104,572,875	22,372,133

This table summarizes the particular features of the futures contracts under consideration, as specified by the CME, NYSE Liffe and TFX exchanges.

* According to the Futures Industry Association Annual Volume Survey 2008.

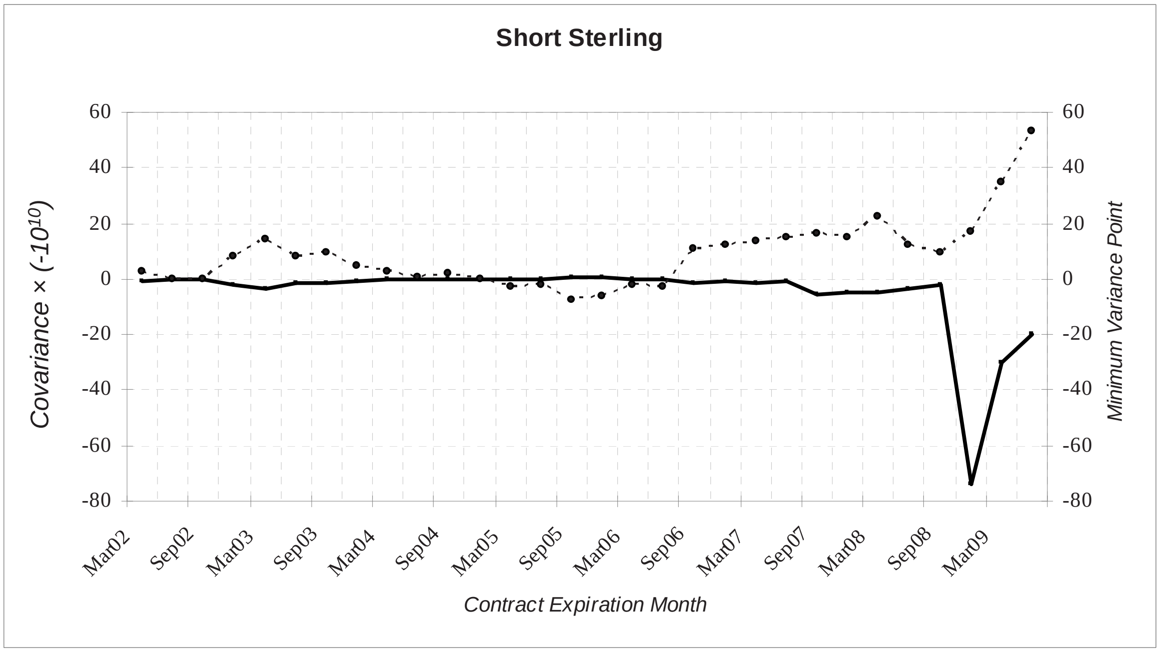
Figure 1: Covariance and minimal variance points for the Eurodollar and Euribor contracts

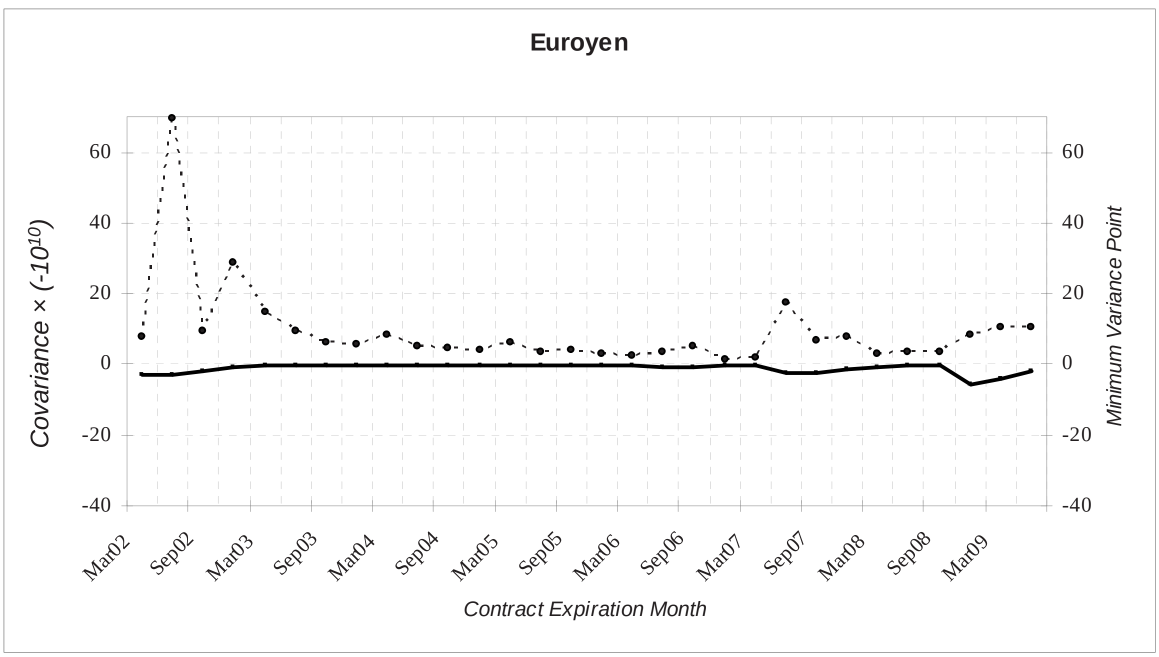




For each contract, points in the continuous line represent the covariance between rates in unexpected spot price appreciation and changes in net carry costs, $\mathrm{Cov}(v_t, \Delta c_t)$, multiplied by 10^{10}. Points in the dotted line correspond to the points $\widehat{m}$ of minimal variance.

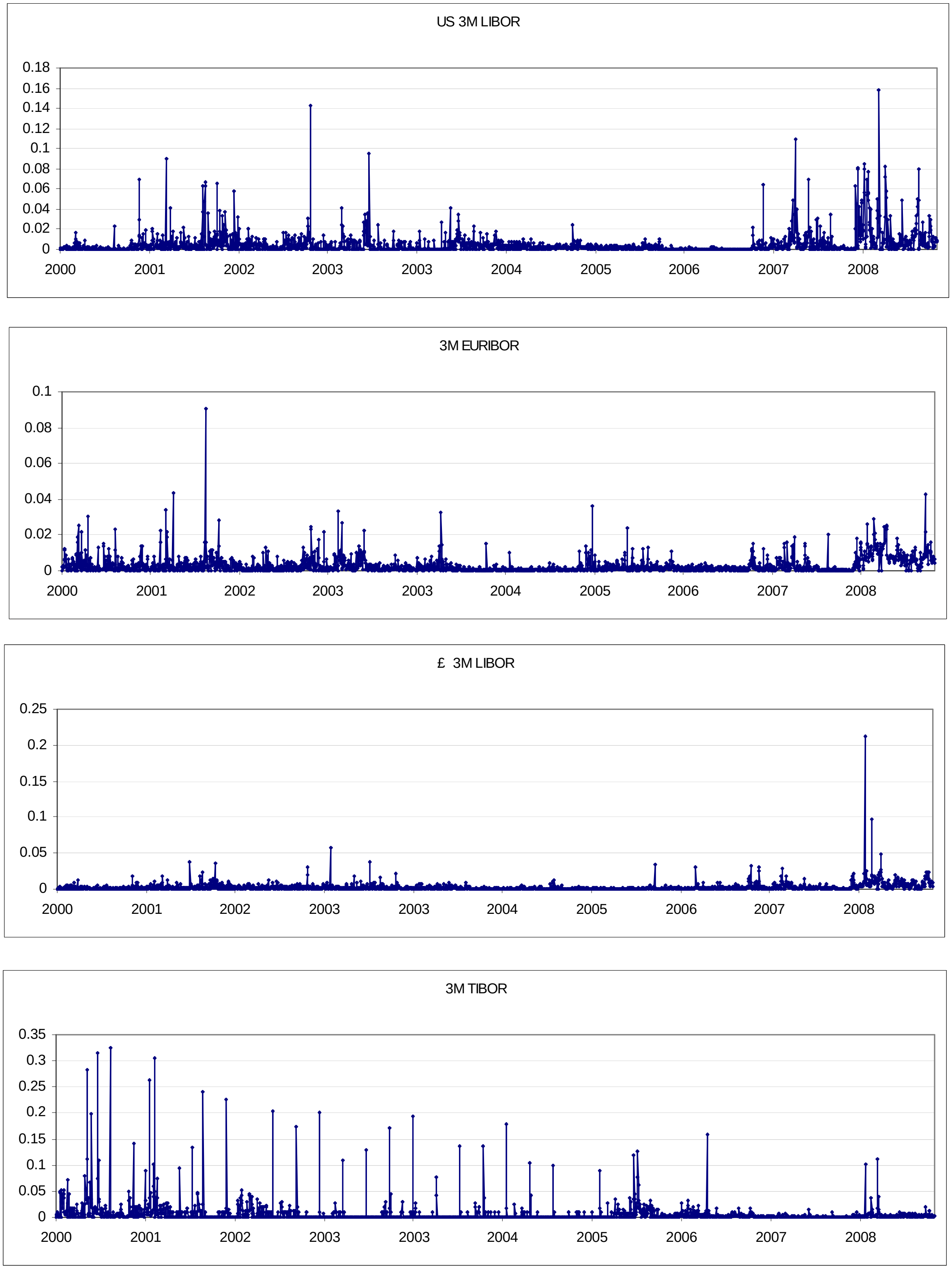
Figure 2: Covariance and minimal variance points for the Short Sterling and Euroyen contracts





For each contract, points in the continuous line represent the covariance between rates in unexpected spot price appreciation and changes in net carry costs, $\mathrm{Cov}(v_t, \Delta c_t)$, multiplied by 10^{10}. Points in the dotted line correspond to the points $\widehat{m}$ of minimal variance.

Figure 3: Volatility of daily spot rate changes



For each of the reference spot rates, volatility is measured as the absolute value of spot rate daily logarithmic differences from January 2000 to June 2009

Table II: Descriptive statistics for CME Eurodollar and Liffe Euribor futures contracts daily price changes

Contract	CME Eurodollar							Liffe Euribor						
Month	*Mean*	*S.D.*	*Skewness*	*Kurtosis*	*JB*	*Q(5)*	*ARCH*	*Mean*	*S.D.*	*Skewness*	*Kurtosis*	*JB*	*Q(5)*	*ARCH*
Mar02	0.03**	0.0109	0.088	4.49	46.9**	23.1	26.3**	0.01	0.0077	-0.399	5.24	117.5**	15.8	3.77
Jun02	0.03**	0.0114	-0.082	4.95	79.7**	21.49	27.81**	0.01	0.0075	-0.543	5.89	199**	18.97	22.08**
Sep02	0.03**	0.0125	-0.332	5.32	121.2**	26.79	37.33**	0.01	0.0079	-0.749	6.30	274.1**	25.84	37.4**
Dec02	0.02*	0.0134	-0.462	5.01	101.8**	23.05	44.99**	0.01	0.0085	-0.765	5.48	177.2**	24.85	36.7**
Mar03	0.02*	0.0136	-0.601	5.20	130.6**	26.59	47.30**	0.01	0.0086	-0.848	5.52	192.7**	25.74	32.74**
Jun03	0.02*	0.0135	-0.521	5.18	121.5**	40.20**	65.98**	0.01*	0.0087	-0.848	5.85	229.1**	27.69	25.26**
Sep03	0.02*	0.0133	-0.474	5.21	120.6**	43.17**	69.96**	0.01	0.0085	-0.756	5.47	175**	33.5*	21.72**
Dec03	0.02**	0.0119	-0.233	4.75	68.1**	36.19*	74.47**	0.01*	0.0077	-0.508	5.08	111.4**	25.02	7.24
Mar04	0.02**	0.0115	-0.279	4.62	60.9**	31.31	52.44**	0.02**	0.0076	-0.663	5.16	133.8**	18.71	4.86
Jun04	0.02*	0.0123	-0.279	4.47	51.8**	42.91**	23.34**	0.01*	0.0084	-0.772	5.39	168.5**	19.9	5.91
Sep04	0.01	0.0125	-0.284	4.83	76.6**	38.35**	12.65*	0.01	0.0087	-0.758	5.57	185.8**	20.55	16.65**
Dec04	0.01	0.0133	-0.161	5.08	92.6**	32.70*	12.39*	0.01	0.0090	-0.792	5.87	223.9**	22.92	22.36**
Mar05	0.00	0.0135	-0.025	5.46	125.7**	31.56*	9.65	0.01	0.0090	-0.689	5.78	200.8**	26.10	17.70**
Jun05	−0.01	0.0134	-0.088	6.43	245.1**	30.42	11.52*	0	0.0086	-0.724	5.99	230.2**	34.63*	19.93**
Sep05	0.00	0.0116	0.086	7.27	379.8**	22.15	1.10	0.01	0.0073	-0.590	6.41	271.4**	54.41**	9.30
Dec05	0.00	0.0108	0.096	8.17	558.1**	22.36	2.62	0.01	0.0067	-0.433	6.50	270.3**	60.72**	10.55
Mar06	−0.01	0.0101	0.020	8.59	650.3**	26.98	5.60	0	0.0064	-0.479	5.84	186.6**	36.85*	11.36*
Jun06	0.00	0.0087	0.598	7.08	376.6**	26.78	7.37	0	0.0059	0.071	4.42	42.2**	17.77	7.27
Sep06	−0.01	0.0078	0.195	4.46	47.6**	25.11	8.85	0	0.0056	0.099	4.21	31.1**	16.38	11.72*
Dec06	−0.01	0.0074	0.247	4.14	32.2**	22.42	14.91*	0	0.0054	0.111	4.44	44**	24.04	14.40*
Mar07	0.00	0.0074	0.220	3.93	21.9**	23.3	14.96*	0	0.0054	0.189	4.65	59.7**	18.92	13.03*
Jun07	−0.01	0.0073	0.331	4.31	45.0**	24.09	10.98	−0.01*	0.0054	0.365	5.20	111.7**	18.19	11.62*
Sep07	0.00	0.0074	0.298	5.07	96.4**	21.85	9.83	−0.01*	0.0053	0.432	5.62	158.9**	21.58	12.72*
Dec07	0.00	0.0084	0.425	5.08	104.9**	29.00	12.27*	−0.01*	0.0055	0.426	5.14	110.8**	22.35	11.68*
Mar08	0.01	0.0100	1.103	9.60	1008.2**	31.74*	13.64*	0	0.0060	0.216	5.49	133.2**	16.61	19.88**
Jun08	0.01	0.0110	0.541	6.79	323.5**	31.08	33.11**	−0.01	0.0069	0.332	5.86	179.8**	22.85	32.11**
Sep08	0.01	0.0116	-0.001	5.04	86.7**	27.39	41.35**	−0.01	0.0079	-0.255	7.70	466.3**	30.53	15.70**
Dec08	0.01	0.0143	-0.248	4.99	87.6**	45.73**	49.34**	0	0.0096	0.085	8.06	534.6**	53.83**	37.38**
Mar09	0.02	0.0157	-0.051	5.32	112.6**	28.79	24.27**	0.01	0.0108	0.046	6.14	205.5**	51.51**	31.42**
Jun09	0.02*	0.0168	-0.084	6.12	203.6**	27.67	32.56**	0.02*	0.0112	-0.195	5.18	102.3**	37.98**	37.87**

This table reports the statistics of the daily log-price changes of the individual futures contracts over 500 days before expiration month. Mean and standard deviation (S.D.) are annualized. JB is the Jarque-Bera statistic for testing the null hypothesis of normal distribution. $Q(5)$ is the Ljung-Box Q-statistic for autocorrelation (5 lags). ARCH is the LM-statistic of autoregressive conditional heteroscedasticity effect with 5 lags. * and ** indicate significance at 5% and 1% levels, respectively.

Table III: Descriptive statistics for Liffe Short Sterling and TFX Euroyen futures contracts daily price changes

Contract	Liffe Short Sterling							TFX Euroyen						
Month	*Mean*	*S.D.*	*Skewness*	*Kurtosis*	*JB*	*Q(5)*	*ARCH*	*Mean*	*S.D.*	*Skewness*	*Kurtosis*	*JB*	*Q(5)*	*ARCH*
Mar02	0.02*	0.0089	-0.562	5.94	206.4**	17.33	14.31*	0.01	0.0106	0.129	219.05	972443.3**	107.37**	205.61**
Jun02	0.01	0.0096	-0.820	6.51	312.2**	29.95	13.18*	0.01*	0.0026	0.098	18.08	4739**	20.12	83.06**
Sep02	0.01	0.0104	-0.942	6.54	334.9**	36.99*	14.83*	0.01	0.0102	0.367	232.56	1097859.3**	122.33**	205.13**
Dec02	0.01	0.0108	-0.820	5.84	224.2**	31.3	14.03*	0.01**	0.0019	0.315	13.57	2337.8**	34.26*	74.36**
Mar03	0.01	0.0109	-0.697	5.43	164.0**	23.7	8.85	0.00	0.0015	-0.224	7.84	491.7**	52.28**	111.08**
Jun03	0.01	0.0107	-0.603	5.40	150.1**	22.73	7.98	0.00	0.0012	0.016	11.41	1472.6**	28.01	76.38**
Sep03	0.01	0.0102	-0.484	5.26	126.1**	21.5	8.08	0.00	0.0015	2.121	68.04	88508.3**	66.36**	115.29**
Dec03	0.01	0.0094	-0.218	4.75	67.7**	18.71	3.19	0.00	0.0029	0.974	70.75	95698.8**	142.95**	184.19**
Mar04	0.01	0.0094	-0.515	5.27	129.1**	27.82	6.39	0.00	0.0012	-1.796	17.87	4878.0**	28.72	34.14**
Jun04	0.00	0.0098	-0.678	5.51	169.1**	35.47*	12.28*	0.00	0.0013	-1.001	16.87	4091.4**	26.3	66.1**
Sep04	0.00	0.0097	-0.755	6.05	241.8**	34.46*	24.56**	0.00	0.0018	-0.959	21.93	7539.1**	31.72*	52.15**
Dec04	0.00	0.0096	-0.786	6.44	297.2**	33.66*	31.07**	0.00	0.0022	-1.827	23.53	9057.7**	40.96**	50.6**
Mar05	0.00	0.0089	-0.287	4.78	73.2**	19.66	24.99**	0.00	0.0025	-1.492	15.33	3350.5**	24.93	39.15**
Jun05	0.00	0.0084	-0.298	5.07	96.3**	24.59	25.05**	0.00	0.0031	-1.820	17.14	4442.6**	34.1*	35.93**
Sep05	0.00	0.0076	-0.075	5.24	105.3**	22.83	5.4	0.00	0.0026	-0.414	13.19	2176.2**	33.41*	40.62**
Dec05	0.00	0.0070	0.028	5.39	118.9**	18.5	7.7	0.00	0.0023	-0.785	10.90	1352.6**	44.89**	113.07**
Mar06	0.00	0.0067	0.024	4.78	65.8**	15.57	9.48	0.00	0.0023	-0.576	10.36	1156.3**	57.69**	113.15**
Jun06	0.00	0.0063	0.234	4.49	50.6**	12.69	9.11	0.01*	0.0021	0.721	6.77	339.0**	45.73**	42.44**
Sep06	0.00	0.0061	-0.065	4.35	38.4**	16.77	3.07	0.00	0.0021	-0.141	5.20	102.2**	32.69*	17.4**
Dec06	0.00	0.0057	-0.164	4.88	75.6**	29.91	1.76	0.00	0.0028	0.603	9.15	818.9**	45.28**	2
Mar07	0.00	0.0058	-0.434	5.87	187.4**	24.05	1.66	0.00	0.0033	0.594	8.27	608.6**	41.67**	2.41
Jun07	−0.01	0.0057	-0.549	5.85	194.6**	23.46	2.91	0.00	0.0036	0.228	7.01	339.3**	39.86**	3.68
Sep07	−0.01*	0.0057	-0.314	4.79	75.1**	18.75	1.31	0.00	0.0038	-0.103	7.71	462.2**	39.4**	2.7
Dec07	−0.01	0.0063	0.404	5.28	121.9**	16.66	43.6**	0.00	0.0039	-0.309	8.62	664.8**	41.36**	5.39
Mar08	0.00	0.0068	0.098	4.71	61.6**	11.76	30.8**	0.00	0.0039	0.395	6.39	252.5**	46.12**	12.04*
Jun08	0.00	0.0076	0.026	3.83	14.3**	24.08	35.85**	0.00	0.0036	0.580	7.03	367.0**	32.14*	11.94*
Sep08	0.00	0.0090	-0.396	5.29	122.3**	24.39	28.49**	0.00	0.0035	0.064	5.59	140.0**	22.37	16.29**
Dec08	0.01	0.0128	0.050	7.57	436.0**	54.18**	76.32**	0.00	0.0039	0.002	6.53	258.9**	20.44	23.05**
Mar09	0.02	0.0137	-0.012	6.04	193.1**	42.39**	31.4**	0.00	0.0046	-0.474	7.92	523.5**	24.1	35.97**
Jun09	0.03**	0.0137	-0.197	5.91	180.1**	32.98*	33.3**	0.01	0.0048	-0.791	9.55	945.5**	26.45	30.51**

This table reports the statistics of the daily log-price changes of the individual futures contracts over 500 days before expiration month. Mean and standard deviation (SD) are annualized. JB is the Jarque-Bera statistic for testing the null hypothesis of normal distribution. $Q(5)$ is the Ljung-Box Q-statistic for autocorrelation (5 lags). ARCH is the LM-statistic of autoregressive conditional heteroscedasticity effect with 5 lags. * and ** indicate significance at 5% and 1% levels, respectively.

Table IV: Regression of daily volatility on days to expiration

Contract	Eurodollar			Euribor			Sterling			Euroyen		
	$\alpha \times 10^3$	$\beta \times 10^4$	$AdjR^2$	$\alpha \times 10^3$	$\beta \times 10^4$	$AdjR^2$	$\alpha \times 10^3$	$\beta \times 10^4$	$AdjR^2$	$\alpha \times 10^3$	$\beta \times 10^4$	$AdjR^2$
Mar02	0.51**	−0.0002	-0.002	0.34**	0.0006	-0.001	0.49*	−0.0031*	0.012	0	0.0055**	0.013
Jun02	0.54**	−0.0005	-0.002	0.34**	0.0001	-0.002	0.56**	−0.0046**	0.022	−0.01	0.0037**	0.153
Sep02	0.54**	0.0012	-0.001	0.36**	0.0001	-0.002	0.55	−0.0028	0.006	−0.09	0.0074	0.026
Dec02	0.46**	0.0058**	0.019	0.41**	−0.0003	-0.002	0.47	0.0011	-0.001	−0.01	0.0027**	0.152
Mar03	0.38**	0.0088**	0.042	0.35**	0.0021	0.004	0.36**	0.005**	0.021	0.01	0.0017**	0.112
Jun03	0.31**	0.0109**	0.065	0.29**	0.0041**	0.024	0.30**	0.0072**	0.048	0.01*	0.0012**	0.079
Sep03	0.20**	0.0142**	0.112	0.21**	0.007**	0.074	0.29**	0.0067**	0.047	0.02**	0.001**	0.027
Dec03	0.15**	0.0139**	0.130	0.19**	0.0062**	0.072	0.32**	0.0042**	0.021	−0.01	0.0025*	0.040
Mar04	0.16**	0.0133**	0.135	0.23**	0.005**	0.048	0.34**	0.0035**	0.013	0.04**	0.0001	-0.002
Jun04	0.16**	0.0146**	0.146	0.25**	0.0053**	0.043	0.30**	0.0054**	0.031	0.03**	0.0005	0.007
Sep04	0.28**	0.0105**	0.073	0.21**	0.0066**	0.059	0.28**	0.0056**	0.033	0.04**	0.0005	0.004
Dec04	0.26**	0.0121**	0.083	0.17**	0.0083**	0.083	0.20**	0.0082**	0.072	0.04**	0.0011*	0.015
Mar05	0.15**	0.0159**	0.133	0.09**	0.0112**	0.154	0.14**	0.0096**	0.120	0.02	0.0023**	0.060
Jun05	0.06	0.0185**	0.177	0.05	0.0119**	0.184	0.14**	0.0089**	0.116	−0.02	0.0047**	0.168
Sep05	0.10**	0.0143**	0.141	0.06**	0.0096**	0.167	0.19**	0.0058**	0.060	−0.02	0.0041**	0.186
Dec05	0.16**	0.0110**	0.095	0.09**	0.0077**	0.134	0.20**	0.0045**	0.042	−0.02*	0.0038**	0.210
Mar06	0.15**	0.0104**	0.102	0.10**	0.0070**	0.132	0.21**	0.0036**	0.029	−0.02	0.0040**	0.235
Jun06	0.21**	0.0067**	0.060	0.12**	0.0055**	0.097	0.17**	0.0047**	0.060	0.03**	0.0020**	0.086
Sep06	0.25**	0.0042**	0.031	0.13**	0.0047**	0.084	0.21**	0.0029**	0.026	0.11**	−0.0005	0.005
Dec06	0.19**	0.0057**	0.066	0.14**	0.0043**	0.074	0.19**	0.0028**	0.027	0.16**	−0.0014**	0.023
Mar07	0.15**	0.0072**	0.107	0.14**	0.0044**	0.072	0.19**	0.0029**	0.026	0.17**	−0.0008	0.004
Jun07	0.18**	0.0057**	0.065	0.11**	0.0051**	0.097	0.19**	0.0029**	0.027	0.11**	0.0017**	0.022
Sep07	0.22**	0.0042**	0.033	0.12**	0.0049**	0.093	0.23	0.0016	0.007	0.08**	0.0032**	0.065
Dec07	0.40**	−0.0007	-0.001	0.20**	0.0023**	0.019	0.34	−0.0016	0.006	0.06**	0.0040**	0.102
Mar08	0.57**	−0.0043**	0.018	0.28**	0.0005	-0.001	0.39*	−0.0021*	0.010	0.06**	0.0043**	0.120
Jun08	0.65**	−0.0057**	0.027	0.41**	−0.0028**	0.018	0.50**	−0.0049**	0.050	0.08**	0.0027**	0.055
Sep08	0.60**	−0.0028	0.004	0.44**	−0.0030*	0.013	0.60**	−0.0069**	0.066	0.10**	0.0020**	0.034
Dec08	1.01**	−0.0130**	0.089	0.64**	−0.0078**	0.066	1.01**	−0.0168**	0.172	0.17**	0.0001	-0.002
Mar09	0.92**	−0.0070**	0.021	0.66**	−0.0061**	0.033	0.94**	−0.0120**	0.079	0.21**	−0.0004	-0.001
Jun09	0.71**	0.0022	0.000	0.52**	−0.0001	-0.002	0.67	−0.0016	-0.001	0.14**	0.0023**	0.019

The table reports the estimates of the regression model $\sigma(F)_t = \alpha + \beta m_t + u_t$ where m_t represents days to maturity. $AdjR^2$ is the adjusted R^2. There are 500 observations (expiration month is excluded). The results are obtained using the Newey and West (1987) heteroscedasticity-consistent covariance procedure. * and ** indicate significance 1% and at 5%, respectively.

Table V: Regression of daily volatility on days to expiration and spot volatility

Contract	Eurodollar				Euribor			
	$\alpha \times 10^3$	$\beta \times 10^4$	γ	$AdjR^2$	$\alpha \times 10^3$	$\beta \times 10^4$	γ	$AdjR^2$
Mar02	0.47**	0.0002	0.1251*	0.006	0.33**	0.0009	0.0779	0.002
Jun02	0.51**	−0.0004	0.1422*	0.008	0.34**	0.0003	0.0843	0.001
Sep02	0.52**	0.0007	0.1361	0.006	0.36**	0.0001	0.0394	-0.003
Dec02	0.46**	0.0055*	0.0566	0.018	0.41**	−0.0002	−0.0328	-0.003
Mar03	0.38**	0.0089**	−0.0179	0.040	0.35**	0.0021	−0.0709	0.005
Jun03	0.31**	0.0111**	−0.0421	0.063	0.30**	0.0042*	−0.1154*	0.027
Sep03	0.20**	0.0142**	−0.0080	0.111	0.21**	0.0071**	−0.1136*	0.077
Dec03	0.15**	0.0139**	0.0212	0.128	0.19**	0.0062**	0.0206	0.070
Mar04	0.16**	0.0132**	0.0798	0.134	0.23**	0.0050**	−0.0137	0.046
Jun04	0.16**	0.0145**	0.0316	0.144	0.25**	0.0055**	−0.1798	0.045
Sep04	0.27**	0.0104**	0.0861	0.071	0.20**	0.0072**	−0.3331*	0.068
Dec04	0.26**	0.0121**	−0.0060	0.081	0.15**	0.0091**	−0.4862	0.095
Mar05	0.17**	0.0157**	−0.1740	0.132	0.08**	0.0120**	−0.7939*	0.172
Jun05	0.05	0.0187**	0.0928	0.176	0.05	0.0119**	−1.4750**	0.223
Sep05	0.12**	0.0140**	−0.1789	0.139	0.06**	0.0097**	−1.3549**	0.210
Dec05	0.17**	0.0108**	−0.1031	0.093	0.07**	0.0083**	−0.7928*	0.166
Mar06	0.17**	0.0104**	−0.1374	0.101	0.08**	0.0075**	−0.6745*	0.159
Jun06	0.22**	0.0067**	−0.1278	0.059	0.11**	0.0059**	−0.2829**	0.101
Sep06	0.26**	0.0041**	−0.0781	0.029	0.12**	0.0051**	−0.2614*	0.089
Dec06	0.18**	0.0056**	0.1552	0.066	0.12**	0.0047**	−0.2397	0.079
Mar07	0.14**	0.0070**	0.1659	0.108	0.12**	0.0047**	−0.2958*	0.080
Jun07	0.18**	0.0057**	−0.0102	0.063	0.10**	0.0052**	−0.2653	0.103
Sep07	0.22**	0.0039**	0.2140*	0.035	0.09**	0.0051**	−0.3127**	0.109
Dec07	0.39**	−0.0005	0.0994	0.000	0.19**	0.0022*	−0.2888	0.034
Mar08	0.51**	−0.0030*	0.2275	0.040	0.28**	0.0003	−0.1578	0.005
Jun08	0.59**	−0.0044*	0.1954*	0.041	0.40**	−0.0029*	−0.0951	0.018
Sep08	0.54**	−0.0016	0.2530**	0.029	0.43**	−0.0031	−0.1538	0.016
Dec08	0.89**	−0.0105**	0.2004	0.112	0.64**	−0.0080**	−0.0747	0.066
Mar09	0.84**	−0.0056*	0.1837*	0.039	0.72**	−0.0079**	−0.2420	0.045
Jun09	0.65**	0.0026	0.1820*	0.015	0.56**	−0.0011	−0.1420	0.001

The table reports the estimates of the regressions $\sigma(F)_t = \alpha + \beta m_t + \gamma\,\sigma(S)_t + u_\tau$, where m_t represents days to maturity and $\sigma(S)_\tau$ is the spot volatility. $AdjR^2$ is the adjusted R^2. There are 500 observations (expiration month is excluded). The results are obtained using the Newey and West (1987) heteroscedasticity-consistent covariance procedure. * and ** indicate significance at 5% and 1% respectively.

Table VI: Regression of daily volatility on days to expiration and spot volatility

Contract	Short Sterling				Euroyen			
	$\alpha \times 10^3$	$\beta \times 10^4$	γ	$AdjR^2$	$\alpha \times 10^3$	$\beta \times 10^4$	γ	$AdjR^2$
Mar02	0.49	−0.0031	0.045	0.010	0.00	0.0055**	−0.0384	0.011
Jun02	0.56*	−0.0046*	0.0122	0.020	−0.01	0.0035**	0.0941	0.154
Sep02	0.55	−0.0027	−0.015	0.004	−0.09	0.0075	−0.0356	0.025
Dec02	0.47	0.0011	−0.0244	-0.003	0.00	0.0024**	0.2627**	0.181
Mar03	0.36**	0.0051**	−0.0468	0.020	0.01	0.0016**	0.4418**	0.141
Jun03	0.30**	0.0073**	−0.0282	0.046	0.01	0.0012**	0.1875	0.078
Sep03	0.29**	0.0067**	−0.0028	0.045	0.01*	0.0010**	0.3886	0.037
Dec03	0.32**	0.0042**	0.1045	0.021	−0.01	0.0024*	0.4246	0.039
Mar04	0.33*	0.0035*	−0.0226	0.011	0.04**	0.0000	0.1554	-0.002
Jun04	0.29**	0.0057**	−0.1094	0.032	0.03**	0.0004	0.1441	0.006
Sep04	0.27**	0.0060**	−0.1614	0.035	0.04**	0.0005	0.1685	0.003
Dec04	0.20**	0.0084**	−0.1329	0.073	0.04**	0.0011	0.1489	0.013
Mar05	0.14**	0.0095**	−0.1665	0.121	0.02	0.0023**	0.3351*	0.058
Jun05	0.14**	0.0087**	−0.2099	0.119	−0.02	0.0047**	0.0301	0.163
Sep05	0.18**	0.0064**	0.2331	0.063	−0.02	0.0041**	−0.0416	0.186
Dec05	0.18**	0.0053**	0.4363	0.055	−0.02	0.0038**	−0.0626	0.204
Mar06	0.19**	0.0043**	0.4664*	0.046	−0.02	0.0039**	0.0491	0.230
Jun06	0.17**	0.0047**	0.5377*	0.078	0.03*	0.0021**	0.5416	0.091
Sep06	0.21**	0.0028**	0.1593	0.028	0.10**	−0.0004	0.2868	0.009
Dec06	0.20**	0.0026**	0.2077	0.034	0.15**	−0.0012*	0.3978*	0.028
Mar07	0.20**	0.0026**	0.1254	0.028	0.16**	−0.0006	0.3988*	0.009
Jun07	0.19**	0.0029**	−0.007	0.025	0.11**	0.0018**	0.1386	0.020
Sep07	0.20*	0.0022*	−0.229*	0.036	0.08**	0.0032**	0.1786	0.063
Dec07	0.35	−0.0017	0.1026	0.013	0.06**	0.004**	0.1773	0.100
Mar08	0.38	−0.0020	0.0268	0.008	0.06**	0.0041**	0.1115	0.115
Jun08	0.50**	−0.0049**	−0.0062	0.048	0.08**	0.0026**	0.2022	0.059
Sep08	0.61**	−0.0070**	−0.0530	0.065	0.10**	0.0019**	0.1201	0.031
Dec08	1.01**	−0.0167**	0.0273	0.171	0.17**	0.0000	0.0606	-0.004
Mar09	0.96**	−0.0124**	−0.0515	0.080	0.21**	−0.0004	0.1599	-0.001
Jun09	0.67	−0.0017	−0.0168	-0.002	0.14**	0.0023*	0.1144	0.017

The table reports the estimates of the regressions $\sigma(F)_t = \alpha + \beta m_t + \gamma\,\sigma(S)_t + u_t$, where m_t represents days to maturity and $\sigma(S)_t$ is the spot volatility. $AdjR^2$ is the adjusted R^2. There are 500 observations (expiration month is excluded). The results are obtained using the Newey and West (1987) heteroscedasticity-consistent covariance procedure. * and ** indicate significance at 5% and 1% respectively.

Table VII: Negative covariance condition

Contract	Eurodollar			Euribor			Sterling			Euroyen		
	$\omega_0 \times 10^5$	$\omega_1 \times 10^3$	$AdjR^2$	$\omega_0 \times 10^5$	$\omega_1 \times 10^3$	$AdjR^2$	$\omega_0 \times 10^5$	$\omega_1 \times 10^3$	$AdjR^2$	$\omega_0 \times 10^5$	$\omega_1 \times 10^3$	$AdjR^2$
Mar02	0.03	−3.91**	0.107	0.01	−3.02**	0.074	0.00	−1.07	0.001	0.00	−2.43**	0.017
Jun02	0.02	−2.96**	0.065	0.00	−2.54**	0.057	−0.01	−0.07	-0.002	0.00	−2.12**	0.146
Sep02	0.02	−2.39**	0.039	0.01	−2.12**	0.031	0.00	0.07	-0.002	0.00	−1.82**	0.015
Dec02	0.04	−3.88*	0.069	0.03*	−4.28*	0.054	0.02	−3.62	0.027	0.00	−1.47**	0.041
Mar03	0.03	−2.82**	0.059	0.02	−2.72**	0.052	0.03	−6.53	0.091	0.00	−3.23*	0.045
Jun03	0.03	−2.17**	0.021	0.03*	−2.96**	0.043	0.02	−2.44	0.018	0.00	−3.45**	0.031
Sep03	0.01	−2.32**	0.023	0.01	−2.28**	0.037	0.01	−3.03	0.026	0.00	−2.47*	0.013
Dec03	0.02	−2.58**	0.020	0.01	−2.40**	0.017	0.00	−1.45	0.005	0.00	−4.47**	0.023
Mar04	0.02	−2.06**	0.009	0.01	−1.51	0.005	0.00	−0.64	-0.001	0.00	−6.10*	0.049
Jun04	0.00	−1.58	0.001	0.01	−1.08	0.001	−0.01	−0.16	-0.002	0.00	−2.43*	0.011
Sep04	−0.01	−2.70*	0.007	0.00	−0.46	-0.001	0.00	−0.46	-0.001	0.00	−3.82	0.014
Dec04	−0.01	−2.72*	0.004	0.00	0.72	-0.001	0.00	−0.03	-0.002	0.00	−3.88	0.014
Mar05	−0.02	−3.10*	0.008	0.00	2.67*	0.007	0.00	1.12	0.001	0.00	−7.24	0.042
Jun05	−0.03	−3.61*	0.010	0.00	4.83**	0.018	0.01	0.71	-0.001	0.00	−3.99*	0.011
Sep05	−0.02	−3.18**	0.007	0.00	3.75**	0.014	0.01*	4.57*	0.033	0.00	−3.98*	0.014
Dec05	−0.05**	−6.56**	0.040	−0.01	−18.25	0.120	0.01*	3.14*	0.017	0.00	−2.86*	0.006
Mar06	−0.05**	−5.90**	0.042	−0.01	−5.55	0.037	0.00	1.78	0.002	0.00	−4.05**	0.007
Jun06	−0.04**	−6.20**	0.030	−0.02*	−7.46*	0.061	0.00	2.53	0.006	−0.01	−20.29*	0.064
Sep06	−0.07*	−10.95*	0.099	−0.02*	−5.60**	0.059	0.00	−13.25	0.142	−0.01	−9.97*	0.047
Dec06	−0.03*	−5.33**	0.056	−0.02**	−4.02**	0.037	−0.01	−4.76	0.057	−0.01	−5.75*	0.006
Mar07	−0.01	−3.59**	0.028	−0.02*	−3.55**	0.030	−0.02*	−7.95*	0.106	−0.01	−4.16	0.005
Jun07	−0.01	−3.09**	0.017	−0.02**	−2.91**	0.024	−0.02**	−3.84**	0.055	−0.01*	−9.05**	0.156
Sep07	−0.03	−21.09	0.181	−0.09	−22.31	0.260	−0.04*	−15.34*	0.245	−0.01	−7.70**	0.048
Dec07	0.01	−11.24**	0.190	−0.03	−8.08*	0.081	0.01**	−7.94**	0.120	0.00	−4.01**	0.029
Mar08	0.06*	−9.68**	0.150	−0.02	−6.71**	0.051	−0.01**	−5.72**	0.126	0.00	−2.63**	0.006
Jun08	0.03	−5.05**	0.083	−0.01	−4.40*	0.023	0.01**	−3.98**	0.046	0.00	−2.04*	0.005
Sep08	0.02	−3.63**	0.069	−0.02	−4.55**	0.031	0.01**	−2.91**	0.025	0.00	−1.97**	0.005
Dec08	0.07	−10.39**	0.186	0.06	−6.34	0.024	0.12**	−20.53**	0.346	0.00	−14.81	0.121
Mar09	0.04	−5.36**	0.150	0.05	−5.80**	0.061	0.07**	−7.78**	0.267	0.01	−9.68**	0.100
Jun09	0.05*	−3.89**	0.145	0.04	−4.40**	0.065	0.07**	−5.10**	0.270	0.01	−4.88**	0.050

The table reports the estimates of the regression model $\Delta c_t = \omega_0 + \omega_1 \Delta S_t + \varepsilon_t$. $AdjR^2$ is the adjusted R^2. There are 500 observations (expiration month is excluded). The results are obtained using the Newey and West (1987) heteroscedasticity-consistent covariance procedure. * and ** indicate significance 1% and at 5%, respectively.