Volatility term structure of interest rate futures

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Abstract

The maturity effect states that the volatility of futures prices should increase as the contract approaches expiration. Numerous studies have investigated this effect for different asset classes. However, the presence of a maturity effect in short term interest rate (STIR) futures has usually only been studied considering these within a wider set of financial futures, without further consideration of their special features. Our study looks at the presence of maturity effects in STIR futures by analyzing the term structure of the volatility of the most worldwide traded contracts. It turns out that STIR futures behave differently to other assets and that an 'inverse' maturity effect, where volatility decreases as the contract approaches expiration, predominates. We propose to explain this phenomenon by relating the empirical evidence to the theoretical models of the volatility of the forward rates.

Keywords: Short-term interest rates futures, maturity effect, volatility, term structure interest rates

JEL Classification: G12, G13, G15

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1. Introduction

The maturity effect or Samuelson hypothesis (Samuelson, 1965) proposes that the volatility of futures prices should increase as the contract approaches expiration because futures prices react strongly to new information when close to maturity. Numerous studies have investigated and debated this effect, for example Rutledge (1976), Milonas (1986), Grammatikos and Saunders (1986), Galloway and Kolb (1996), Daal, Farhat and Wei (2006) and Duong and Kalev (2008). Most studies derive general conclusions about futures contracts volatility patterns grouping contracts by type of underlying asset: commodities, currencies and financial futures. Empirical evidence proves that the effect exists in agricultural futures, but the evidence is mixed for metal and financial futures. In general, understanding the relation between volatility and time to maturity is important for various reasons: for example, it may suggest that time to maturity should be considered when setting margin requirements, when pricing options on futures contracts, or when implementing hedging strategies.

When assessing the Samuelson hypothesis, previous analysis have grouped short-term interest rates (STIR) futures together with other types of financial futures and have usually coincided in that the evidence of maturity effect in financial futures is weak in general. However, given the particular characteristics of STIR futures markets, the question remains as to whether there is evidence of any relation between volatility and time to maturity in the specific case of STIR futures. The first objective of our study is to empirically answer this question. For this purpose, we examine the volatility term structure of the three most traded STIR futures worldwide.

It turns out that STIR futures behave differently to other assets and that an 'inverse' maturity effect, where volatility decreases as the contract approaches expiration, predominates. While one could attribute the absence of maturity effect in STIR futures to the fact that the usual cost-of-carry model does not necessarily apply in this case and therefore STIRs are not amenable to be studied under Samuelson's framework, this would still fail to explain the presence of an inverse maturity effect and suggests that other factors should be considered. In particular, in this paper we propose to explain this phenomenon by relating the empirical evidence to the theoretical models of the volatility of the forward rates.

From a methodological standpoint, this research also differs from previous studies by modeling the variance for each STIR contract and for each maturity date individually using days to maturity and controlling for financial markets conditions. We derive conclusions without pooling the results, assessing whether the behavior of STIR contracts' volatility is uniform and unique for each contract or if it changes over time, and which factors may

affect their behavior. We also explore how our findings may relate to the calibration of the volatility of the short term rate models. like the ones of Vasicek (1977) and Cox, Ingersoll, Ross (1985) (CIR).

Our main results can be summarized as follows. Out of the 201 contracts expiring between December 2000 and June 2017, 76% of them show decreasing volatility towards maturity (an 'inverse' maturity effect) and 11% has no relation between volatility and time to expiration when we monitor daily volatility from 3 years before maturity. The trend occasionally reverses becoming the regular maturity effect when the general market conditions are unstable (12% of the contracts). In fact, the maturity effect tends to arise in contracts expiring during the 2008-2009 sub-prime financial crisis. To further control for the general state of financial markets we include in the estimations proxies to capture market volatility, such as the VIX index. We find that the positive relation between volatility and time to maturity prevails, but the regular maturity effect weakens or disappears when we control for market volatility. In this case, the level of volatility decreases towards maturity for 77% of contracts, increases for 5% and has no relation in 18% of contracts. Regarding the period of time before expiration considered for the estimation, the relation between volatility and time to maturity is more likely to manifest over longer time frames. Interestingly, the regular maturity effect is almost not present if one analyzes only the last 12 months of contracts life –only 3% of the contracts present a negative relation between volatility and time to expiration–. Our results are robust to seasonality and trading volume. In sum, the most common volatility trend of STIR futures is that it decreases towards maturity, increasing only when market conditions are unstable around expiration dates.

Our analysis expands the existing literature in several ways. First, we generalize previous findings by examining the three 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) contract which is traded in ICE Futures Europe; and 3) the 3-month Euribor futures, also traded in ICE Futures Europe.[1] Although there are some studies that have considered the Eurodollar contracts (among others, Daal, Farhat and Wei, 2006; Galloway and Kolb, 1996 and Doung and Kaleb, 2008), contract volatility and its relation to time to maturity has not been analyzed for Euribor and Short-Sterling contracts. In fact, literature about the behavior of Short Sterling is more limited (see Kalotychou and Staikouras, 2006). Second, the study extends both the empirical literature on maturity effect and the term structure of interest rates by examining the volatility behavior during the recent financial crisis. Our data arrangement allows us to show that, even when considering contracts with the same underlying asset, the relation

[1] The Short Sterling and the Euribor contracts were originally traded in the London International Futures and Options Exchange (LIFFE). In 2002, LIFFE was acquired by Euronext and in 2007 Euronext was taken over by the New York Stock Exchange (NYSE) to form NYSE Euronext. Intercontinental Exchange (ICE) then purchased NYSE Euronext in 2013. LIFFE is currently part of ICE NYSE group under the name ICE Futures Europe.

between volatility and maturity may radically change over time depending on market conditions. Third, the study complements the volatility function by incorporating the market volatility in the volatility specification. Finally, as a test of robustness, we complement the literature by analyzing the impact of the choice of the sampling window on the observation of the maturity effect, an issue that has been frequently ignored. Samuelson (1976) explicitly referred to the comparison of variance between contracts close to expiration and contracts "sufficiently far". If one chooses to analyze volatility over the last 12 months of the contract life, the most likely finding will be constant variance. However, using longer observation windows the most probable result will be time varying volatility.

As mentioned before, the empirical research on Samuelson hypothesis has generally performed the analysis on groups of futures contracts across asset classes. The most frequent outcome is that the maturity effect is strongly present in agricultural futures but is statistically insignificant or totally nonexistent in metals and financial futures. An early study about the maturity effect using non-agricultural futures was Barnhill, Jordan and Seale (1987) where they studied futures on Treasury Bonds, finding strong support of volatility increasing towards maturity, noting that Treasury Bonds futures have an underlying asset that can be delivered. Without making particular emphasis on it, some of these studies have also produced cases in which volatility decreased as the contract moved closer to maturity. For example, Galloway and Kolb (1996) include in the sample, among many other futures, Eurodollar and T-Bill futures (from 1976 and 1982 respectively, to 1992) finding that volatility decreases towards maturity in the case of Eurodollar futures.

Adding to the debate, Bessembinder, Coughenour, Seguin, and Monroe Smoller (1996) affirmed that neither the clustering of information flows near delivery dates nor the assumption of that each futures price is an unbiased forecast of the delivery date spot price are necessary conditions for the presence of the maturity effect. Instead they focus on the stationarity of prices. They show that Samuelson hypothesis is generally supported in markets where spot price changes include a predictable temporary component, a condition which is more likely to be met in markets for real assets than for financial assets. Their analysis predicts that the Samuelson hypothesis will be empirically supported in those markets that exhibit negative covariation between spot price changes and the futures term slope. Since financial assets do not provide service flows, they predict that the Samuelson hypothesis will not hold for financial futures.

Daal, Farhat and Wei (2006) examined contracts from 61 commodities during the 80s and 90s. Their results show that the maturity effect is absent in the majority of contracts but, when existent, it tends to be stronger in energy and agricultural commodities than in financial futures. In addition, the percentage of interest rate futures that exhibit an inverse effect is relatively high. Duong and Kalev (2008) found that 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 Kalev and Duong (2008) the inverse effect is again observed only in the financial futures included in the sample (Eurodollar). Gurrola and Herrerias (2010) analyzed the Mexican interbank interest-rate futures market and, using a panel data approach and standard OLS regression, showed that the inverse relation between volatility and maturity do not correspond to Samuelson hypothesis, but rather it can be explained mainly by the dynamics of the term structure of interest rates.

The remainder of the paper is organized as follows. Section 2 presents the data and the methodology. In section 3 we present the results. Section 4 discusses these results and their relation with the theoretical framework of forward rates. Our concluding remarks are in section 5.

2. Data and methodology

To empirically test the relation between volatility and time to maturity, we consider three of the most traded short-term interest rate future contracts (STIR) 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 Short Sterling contract; and 3) the 3-month Euribor futures contract, both traded on the Intercontinental Exchange, Inc. (ICE). In addition to their high liquidity and data availability, the main reason for choosing these contracts is that they share similar characteristics, which allows for a direct comparison. All of them are cash settled to 100 minus their respective reference rate, and the reference is the corresponding interbank rate. The Euribor contract is based on the European Money Markets Institute Euribor Rate (EMMI Euribor) for 3-month Euro deposits. In the case of the Eurodollar, the reference rate is the 3-month U.S. Dollar Libor and for Sterling deposits it is 3-month Sterling Libor (GBP Libor), both administrated by ICE Benchmark Administration Limited.[2] Additionally, all three contracts have quarterly maturity months (March, June, September, and December), and they are available for trading at least five years in advance (10 years in the case of the Eurodollar). The last trading day for all contracts is either two business days prior to the third Wednesday of the delivery month (in the case of the Eurodollar and Euribor) or on that same Wednesday (Short Sterling).

To provide some background on the level and volatility of each underlying interest rate and market volatility, we present in Figures 1 to 3 the evolution of the 3 spot rates from December 2000 to June 2017 –Euribor, Eurodollar,

[2] In early 2014, NYSE Euronext took over the administration of Libor from the British Bankers Association. The new administrator was NYSE Euronext Rates Administration Limited. On November 2013, the Intercontinental Exchange (ICE) Group acquired NYSE Euronext and the NYSE Euronext Rate Administration Limited was renamed ICE Benchmark Administration Limited.

and Shor-Sterling rates respectively (upper panels). All rates reached the highest level just before the subprime crisis and all of them progressively decreased. Noticeably, since late 2014 and up to the end of the sample (June 2017) the Euribor rate has been negative. The mid panel in each figure shows the volatility of daily rate changes where one can see that all rates also tend to coincide in periods of high volatility: between 2001 and 2002, and during the sub-prime crisis from December 2007 to December 2009. Euribor rate has an additional period of instability that seems to be related to the sovereign debt crisis in Europe in 2010-2012, which apparently caused similar volatility to the one during the 2008 sub-prime crisis.

The data includes daily settlement prices and trading volume for all contracts expiring quarterly between December 2000 and June 2017 (67 quarters per each underlying rate), for a total of 201 contracts. For every contract in the sample we use approximately the last 750 trading days before expiration (3 calendar years), and we follow the usual practice of excluding from the analysis the last two weeks before the expiration date to avoid abnormal price variability generated by the rollover of the positions. All data are from Bloomberg.

The study considers daily logarithmic price returns expressed in basis points,

$$\Delta F_t = \ln\left(\frac{F_t}{F_{t-1}}\right) \times 10{,}000 \tag{1}$$

Where F_t denotes the futures settlement price on calendar day *t*.

Table 1 presents the summary statistics for the log price changes ΔF_t. The majority of mean log changes tend to be not significantly different from zero, but each underlying asset shows specific periods where mean return is significantly different from zero. For instance Euribor and Eurodollar contracts expiring between 2003 and 2005 and many Short-Sterling and Euribor contracts expiring between 2009 and 2014 present non-zero mean return. There are clearly-defined periods where negative or positive skewness prevail. The Ljung-Box Q-statistic for autocorrelation (with 5 lags) shows evidence of autocorrelation in many series. All contracts are leptokurtic, and in all cases the Jarque-Bera statistic rejects the hypothesis of normality.

Next, for a contract with maturity at time T, we measure daily variability using the absolute value of the logarithmic rate changes at time t:

$$\sigma_F(t,T) = abs[\Delta F_t] \tag{2}$$

We estimate then the presence of the maturity or the inverse effect for each individual contract expiring in *T*, performing a standard OLS estimation of the contract's daily volatility $\sigma_F(t,T)$ on the number of days remaining to expiration $(T-t)$, as specified by the model,

$$\sigma_F(t,T) = \alpha + \beta(T-t) + u_t \quad (3)$$

Where u_t are the disturbances. We determine the relation between volatility and time to maturity by the sign and significance of the coefficient β; if β is negative and statistically significant, the maturity effect prevails or if β is positive and significant then the inverse maturity effect is present[3]. Additionally, as robustness test, we used the squared values of futures price changes as proxy for volatility in the OLS specification. We also modeled volatility with a GARCH(1,1) specification using futures price changes and including days to expiration in the variance equation. All results were qualitative the same as the reported here.

In a second model we include a proxy to capture the general market conditions. The purpose is to assess if the relation between volatility and time to maturity prevails or if it is related to secular changes in the economy and dependent on specific market circumstances (S_{Mt}):

$$\sigma_F(t,T) = \alpha + \beta(T-t) + \varphi S_{Mt} + u_t \quad (4)$$

For Eurodollar S_{Mt} is the daily closing price of the VIX expressed in logarithms. In the case of Short-Sterling and Euribor we use the logarithm of daily closing prices of FTSE 100 (VFTSE) and STOXX 50 (VSTOXX) volatility indexes respectively[4]. The lower panels in Figures 1 to 3 present daily closing prices from December 2000 and June 2017 of VSTOXX, VIX and VFTSE respectively. All indexes show very similar trends reaching historical maximums at the end of 2008 and hiking again during Europe's debt crisis in 2010.

Finally we use 2 different observation windows –one and three years before maturity– to test whether the relation between futures volatility and time to maturity prevails irrespectively of the period of time evaluated. To avoid results driven by abnormal trading from rollover strategies, all estimations exclude the last two weeks before maturity.

[3] Additional results are available from the authors upon request.
[4] Data on FTSE 100 volatility index is only available from January 2000.

3. Results

3.1 Estimates of time-to-maturity effects

We evaluate the relation between volatility and time to maturity, estimating the significance and sign of the β coefficient in equations (3) and (4). Results are presented in Table 2 to Table 4, for Euribor, Eurodollar and Short-Sterling rates respectively. Our base case is the analysis of data from three years to two weeks before maturity (Panel A in each table). From 201 contracts analyzed, 153 of them (76.1%) deliver a positive and significant coefficient for the time to maturity variable or decreasing variance towards expiration. The analysis by underlying interest rate shows that 79% of Euribor contracts have positive and significant coefficients for time to maturity compared to 76% of Short-Sterling and 73% of Eurodollar contracts. Of all contracts, the volatility of only 25 (12.4%) are not dependent on time to maturity at all. Regarding the regular maturity effect, 23 contracts (11.4%) show negative and significant coefficients for time to maturity, and this behavior seems to appear in clusters. For instance, Short Sterling contracts expiring between September 2002 and March 2003 have negative and significant coefficients which can be associated to the burst of the "dot-com" bubble and the threat at that time of war in Iraq. All contracts expiring before and during the sub-prime crisis in 2008 and 2009 present higher volatility close to expiration (Euribor contracts from June 2008 to December 2009, and Eurodollar and Short Sterling contracts from March 2008 to September 2009). From our results we can conclude that the most regular pattern is decreasing volatility towards maturity, while the maturity effect tends to appear in clusters of time, and is related to high levels of market volatility and high levels of interest rates.

Next we cut the sample period to assess if the positive or negative tendency in volatility could change or fade by modifying the length of the analyzed period. We repeat all regressions using futures prices from one year to two weeks before maturity (Panel B in tables 2, 3 and 4). The results show that the inverse maturity effect prevails and now 175 contracts (87%) present positive and significant coefficient for time to maturity, the volatility of 21 contracts have no relation with time to maturity and just 5 contracts present a negative and significant coefficient. Euribor March 2016, Eurodollar June 2001, and Short-Sterling December 2007 and March and December 2008 are the contracts with negative and significant coefficients. In fact, the negative relation appearing when we analyze the three years period is no longer present when we reduce the data to one year before maturity. Some of those contracts present now the inverse effect. Again, we assert that the inverse maturity effect is the most common volatility pattern for STIR futures prevailing regardless the time horizon analyzed, and that the maturity effect is most likely to appear if the time frame is sufficiently long.

3.2 Market volatility

As mentioned in in the previous sub-section, contracts delivering a maturity effect tend to be grouped in certain periods of widespread unstable economic conditions. For this reason, we include in all estimations an equity volatility index as a proxy to control for the general market conditions, and to test whether the relation between time to maturity and volatility survives or if futures volatility is responding to secular changes in financial markets.

Next to our base case, right columns in tables 2 to 4, present results for the regressions including time to maturity and the log of the closing price of the corresponding volatility index. Considering the data from three years before maturity, the majority of contracts deliver a positive and significant relation between market volatility and futures contract volatility (55%), 37% do not show a statistically significant relation and 8.5% of all contracts present negative and significant coefficient for market volatility.

Regarding maturity effects, we observe that now 155 (77%) have a positive relation between volatility and time to maturity and 9 contracts (4%) have negative relation. Furthermore 37 contracts (18%) do not show any trend in volatility. In the case of Euribor, the regular maturity effect disappears in all contracts except March 2009. For Eurodollar, the effect remains in December 2008 and March 2009 contracts and the negative coefficient of June 2001 contract becomes significant when controlling for market conditions. Similarly, the maturity effect persist in December 2008 and March 2009 Short-Sterling contracts confirming a period of high volatility particular to the futures markets. Noticeable the negative relation between volatility and time to expiration do not change in Short-Sterling contracts maturing between September 2002 and March 2003 which points to another period of volatility intrinsic to the British market. Although not all contracts present a relation with market volatility the results indicate that in most cases the inverse maturity effect remains after controlling for market volatility while the regular maturity effect tends to disappear.

We reach similar conclusions using the one year period: the inverse maturity effect remains and only one contract out of 201 shows evidence of maturity effect. However, market volatility has less predictive power on futures volatility since 60% of contracts deliver no statistically different from zero coefficients. This last finding may imply that the link between market conditions and futures contracts volatility is in the long run.

Apparently futures contract volatility increases towards maturity when market conditions are volatile and not because the nature of the contract nor particular attributes of futures. In any case, volatility declining towards expiration seems to be an attribute of STIRs futures.

3.3 Robustness check: Seasonality and trading volume

Ballocchi, Dacorogna, Gencay, and Piccinato (2001) report a seasonal pattern for Eurofutures (Eurodollar, Euromark and Short Sterling) as a function of the time left to expiry, consistent with our findings. They also reported an unexpected behavior of oscillatory movements in volatility peaking every 60 days resulting from the rollover of all contracts as the quarterly expiration approaches.

To test whether the relation between volatility and time to maturity remains after controlling for the seasonal behavior, we include in regression (3) a dummy variable that takes the value of 1 on trading dates within months of contract expiration. Abnormal price volatility can be expected in non-expiring contracts during March, June, September and December given that investors will close some positions and open new ones, once the nearest contract reaches maturity. Our results (available from the authors upon request) indicate that our sample occasionally present seasonal behavior that is concentrated in contracts expiring between 2009 and 2010. The seasonal anomaly seems to be related only to contracts that present higher price volatility in general. In any case, the relation with time to expiration, positive or negative, remains unchanged in the majority of contracts even in those presenting a seasonal volatility pattern.

On the other hand, some previous studies like Kalotychou and Staikouras (2006) have shown that rate variability of STIR futures is positively related to trading volume and open interest. Particularly, they analyzed Short-Sterling futures using a GARCH model. For this reason we also test the potential effects of volume trading on the relation between futures price volatility and time to maturity. The question remains as to whether the finding of a decline in futures price volatility close to the expiration of the futures contract does not just reflect the decline in trading volume. At first sight this should not be the case, since volume patterns differ greatly between contracts with different expiration dates as well as between the different contracts considered. To test for the effects of volume, we also include in the regression (3) the log of daily trading volume as a control variable. Our results show that trading volume is positively related to volatility for almost every contract. Including volume in estimations barely changes the relation between volatility and and time to maturity. In fact, very few contracts show a qualitative change with respect to the results reported above. We conclude that the decline in futures price volatility as maturity approaches is not driven by the level of trading volume.

4. Analysis of results

Results in section 3 show that STIR futures volatility is related to time to maturity and that, most of the time, this relation is positive. This finding is in line with interest rates models that predict volatility decreasing with time to maturity. However the results suggest the relation is affected by overall market conditions.

There are at least two reasons why one can expect decreasing volatility towards maturity. First, to transmit monetary policy intentions, central banks set targets for short term interest rates controlling the short end of the yield curve. Central banks do not set targets for long term rates that are defined by market activities and supply and demand forces. This simple fact should make long term interest rates more volatile than the short-term ones. And second, according to the expectation hypothesis of interest rates, futures rates represent an unbiased predictor of future spot rates and are part of the term structure of interest rates in a particular day. A series of quoted futures rates –implicit in futures prices– expiring from 3 months to 36 months ahead can be used to construct a series of zero rates for each particular maturity. If volatility depends on interest rates levels, then higher interest rates will be associated with higher volatility, and an upward term structure would present higher volatility in the long end, compared to nodes in the short end of the curve. Interest rates futures far from expiration are part of the long end of the curve and so, we can expect them to be more volatile. Furthermore, in tranquil times the slope of the term structure of interest rates tends to be positive; if that is the case, then diminishing volatility towards expiration should be the common pattern in the absence of markets instability. In the same line of though, the maturity effect should not be a common feature of STIR futures unless short-term rates were above long term rates. STIR futures should only present maturity effect with downward or humped term structures, which are interpreted as a signal of an expected slowdown in the economic activity or an upcoming recession. Our results confirm that actually the maturity effect is related to unstable market conditions, and controlling for market volatility, the effect diminishes or disappear.

Compared to other type of futures contracts, the similarity is that the volatility of STIR futures also depends on investors' expectations. However, those expectations are embedded in the term structure of interest rates that reflect whether the market assumes interest rates to increase or decrease in the future. In fact, and compared to other underlying assets, there is much more information about future interest rates because of the availability of debt and derivative instruments with different maturities. For this reason, the volatility pattern of STIR futures cannot be analyzed only under the premise of the amount of available information, but rather recognizing that futures rates also have to adjust to the term structure of interest rates on a particular day.

4.1 Models of the forward rates

We can frame the question of the existence of a maturity effect in the context of models for the forward rates. In particular, in a Gaussian HJM framework (Heath, Jarrow and Morton, 1992), the dynamics of the instantaneous forward rate $f(t,T)$is given by

$$df(t,T) = \alpha(t,T)dt + \sigma_f(t,T) \cdot dW_t \tag{5}$$

where W_t is a Brownian motion and the volatility of the forward rate, $\sigma_f(t,T)$, is a deterministic function. The volatility $\sigma_f(t,T)$ can be chosen rather arbitrarily and it completely determines the whole family of forward rates (and all claim prices) since, for each choice, the drifts $\alpha(t,T)$ are uniquely determined under the risk neutral measure by the no arbitrage condition,

$$\alpha(t,T) = \sigma_f(t,T)\left[\int_t^T \sigma_f(t,u)du\right] \tag{6}$$

Since a short term rate is a particular forward rate, many of the specifications for the evolution of spot interest rates that we find in the literature can be treated as special cases of HJM models by specifying the volatility of forward interest rates. For example, the Cox, Ross and Rubinstein (1979) and the Ho and Lee (1986) models correspond to constant forward rate volatility,

$$\sigma_f(t,T) = \sigma_0 \tag{7}$$

for a constant $\sigma_0 > 0$. Similarly, if we assume that the volatility is exponentially decreasing with time to maturity $T-t$,

$$\sigma_f(t,T) = \sigma_0 \mathrm{e}^{-\lambda(T-t)} \tag{8}$$

for parameters $\lambda, \sigma > 0$, we obtain the Hull and White (1990) extended Vasicek (1977) process:

$$dr_t = (a_t - \lambda r_t)dt + \sigma_0 dW_t \tag{9}$$

where r_t is the instantaneous spot rate (see Chiarella and El-Hassan, 1996).

One can nest the different cases under a general specification for the volatility of the forward rate:

$$\sigma_f(t,T) = \sigma_0 r_t^{\gamma} \cdot \mathrm{e}^{-\lambda(T-t)} \tag{10}$$

In this representation, the volatility is completely determined by the scale parameter σ_0, the elasticity γ, and the dampening parameter λ. The spot rate at time t is given as $\sigma_r(t) = \sigma_0 r_t^{\gamma}$ (Amin and Morton, 1994; Bhar and Chiarella, 1997; Ritchken and Sankarasubramanian, 2000). For example, when γ is equal to 0.5 the specification above becomes the extended CIR (1985) model.

$$dr = \alpha(\pi - r_t)dt + \sigma_0\sqrt{r_t}\, dW_t \tag{11}$$

The parameters in (10) are unknown and have to be estimated with market data. Amin and Morton (1994), for example, estimate the implied volatility by fitting the option prices derived from the model to the market prices of Eurodollar futures options. Using data from 1987-1992, they test six different specifications and they find, in particular, that for the case when $\gamma = 0$, the implied parameter λ in (10) is negative on average. This means that, everything else remaining the same, the instantaneous forward rate volatility decreases as maturity approaches.

To see how this relates with equations (3) and (4) we first note that, in general, the volatility of the futures contract is not the same as the volatility of the forward rate. However, in some cases the relation is more or less straightforward. For example, in the Vasicek model we have that

$$\sigma_f(t,T) = \sigma_F(t,T) = \sigma_0 \mathrm{e}^{-\lambda(T-t)} \tag{12}$$

where $\sigma_F(t,T)$ is the volatility of the price $F(t,T)$ at time t of a futures contract on the short rate r_T. In such cases, the existence (or not) of a maturity effect in futures contracts can provide information about how these models fit the data, depending on the sign of the dampening parameter λ in (10).

From this perspective, the empirical results can also provide some information on the calibration of the volatility function in (3). First, we observe that by taking logarithms on both sides of equation (10), we obtain the equivalent expression:

$$\ln(\sigma_f(t,T)) = \ln\sigma_0 + \ln[r_t^{\gamma}] - \lambda(T-t) \tag{13}$$

Assuming that the volatility of futures can be proxied by the volatility of forwards, then, equation (8) would seem consistent with a specification of the volatility of the futures of the form,

$$\ln[\sigma_F(t,T)] = \alpha_t + \gamma \ln(r_t) - \lambda(T-t) + u_t \quad (14)$$

Where $\sigma_F(t,T)$ is the volatility of the futures at time *t*. We can expect that, for the case $\gamma = 0$, equations (3) and (14) would show the same behavior. To confirm this is indeed the case, we have separately run the regressions on equation (14), including controlling for market volatility effects by adding a control variable:

$$\log[\sigma_F(t,T)] = \alpha_t + \gamma \log(r_t) - \lambda(T-t) + \phi \log(S_{Mt}) + u_t \quad (15)$$

where S_{Mt} is the log of the closing price of the corresponding volatility index (Eurodollar, VIX; Short-Sterling, FTSE; Euribor, STOXX) on day *t*. Although not reported here, the results using the specifications (14) and (15), without any constraint on γ, confirm our conclusions: most of the time volatility decreases with time to maturity and, in those cases where it increases, the effect disappears when we include market volatility as a control variable. This strongly suggests that the elasticity parameter λ in (10) should be negative most of the time, which would be consistent with the results of Amin and Morton (1994) for the case of Eurodollar futures.

5. Conclusions

The volatility patterns of futures contracts and its relation with time to maturity has been widely revised in the literature. In this document we focus our attention on the 3 most traded STIR futures contracts around the world, Eurodollar, Euribor and Short-Sterling analyzing the volatility pattern of each contract individually expiring from December 2000 to June 2017. We find that most of the times the volatility of STIR futures decreases towards maturity, presenting what we define as the inverse maturity effect. However, occasionally the volatility pattern reverses and STIR futures present the traditional maturity effect when the overall market conditions are unstable.

Including a control variable for market conditions in the estimations, the maturity effect tends to disappear but not the inverse maturity effect. The length of time before maturity that one chooses for the analysis also impacts the results. The longer the time frame, the most likely a downward or upward trend will appear and price volatility will be not constant. In this sense, maturity effect is more likely to manifest in longer horizons, while the inverse maturity effect is evident even considering shorter periods of time before expiration. Our results are robust to trading volume and seasonality.

Our findings have several implications. First, STIR futures cannot be analyzed under the framework applied to contracts applying the usual cost-of-carry relation. Instead we discuss the behavior of STIR futures in the

framework of models for the forward rates. Specifically, if the expected trend is volatility decreasing towards expiration, then the elasticity parameter λ in the general specification for the volatility of the forward rate should be negative. This finding is in line with the results of Amin and Morton (1994). Second, the analysis of STIR futures needs to consider the economic environment to model the volatility and, as other futures contracts, volatility is not constant over time and also depends on time to maturity.

The relation between volatility and time to maturity has some important implications. For example, it suggests that time to maturity could be considered when setting margin requirements and that option prices on futures contracts should be adjusted to reflect this relation. Also related to option pricing, it is very likely that variance risk premium would be non-constant and time dependent; this should be a relevant topic for future research.

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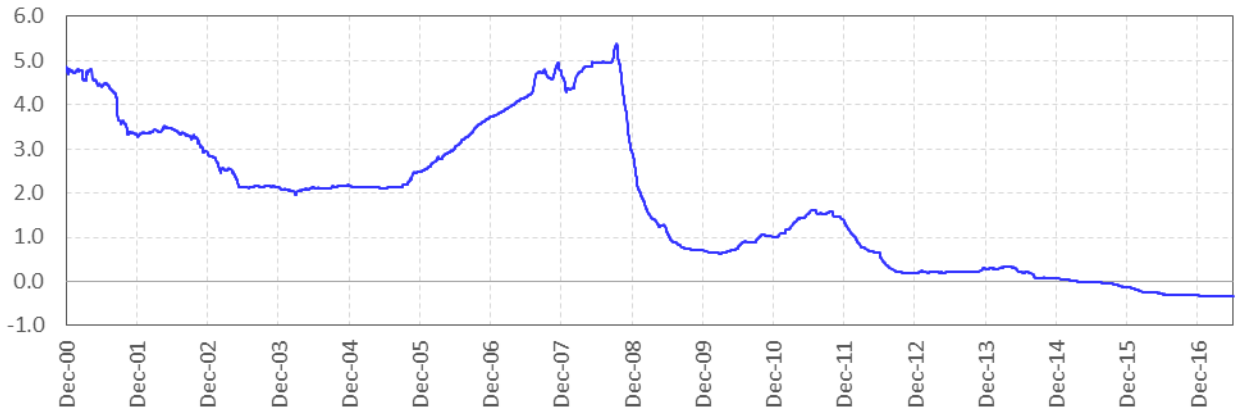
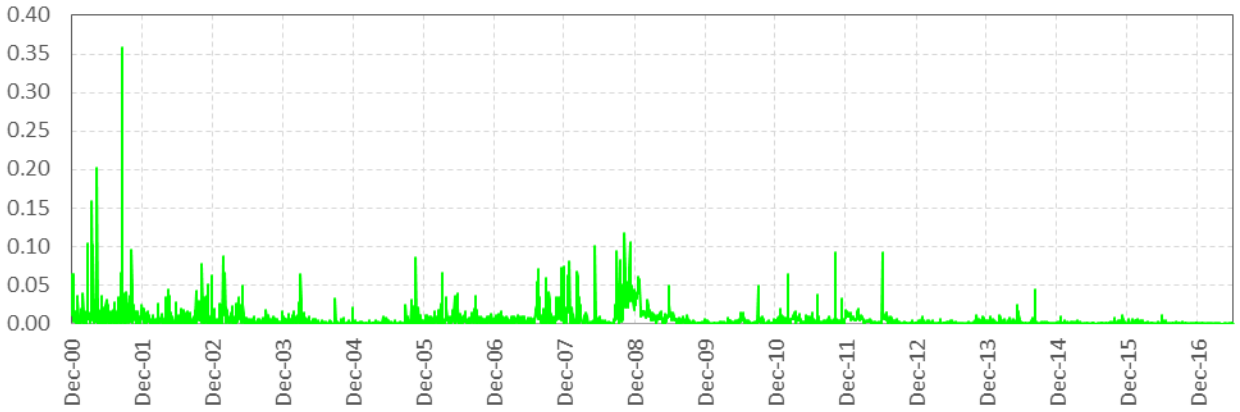
Figure 1. Euribor spot rate, spot rate volatility and STOXX volatility index (Dec 2000− June 2017)

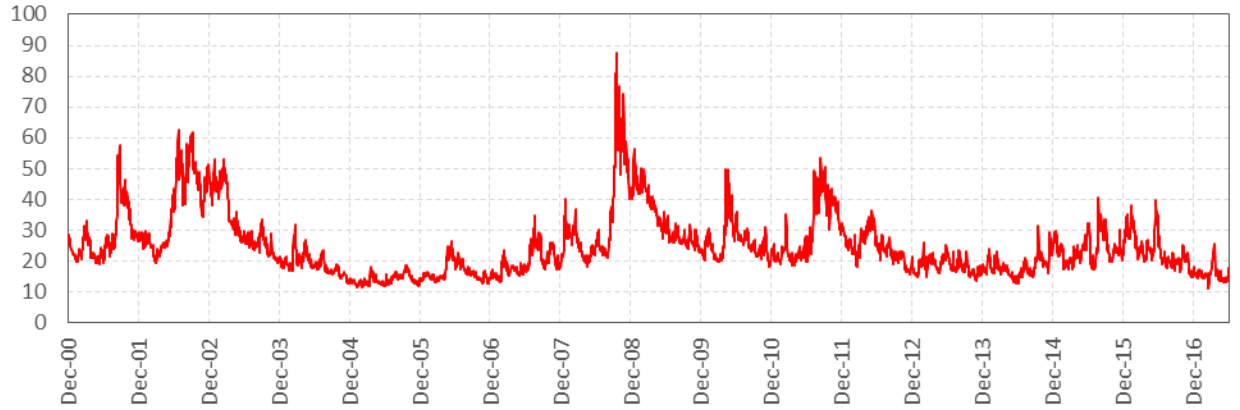
Panel A. Euribor spot rate



Panel B. Euribor spot rate volatily



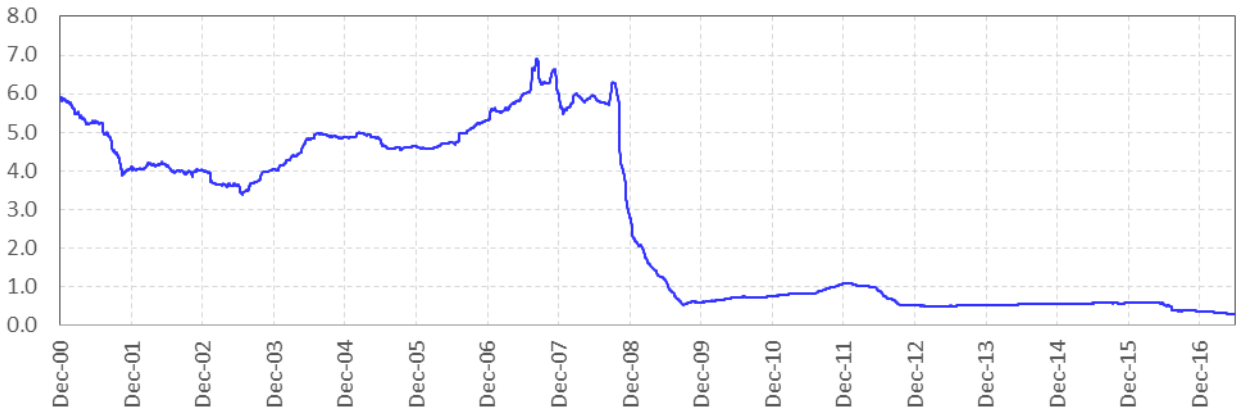
Panel C. STOXX 50 volatility index



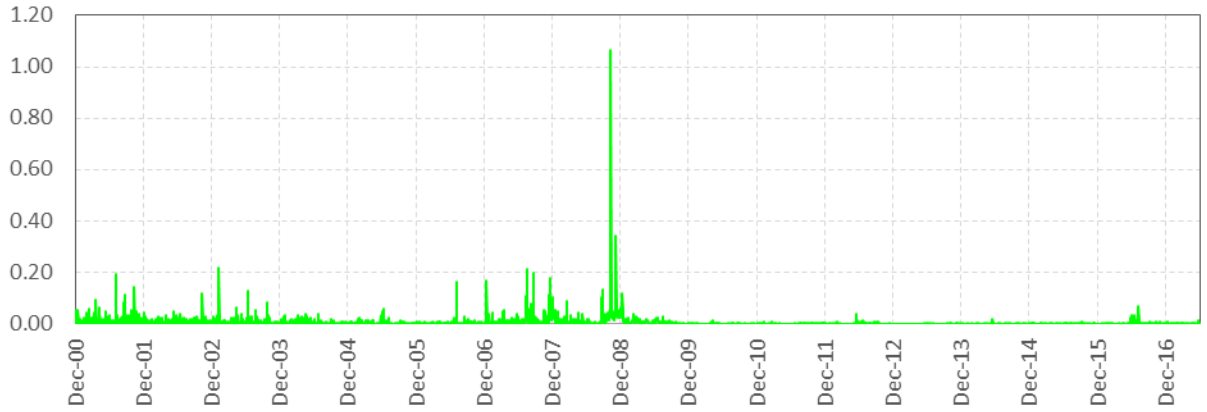
Note: The upper panel reports daily rates for the three month Euro deposits reported by the European Money Markets Institute Euribor Rate (EMMI Euribor). Panel B reports daily volatility estimated as the absolute value of daily Euribor rates changes. The lower panel reports the daily closing price of the STOXX 50 volatility index.

Figure 2. GBP Libor spot rate, spot rate volatility and FTSE 100 volatility index (Dec 2000− June 2017)

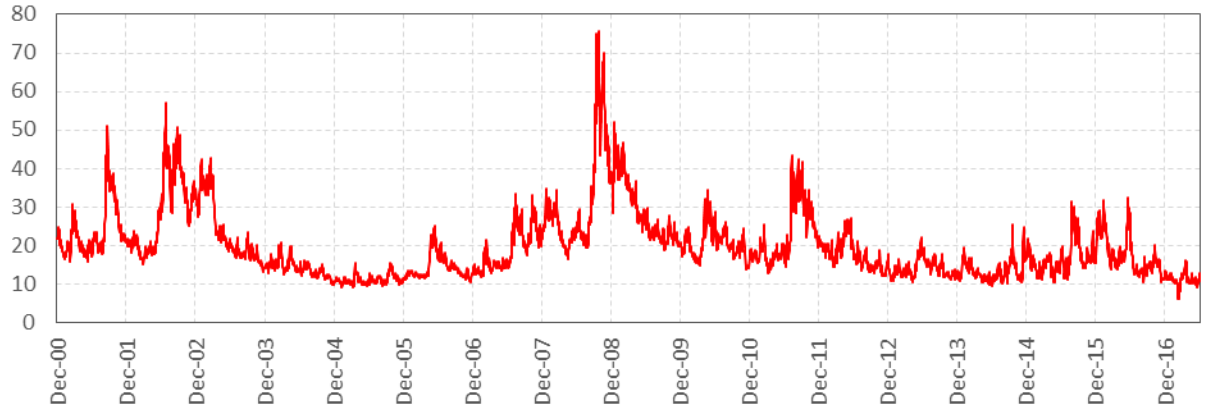
Panel A. GBP Libor spot rate



Panel B. GBP Libor spot rate volatily



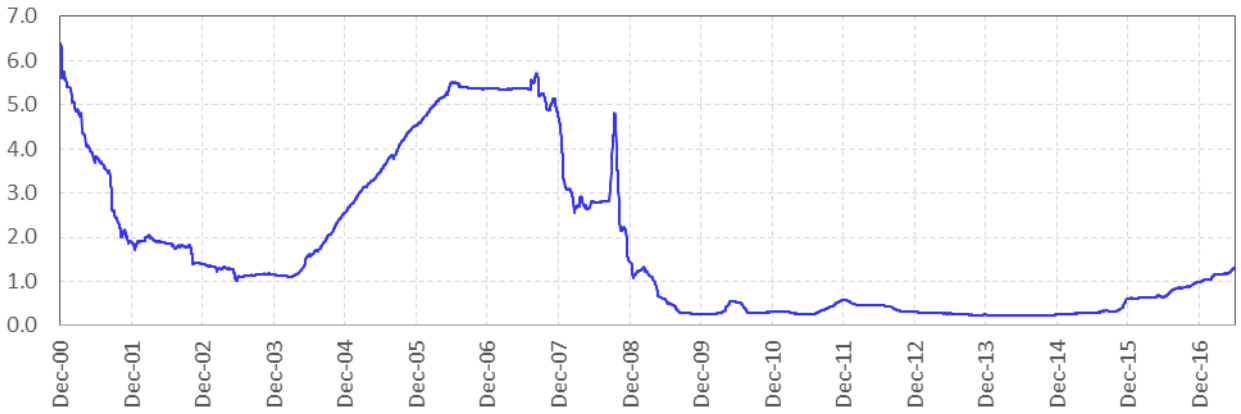
Panel C. FTSE 100 volatility index



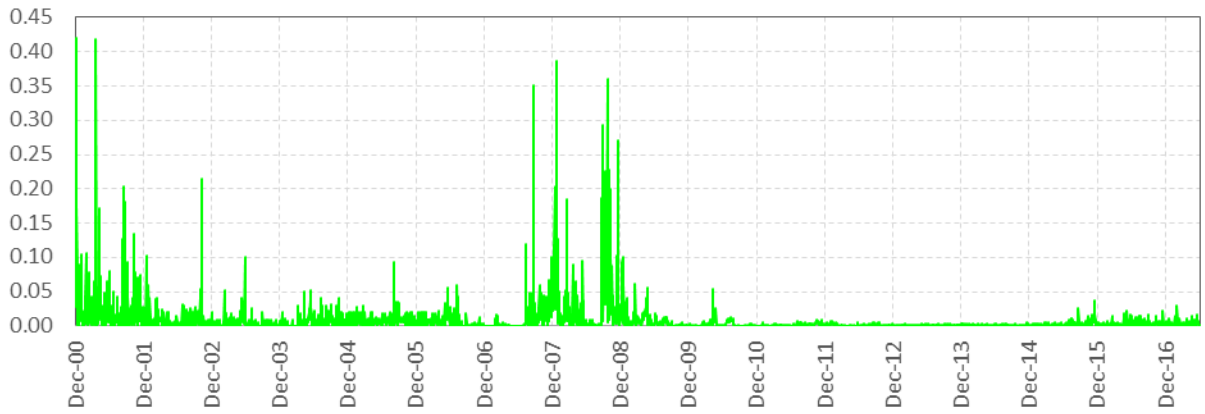
Note: The upper panel reports daily rates for the 3-month Sterling Libor (GBP Libor) administered by the ICE Benchmark Administration Limited. Panel B reports daily volatility estimated as the absolute value of daily GBP Libor rates changes. The lower panel reports the daily closing price of the FTSE 100 volatility index.

Figure 3. USD Libor spot rate, spot rate volatility and VIX index (Dec 2000− June 2017)

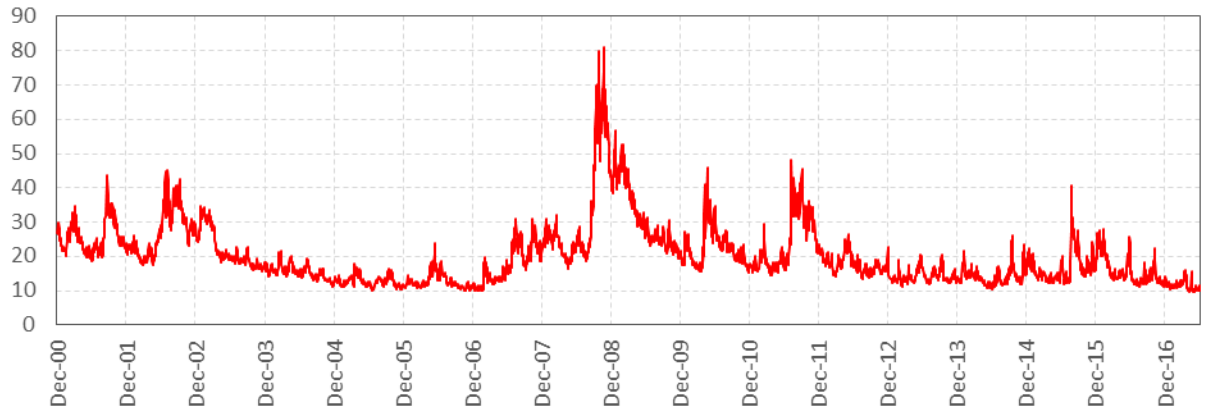
Panel A. USD Libor spot rate



Panel B. USD Libor spot rate volatily



Panel C. VIX volatility index



Note: The upper panel reports daily rates for the 3-month U.S. dollar Libor (USD Libor) administered by the ICE Benchmark Administration Limited. Panel B reports daily volatility estimated as the absolute value of daily USD Libor rates changes. The lower panel reports the daily closing price of VIX index.

Table 1. Descriptive statistics, STIR Futures contracts (December 2000 to June 2017)

Panel A. Euribor contracts

Exp. Month	Obs	Mean		St. Dev	Skewness	Kurtosis	JB		Q(5)		*Exp. Month*	Obs	Mean		St. Dev	Skewness	Kurtosis	JB		Q(5)	
Dec-00	514	-0.308		24.45	-0.585	2.77	193.1	*	4.29		Mar-09	756	0.293		35.51	0.127	4.08	525.8	*	19.10	*
Mar-01	576	-0.239		26.11	-0.480	2.34	153.4	*	5.75		Jun-09	756	0.383		37.86	-0.053	3.13	308.2	*	15.26	*
Jun-01	639	-0.156		27.86	-0.404	1.88	111.2	*	8.01		Sep-09	756	0.397		38.26	-0.194	3.42	373.5	*	13.06	*
Sep-01	704	-0.075		28.72	-0.338	2.02	133.3	*	8.77		Dec-09	756	0.446	*	38.77	-0.242	2.98	287.2	*	11.93	*
Dec-01	756	0.058		29.38	-0.337	1.84	120.4	*	10.52		Mar-10	756	0.471	*	38.37	-0.315	2.68	238.4	*	11.29	*
Mar-02	756	0.056		30.63	-0.468	1.63	110.9	*	9.80		Jun-10	756	0.542	*	38.69	-0.415	2.41	205.1	*	10.75	
Jun-02	756	0.158		30.15	-0.475	1.71	120.4	*	8.34		Sep-10	756	0.480	*	38.28	-0.457	2.27	188.1	*	9.83	
Sep-02	756	0.272		28.03	-0.518	2.12	175.6	*	6.65		Dec-10	756	0.437	*	36.34	-0.481	2.25	188.2	*	11.31	*
Dec-02	756	0.354		27.33	-0.605	2.46	237.2	*	7.50		Mar-11	756	0.381		33.08	-0.488	2.54	233.4	*	17.03	*
Mar-03	756	0.400	*	25.93	-0.697	2.58	270.3	*	8.45		Jun-11	756	0.481	*	28.93	-0.368	2.50	213.4	*	20.59	*
Jun-03	756	0.470	**	24.76	-0.734	3.21	393.2	*	6.44		Sep-11	756	0.376	*	26.80	-0.375	2.66	240.7	*	26.46	*
Sep-03	756	0.473	**	24.48	-0.655	2.77	295.2	*	7.08		Dec-11	756	0.268		25.71	-0.287	1.87	120.0	*	30.92	*
Dec-03	756	0.383	*	24.06	-0.666	2.37	232.8	*	8.80		Mar-12	756	0.327		24.47	-0.139	1.97	124.5	*	15.45	*
Mar-04	756	0.368	*	25.13	-0.657	1.84	160.5	*	11.92	*	Jun-12	756	0.369	*	23.17	0.130	2.03	132.1	*	14.91	*
Jun-04	756	0.393	*	27.42	-0.745	2.12	211.9	*	12.95	*	Sep-12	756	0.397	*	23.16	0.186	2.19	155.7	*	14.53	*
Sep-04	756	0.349		29.24	-0.756	2.21	226.2	*	12.79	*	Dec-12	756	0.386	*	22.45	0.263	2.53	210.9	*	10.14	
Dec-04	756	0.386	*	28.83	-0.705	2.60	274.9	*	9.47		Mar-13	756	0.342	*	22.18	0.329	2.30	180.4	*	10.92	
Mar-05	756	0.428	*	29.20	-0.739	2.78	312.9	*	10.30		Jun-13	756	0.261		21.35	0.357	2.28	180.3	*	10.34	
Jun-05	756	0.400	*	29.15	-0.706	2.55	268.1	*	10.58		Sep-13	756	0.236		19.99	0.339	2.34	186.5	*	11.39	*
Sep-05	756	0.299		27.65	-0.691	2.59	270.8	*	9.05		Dec-13	756	0.325	*	17.98	0.386	2.59	229.6	*	13.90	*
Dec-05	756	0.201		26.15	-0.643	2.43	238.0	*	7.22		Mar-14	756	0.414	**	16.81	0.498	2.69	258.5	*	17.89	*
Mar-06	756	0.179		23.16	-0.542	2.33	207.3	*	5.29		Jun-14	756	0.372	*	15.93	0.422	2.97	300.8	*	22.31	*
Jun-06	756	0.066		20.57	-0.445	2.25	184.1	*	5.37		Sep-14	756	0.245		12.09	-0.143	2.77	244.0	*	13.15	*
Sep-06	756	0.106		16.70	-0.178	1.83	109.1	*	11.16	*	Dec-14	756	0.210		9.65	-0.375	2.55	222.1	*	16.72	*
Dec-06	756	0.043		15.09	-0.179	1.78	104.0	*	14.08	*	Mar-15	756	0.201		9.28	-0.429	2.99	305.2	*	8.12	
Mar-07	756	-0.017		13.65	0.031	1.13	40.7	*	9.21		Jun-15	756	0.150		8.71	-0.646	4.18	602.1	*	12.59	*
Jun-07	756	-0.013		12.63	0.172	1.30	56.8	*	5.48		Sep-15	756	0.126		7.97	-0.702	5.74	1100.4	*	8.28	
Sep-07	756	-0.132		12.26	0.264	1.33	64.7	*	7.92		Dec-15	756	0.124		8.33	-0.843	7.00	1634.4	*	7.47	
Dec-07	756	-0.221		12.67	0.212	1.54	80.7	*	11.96	*	Mar-16	756	0.129		7.60	-1.017	10.69	3728.6	*	12.85	*
Mar-08	756	-0.180		14.29	0.169	1.99	128.3	*	9.68		Jun-16	756	0.197	*	5.93	-0.231	7.64	1847.7	*	11.15	*
Jun-08	756	-0.293		17.98	0.193	2.57	212.9	*	5.28		Sep-16	756	0.228	**	4.08	-0.204	9.30	2727.5	*	14.02	*
Sep-08	756	-0.280		21.51	-0.182	4.31	589.9	*	8.23		Dec-16	756	0.207	**	3.15	-0.707	12.28	4816.2	*	26.15	*
Dec-08	756	0.006		30.39	0.154	5.27	878.3	*	18.89	*	Mar-17	756	0.165	**	2.60	-0.936	16.01	8186.3	*	21.37	*
											Jun-17	756	0.117	*	2.25	-2.151	24.06	18812.1	*	15.53	*

Table 1. Continues…

Panel B. Eurodollar contracts

Exp. Month	Obs	Mean		St. Dev	Skewness	Kurtosis	JB		Q(5)	
Dec-00	747	-0.077		34.31	0.077	2.67	222.8	*	61.31	*
Mar-01	747	0.128		37.97	0.123	2.29	164.7	*	93.83	*
Jun-01	747	0.277		42.03	0.258	2.34	178.2	*	83.34	*
Sep-01	747	0.274		42.59	0.082	1.57	77.1	*	78.71	*
Dec-01	747	0.473		44.76	0.179	1.18	47.4	*	40.21	*
Mar-02	747	0.531	*	47.74	0.133	1.15	43.2	*	32.81	*
Jun-02	747	0.684	**	51.13	0.042	1.35	56.8	*	34.61	*
Sep-02	747	0.688	*	54.22	-0.201	2.13	146.2	*	39.98	*
Dec-02	747	0.779	**	58.99	-0.371	2.24	173.0	*	43.76	*
Mar-03	747	0.829	**	64.26	-0.446	2.28	186.6	*	45.45	*
Jun-03	747	0.818	**	65.88	-0.421	2.17	168.8	*	36.53	*
Sep-03	747	0.780	**	68.31	-0.448	2.00	149.7	*	31.09	
Dec-03	747	0.677	*	66.69	-0.432	1.75	118.4	*	30.17	
Mar-04	747	0.625	*	63.26	-0.496	1.60	110.4	*	26.28	
Jun-04	747	0.658	*	65.09	-0.430	1.36	80.8	*	34.47	*
Sep-04	747	0.485		71.03	-0.370	1.28	68.3	*	31.33	
Dec-04	747	0.550		72.32	-0.266	1.41	70.6	*	23.87	
Mar-05	747	0.445		73.16	-0.224	1.73	99.1	*	21.66	
Jun-05	747	0.283		74.52	-0.227	2.17	153.4	*	24.55	
Sep-05	747	0.028		70.69	-0.159	2.90	264.0	*	15.38	
Dec-05	747	-0.044		65.77	-0.095	3.30	339.8	*	16.72	
Mar-06	747	-0.122		61.35	0.006	3.50	382.3	*	25.33	
Jun-06	747	-0.255		56.17	-0.049	3.79	446.8	*	21.48	
Sep-06	747	-0.173		42.42	0.142	3.22	325.7	*	30.50	
Dec-06	747	-0.103		35.71	0.141	3.62	411.2	*	33.44	*
Mar-07	747	-0.182		31.63	-0.002	3.63	409.2	*	29.88	
Jun-07	747	-0.041		27.54	0.348	1.67	101.7	*	20.57	
Sep-07	747	-0.179		26.26	0.182	1.20	49.0	*	17.77	
Dec-07	747	-0.094		29.43	0.271	1.24	56.7	*	31.02	
Mar-08	747	0.300		36.75	0.883	5.33	982.4	*	33.66	*
Jun-08	747	0.233		41.72	0.562	3.59	440.3	*	29.65	
Sep-08	747	0.236		43.99	0.076	2.27	161.7	*	20.15	
Dec-08	747	0.379		63.37	-0.205	2.69	231.3	*	54.09	*
Mar-09	747	0.542		75.26	-0.008	3.29	337.9	*	32.26	*
Jun-09	747	0.645		83.86	-0.024	4.45	616.0	*	35.29	*
Sep-09	747	0.652		89.94	-0.131	5.68	1006.2	*	41.60	*
Dec-09	747	0.609		92.87	-0.262	5.91	1094.2	*	43.52	*
Mar-10	747	0.619		95.72	-0.398	6.67	1406.5	*	41.69	*
Jun-10	747	0.706	*	96.51	-0.460	6.03	1159.3	*	42.70	*
Sep-10	747	0.600		95.00	-0.485	5.26	891.1	*	40.14	*
Dec-10	747	0.557		88.55	-0.441	4.04	533.4	*	37.36	*
Mar-11	747	0.499		79.45	-0.362	4.15	552.7	*	33.40	*
Jun-11	747	0.662	*	70.56	-0.215	4.67	683.7	*	31.24	
Sep-11	747	0.509		68.53	-0.191	4.89	748.5	*	35.69	*
Dec-11	747	0.248		49.95	-0.460	3.79	473.0	*	39.98	*
Mar-12	747	0.325		45.74	-0.578	3.91	517.1	*	44.78	*
Jun-12	747	0.523	*	36.75	-0.044	2.09	136.2	*	44.78	*
Sep-12	747	0.474	*	31.09	0.009	1.98	121.6	*	37.35	*
Dec-12	747	0.454	*	30.40	-0.034	2.63	216.0	*	27.71	
Mar-13	747	0.452	*	30.88	-0.009	3.10	298.3	*	27.68	
Jun-13	747	0.360		27.30	-0.124	4.39	602.9	*	34.77	*
Sep-13	747	0.253		24.87	-0.064	6.24	1213.6	*	43.01	*
Dec-13	747	0.379	*	18.48	0.690	7.12	1638.9	*	39.98	*
Mar-14	747	0.347	*	13.92	0.975	8.57	2402.8	*	52.59	*
Jun-14	747	0.298	*	12.45	0.863	9.50	2902.5	*	38.11	*
Sep-14	747	0.155		8.75	0.247	6.09	1162.6	*	48.61	*
Dec-14	747	0.158		7.45	0.003	6.67	1384.5	*	37.29	*
Mar-15	747	0.178		7.37	-0.101	4.93	758.7	*	57.41	*
Jun-15	747	0.105		8.67	-0.394	4.38	616.1	*	36.98	*
Sep-15	747	0.068		11.67	-0.443	5.15	851.4	*	32.54	*
Dec-15	747	0.050		15.78	-0.460	5.07	827.1	*	24.17	
Mar-16	747	0.072		20.38	-0.425	5.14	846.1	*	22.04	
Jun-16	747	0.132		24.06	-0.282	5.70	1022.7	*	14.70	
Sep-16	747	0.177		19.60	-0.042	2.92	266.3	*	19.87	
Dec-16	747	0.144		20.19	0.059	3.16	312.2	*	28.98	
Mar-17	747	0.165		19.67	0.082	3.39	359.4	*	20.99	
Jun-17	747	0.179		19.33	0.294	2.80	255.2	*	24.39	

Table 1. Continues…

Panel C. Short-Sterling contracts

Exp. Month	Obs	Mean		St. Dev	Skewness	Kurtosis	JB		Q(5)		*Exp. Month*	Obs	Mean		St. Dev	Skewness	Kurtosis	JB		Q(5)	
Dec-00	747	0.074		36.10	-0.910	3.44	470.8	*	53.56	*	Mar-09	747	0.418		55.18	0.090	4.55	645.0	*	62.98	*
Mar-01	747	0.107		36.92	-0.997	3.72	554.3	*	63.84	*	Jun-09	747	0.562	*	54.95	-0.044	4.36	591.4	*	57.05	*
Jun-01	747	0.175		36.48	-0.952	3.85	575.3	*	57.91	*	Sep-09	747	0.603	*	53.54	-0.117	4.23	558.0	*	51.04	*
Sep-01	747	0.157		37.27	-1.031	4.62	797.2	*	67.21	*	Dec-09	747	0.651	*	52.64	-0.245	3.93	488.1	*	42.34	*
Dec-01	747	0.194		39.01	-0.865	4.10	616.6	*	58.14	*	Mar-10	747	0.674	*	53.06	-0.298	3.64	423.5	*	30.96	
Mar-02	747	0.187		40.88	-0.899	3.98	593.3	*	51.22	*	Jun-10	747	0.749	**	54.54	-0.323	3.37	366.1	*	24.69	
Jun-02	747	0.340		38.69	-0.646	2.35	223.9	*	26.58		Sep-10	747	0.648	*	55.13	-0.298	3.19	328.0	*	20.41	
Sep-02	747	0.467	*	37.90	-0.866	3.34	440.2	*	29.65		Dec-10	747	0.562	*	51.74	-0.325	2.76	249.8	*	24.78	
Dec-02	747	0.448	*	37.35	-0.807	3.35	430.2	*	24.19		Mar-11	747	0.575	*	47.21	-0.289	2.57	216.7	*	32.47	*
Mar-03	747	0.455	*	37.05	-0.736	3.19	383.3	*	19.41		Jun-11	747	0.692	**	39.46	-0.069	1.90	112.6	*	41.89	*
Jun-03	747	0.432		36.64	-0.594	2.92	308.9	*	16.49		Sep-11	747	0.549	*	36.46	-0.104	1.89	113.1	*	50.79	*
Sep-03	747	0.376		36.91	-0.500	2.49	223.4	*	15.70		Dec-11	747	0.330		32.25	-0.229	1.55	81.1	*	39.82	*
Dec-03	747	0.278		37.21	-0.497	2.10	168.7	*	17.60		Mar-12	747	0.381		31.35	-0.253	1.79	108.0	*	31.93	*
Mar-04	747	0.155		38.34	-0.566	2.00	165.1	*	19.96		Jun-12	747	0.498	**	27.94	-0.101	1.15	42.6	*	36.10	*
Jun-04	747	0.192		38.57	-0.686	2.33	227.6	*	24.47		Sep-12	747	0.465	*	27.18	-0.048	1.59	79.0	*	37.79	*
Sep-04	747	0.078		37.13	-0.730	2.55	269.1	*	28.72		Dec-12	747	0.492	**	25.62	0.016	1.96	120.0	*	42.23	*
Dec-04	747	0.133		33.78	-0.709	2.93	330.2	*	33.39	*	Mar-13	747	0.417	*	25.65	0.071	2.16	146.4	*	46.36	*
Mar-05	747	0.119		32.58	-0.593	2.80	287.5	*	34.06	*	Jun-13	747	0.311		24.04	0.171	2.90	265.4	*	46.02	*
Jun-05	747	0.113		31.74	-0.532	2.55	237.7	*	35.47	*	Sep-13	747	0.236		21.88	0.193	3.68	426.9	*	50.73	*
Sep-05	747	0.045		30.18	-0.473	2.81	272.9	*	27.36		Dec-13	747	0.375	*	18.96	0.719	4.03	569.9	*	41.57	*
Dec-05	747	0.030		27.96	-0.461	2.54	226.8	*	27.51		Mar-14	747	0.415	**	16.83	0.979	4.65	793.2	*	31.64	*
Mar-06	747	-0.006		24.61	-0.189	1.42	67.4	*	16.19		Jun-14	747	0.288	*	14.44	0.922	4.95	869.6	*	29.03	
Jun-06	747	-0.043		21.65	-0.103	1.50	71.0	*	10.68		Sep-14	747	0.143		12.34	0.195	2.41	185.8	*	45.08	*
Sep-06	747	-0.030		18.33	-0.149	1.42	66.0	*	12.62		Dec-14	747	0.122		12.87	-0.027	2.98	275.9	*	50.53	*
Dec-06	747	0.008		15.37	-0.054	1.54	74.1	*	12.91		Mar-15	747	0.131		13.65	-0.208	3.69	429.5	*	39.88	*
Mar-07	747	-0.064		15.15	-0.254	1.84	113.8	*	13.88		Jun-15	747	0.070		14.21	-0.539	3.92	514.2	*	39.78	*
Jun-07	747	-0.037		14.49	-0.199	1.86	112.2	*	14.37		Sep-15	747	0.045		15.86	-0.619	4.38	645.1	*	38.29	*
Sep-07	747	-0.212		14.00	-0.238	1.03	40.4	*	13.74		Dec-15	747	0.086		18.56	-0.653	4.44	667.5	*	41.87	*
Dec-07	747	-0.230		15.39	0.278	1.54	83.2	*	17.89		Mar-16	747	0.026		21.02	-0.661	4.46	674.6	*	40.90	*
Mar-08	747	-0.089		17.00	0.071	1.43	64.3	*	16.46		Jun-16	747	0.146		19.25	-0.342	3.09	311.1	*	44.03	*
Jun-08	747	-0.200		19.81	0.033	0.89	24.7	*	29.51		Sep-16	747	0.235		16.52	-0.116	2.99	280.4	*	37.27	*
Sep-08	747	-0.155		26.05	-0.369	2.64	234.6	*	44.87	*	Dec-16	747	0.278		15.14	0.161	3.35	352.5	*	29.55	
Dec-08	747	0.226		49.03	0.127	6.09	1156.5	*	75.05	*	Mar-17	747	0.284	*	14.90	0.616	4.05	558.9	*	29.21	
											Jun-17	747	0.315	*	14.96	0.738	6.23	1276.5	*	35.11	*

Note: The table reports the statistics of the daily log-price changes of the individual futures contracts over the last 760 observations for each contract (around 3 years before maturity). Mean and standard deviation (s.d.) are given in basis points. JB is the Jarque-Bera statistic to test the null hypothesis of normal distribution. Q(5) is the Ljung-Box Q-statistic for autocorrelation (5 lags). * and ** indicate significance at the 5% and 1% levels, respectively.

Table 2. Euribor Futures Contracts – Volatility and Time to Maturity

Panel A. Three years before expiration

	Time to maturity			*Time to maturity & Market Volatility*					*Time to maturity*			*Time to maturity & Market Volatility*			
Exp. Month	α	β	Adj. R^2	α	β	φ	Adj. R^2	*Exp. Month*	α	β	Adj. R^2	α	β	φ	Adj. R^2
Dec-00	2.947 **	0.002 **	0.011	11.824 **	0.003 **	-2.862 **	0.030	Mar-09	6.200 **	**-0.003** **	0.063	1.087	**-0.002** **	1.391	0.071
Mar-01	3.050 **	0.002 **	0.011	11.011 **	0.003 **	-2.577 *	0.024	Jun-09	5.973 **	**-0.003** **	0.038	2.434	**-0.002**	0.937	0.041
Jun-01	3.242 **	0.001 **	0.008	10.029 **	0.002 **	-2.193 *	0.017	Sep-09	5.223 **	**-0.001** **	0.009	-4.220	0.001	2.482 **	0.030
Sep-01	3.256 **	0.001 **	0.010	10.107 **	0.002 **	-2.215 *	0.019	Dec-09	4.556 **	**0.000**	-0.001	-8.417 **	0.003 **	3.495 **	0.051
Dec-01	3.244 **	0.001 **	0.012	6.593 **	0.001 **	-1.021	0.014	Mar-10	3.618 **	0.002 **	0.011	-10.284 **	0.003 **	3.872 **	0.086
Mar-02	3.026 **	0.002 **	0.026	-2.705	0.002 **	1.722 *	0.030	Jun-10	3.206 **	0.003 **	0.032	-8.289 **	0.003 **	3.301 **	0.090
Jun-02	2.643 **	0.003 **	0.046	-7.492 **	0.003 **	3.074 **	0.066	Sep-10	2.552 **	0.004 **	0.075	-7.875 **	0.004 **	3.028 **	0.124
Sep-02	3.064 **	0.002 **	0.019	-0.576	0.002 **	1.056	0.022	Dec-10	1.789 **	0.005 **	0.134	-6.288 **	0.005 **	2.444 **	0.164
Dec-02	3.867 **	0.000	-0.001	-0.221	0.001	1.129 *	0.003	Mar-11	1.322 **	0.005 **	0.169	-4.680 **	0.005 **	1.885 **	0.186
Mar-03	4.086 **	**-0.001**	0.001	0.684	0.000	0.910	0.003	Jun-11	1.417 **	0.005 **	0.156	-3.616	0.004 **	1.655 **	0.167
Jun-03	4.017 **	**-0.001**	0.002	-2.611	0.001	1.736 **	0.013	Sep-11	1.853 **	0.004 **	0.103	-3.283	0.003 **	1.696 **	0.115
Sep-03	3.465 **	0.000	0.000	-7.283 **	0.002 **	2.903 **	0.049	Dec-11	3.151 **	0.001 **	0.013	-2.138	0.001 *	1.618 **	0.028
Dec-03	2.965 **	0.001 **	0.012	-8.037 **	0.002 **	3.054 **	0.081	Mar-12	3.432 **	0.001	0.002	-0.734	0.001	1.244 *	0.009
Mar-04	2.959 **	0.002 **	0.017	-5.061 **	0.001 **	2.364 **	0.067	Jun-12	3.332 **	0.001	0.001	-0.066	0.001 *	1.011	0.004
Jun-04	3.191 **	0.001 **	0.012	-2.761	0.001	1.848 **	0.036	Sep-12	2.861 **	0.001 **	0.014	-3.539	0.002 **	1.905 **	0.029
Sep-04	2.866 **	0.002 **	0.026	-1.337	0.001 *	1.377 **	0.036	Dec-12	2.048 **	0.003 **	0.051	-4.905 **	0.003 **	2.120 **	0.072
Dec-04	2.884 **	0.002 **	0.021	-2.086	0.000	1.722 **	0.035	Mar-13	1.338 **	0.004 **	0.120	-5.452 **	0.003 **	2.177 **	0.144
Mar-05	2.588 **	0.002 **	0.036	-1.315	0.001	1.492 **	0.041	Jun-13	0.930 **	0.004 **	0.160	-6.329 **	0.004 **	2.375 **	0.188
Jun-05	2.030 **	0.003 **	0.069	7.931 **	0.007 **	-2.401 *	0.075	Sep-13	0.627 **	0.005 **	0.193	-6.175 **	0.004 **	2.269 **	0.220
Sep-05	1.497 **	0.004 **	0.106	8.574 **	0.008 **	-2.953 **	0.119	Dec-13	0.470 **	0.005 **	0.206	-5.366 **	0.004 **	2.027 **	0.228
Dec-05	1.339 **	0.004 **	0.129	5.406 **	0.006 **	-1.672 *	0.133	Mar-14	0.371 **	0.005 **	0.218	-4.416 **	0.003 **	1.720 **	0.232
Mar-06	1.238 **	0.004 **	0.143	4.255	0.005 **	-1.215	0.145	Jun-14	0.209	0.005 **	0.239	-3.228	0.004 **	1.281	0.244
Jun-06	1.345 **	0.004 **	0.121	2.861	0.004 **	-0.602	0.125	Sep-14	0.436 **	0.004 **	0.201	-1.641	0.003 **	0.778	0.205
Sep-06	1.533 **	0.003 **	0.089	4.851 **	0.003 **	-1.254 **	0.101	Dec-14	0.452 **	0.003 **	0.190	1.597	0.003 **	-0.418	0.194
Dec-06	1.541 **	0.003 **	0.081	2.866	0.003 **	-0.495	0.084	Mar-15	0.236 **	0.003 **	0.223	0.083	0.004 **	0.052	0.225
Mar-07	1.658 **	0.002 **	0.065	0.511	0.002 **	0.422	0.066	Jun-15	0.051	0.004 **	0.235	-0.643	0.004 **	0.236	0.235
Jun-07	1.651 **	0.002 **	0.057	0.271	0.002 **	0.492	0.058	Sep-15	-0.108	0.004 **	0.240	-1.227	0.004 **	0.362	0.243
Sep-07	1.838 **	0.002 **	0.040	-1.711	0.002 **	1.203 *	0.048	Dec-15	-0.450 **	0.004 **	0.302	-4.163 **	0.005 **	1.176 **	0.308
Dec-07	2.353 **	0.001 **	0.009	-2.859	0.002 **	1.708 **	0.021	Mar-16	-0.299 *	0.004 **	0.239	-5.889 **	0.004 **	1.716 **	0.254
Mar-08	2.847 **	0.000	-0.001	-4.949	0.001 **	2.486 **	0.027	Jun-16	-0.216	0.003 **	0.231	-3.771 **	0.004 **	1.082 **	0.235
Jun-08	3.763 **	**-0.001** **	0.011	-9.649 **	0.001 **	4.202 **	0.080	Sep-16	0.010	0.002 **	0.184	-1.017	0.002 **	0.316	0.180
Sep-08	3.975 **	**-0.001** *	0.008	-9.958 **	0.001 *	4.300 **	0.061	Dec-16	0.141	0.002 **	0.152	0.036	0.002 **	0.033	0.152
Dec-08	5.663 **	**-0.003** **	0.061	-6.645	**0.000**	3.505 **	0.112	Mar-17	0.232 **	0.001 **	0.117	-0.252	0.002 **	0.156	0.118
								Jun-17	0.2928 **	0.001 **	0.092	-1.6437 **	0.001 **	0.654 **	0.106

	Time to maturity	*Time to maturity*	*Market Volatility*
Positive Relation	53	56	39
Negative Relation	6	1	8
No relation	8	10	20

Table 2. Continues….

Panel B. One year before expiration

	Time to maturity			*Time to maturity & Market Volatility*					*Time to maturity*			*Time to maturity & Market Volatility*			
Exp. Month	α	β	Adj. R^2	α	β	φ	Adj. R^2	*Exp. Month*	α	β	Adj. R^2	α	β	φ	Adj. R^2
Dec-00	1.654 **	0.008 **	0.056	1.044	0.007 **	0.195	0.053	Mar-09	3.846 **	0.010 **	0.030	-14.907 **	0.024 **	4.569 **	0.073
Mar-01	1.854 **	0.007 **	0.046	-4.647	0.006 **	2.088	0.048	Jun-09	1.876 **	0.017 **	0.111	-10.186	0.021 **	3.082 **	0.139
Jun-01	3.047 **	0.000	-0.004	-0.201	0.000	1.023	-0.006	Sep-09	-0.089	0.023 **	0.231	6.510	0.027 **	-1.993	0.234
Sep-01	2.843 **	0.002	0.001	9.628	0.003	-2.144	0.002	Dec-09	0.514	0.015 **	0.193	3.332	0.017 **	-0.903	0.192
Dec-01	2.144 **	0.008 **	0.048	-3.527	0.010 **	1.583	0.052	Mar-10	0.107	0.014 **	0.215	2.695	0.015 **	-0.836	0.215
Mar-02	2.158 **	0.008 **	0.046	-4.876	0.009 **	2.031	0.056	Jun-10	1.074 **	0.008 **	0.105	-5.971	0.008 **	2.170 *	0.122
Jun-02	1.893 **	0.008 **	0.050	-8.543	0.006 **	3.245 **	0.086	Sep-10	1.201 **	0.007 **	0.095	-8.578 **	0.008 **	2.878 **	0.140
Sep-02	1.296 **	0.013 **	0.127	3.582	0.013 **	-0.655	0.131	Dec-10	1.013 **	0.007 **	0.112	-7.101 **	0.007 **	2.472 **	0.163
Dec-02	2.588 **	0.006 **	0.040	-6.864	0.013 **	2.332 **	0.069	Mar-11	0.951 **	0.007 **	0.122	-3.825	0.005 **	1.569 *	0.138
Mar-03	1.973 **	0.009 **	0.074	-14.714 **	0.018 **	4.112 **	0.147	Jun-11	1.367 **	0.005 **	0.061	-3.311	0.004 *	1.561	0.064
Jun-03	0.799 **	0.015 **	0.196	-6.301	0.014 **	1.951	0.203	Sep-11	2.323 **	0.002	0.003	-5.729	0.004 **	2.391 **	0.031
Sep-03	0.774 **	0.011 **	0.165	-1.422	0.010 **	0.672	0.170	Dec-11	3.221 **	0.003	0.002	-13.836 **	0.014 **	4.477 **	0.057
Dec-03	0.767 **	0.010 **	0.138	-1.820	0.008 **	0.831	0.144	Mar-12	2.133 **	0.007 **	0.046	-8.554 **	0.011 **	2.972 **	0.099
Mar-04	0.674 **	0.013 **	0.165	-4.284	0.008	1.755	0.156	Jun-12	0.178	0.016 **	0.216	-4.799	0.015 **	1.522	0.220
Jun-04	0.697 *	0.014 **	0.148	1.926	0.014 **	-0.397	0.142	Sep-12	0.525 *	0.010 **	0.156	-6.143	0.006 **	2.148 **	0.174
Sep-04	-0.013	0.015 **	0.216	2.609	0.016 **	-0.900	0.221	Dec-12	0.481 **	0.006 **	0.130	-5.499 **	0.004 **	1.945 **	0.157
Dec-04	0.293	0.012 **	0.159	3.141	0.013 **	-1.041	0.172	Mar-13	0.415 **	0.006 **	0.159	-1.873	0.005 **	0.809	0.164
Mar-05	-0.027	0.013 **	0.213	8.535	0.019 **	-3.408	0.226	Jun-13	0.577 **	0.004 **	0.083	0.748	0.004 **	-0.054	0.077
Jun-05	-0.322	0.013 **	0.255	2.024	0.014 **	-0.929	0.251	Sep-13	0.815 **	0.003 **	0.037	2.671	0.003 **	-0.628	0.036
Sep-05	-0.095	0.010 **	0.282	1.605	0.010 **	-0.661	0.286	Dec-13	0.363 *	0.006 **	0.120	-3.851	0.006 **	1.453	0.134
Dec-05	1.016 **	0.004 **	0.070	4.002	0.004 **	-1.096	0.077	Mar-14	0.505 **	0.005 **	0.101	-6.726	0.004 **	2.555 *	0.136
Mar-06	0.891 **	0.006 **	0.091	2.265	0.006 **	-0.513	0.094	Jun-14	0.176	0.006 **	0.180	-8.188 **	0.005 **	2.975 **	0.223
Jun-06	0.744 **	0.007 **	0.114	0.583	0.007 **	0.057	0.111	Sep-14	0.332 **	0.004 **	0.148	-0.012	0.004 **	0.127	0.140
Sep-06	0.392 *	0.009 **	0.164	-2.117	0.010 **	0.846	0.163	Dec-14	0.182 *	0.004 **	0.178	-1.159	0.004 **	0.467	0.169
Dec-06	0.499 **	0.008 **	0.165	-3.859	0.008 **	1.528 *	0.180	Mar-15	0.321 **	0.002 **	0.083	-1.655	0.003 **	0.623	0.092
Mar-07	0.347 *	0.009 **	0.194	-5.123 **	0.008 **	2.027 **	0.218	Jun-15	0.460 **	0.001	0.008	-0.392	0.001 *	0.269	0.008
Jun-07	0.030	0.009 **	0.243	-0.886	0.009 **	0.332	0.239	Sep-15	0.324 **	0.001 **	0.031	-0.276	0.001 **	0.187	0.032
Sep-07	0.972 **	0.005 **	0.072	-11.882 **	0.011 **	4.142 **	0.164	Dec-15	0.452 **	0.000	0.001	0.904	0.000	-0.143	0.000
Dec-07	2.515 **	**-0.002**	0.004	-8.517 **	0.004 *	3.413 **	0.074	Mar-16	0.930 **	**-0.001** *	0.016	2.912	**-0.002** *	-0.579	0.024
Mar-08	3.101 **	**-0.002**	0.000	-15.643 **	0.006 **	5.646 **	0.125	Jun-16	0.681 **	0.000	-0.004	0.330	0.000	0.113	-0.008
Jun-08	3.625 **	0.001	-0.003	-18.324 **	0.005 **	6.790 **	0.134	Sep-16	0.115	0.004 **	0.071	-0.581	0.004 **	0.223	0.070
Sep-08	2.490 **	0.008 **	0.036	-17.674	0.010 **	6.285 **	0.092	Dec-16	0.125	0.003 **	0.085	-2.220	0.002 **	0.792 *	0.109
Dec-08	5.219 **	0.001	-0.004	-15.877 **	0.014 **	5.531 **	0.095	Mar-17	0.224 **	0.001 **	0.041	-1.719	0.000	0.706 *	0.089
								Jun-17	0.0886	0.002 **	0.104	-0.7202	0.001 **	0.306	0.106

	Time to maturity	*Time to maturity*	*Market Volatility*
Positive Relation	55	60	26
Negative Relation	1	1	0
No relation	11	6	41

The table reports $\beta$and φ coefficients from regressions $\sigma_F(t,T) = \alpha + \beta(T-t) + u_t$ and $\sigma_F(t,T) = \alpha + \beta(T-t) + \varphi S_{Mt} + u_t$ where *(T – t)* are days to maturity and S_{Mt} is the market volatility (STOXX50 volatility index). We exclude data from 10 days before expiration date. * and ** indicate significance at the 5% and 1% levels, respectively. Bold numbers indicate the presence of maturity effect or negative relation with market volatility. The numbers at the bottom of each panel show the total count of contracts with positive or negative and significant relation with time to maturity and the number of contracts with no relation.

Table 3. Eurodollar Futures Contracts – Volatility and Time to Maturity

Panel A. Three years before expiration

	Time to maturity			*Time to maturity & Market Volatility*					*Time to maturity*			*Time to maturity & Market Volatility*			
Exp. Month	α	β	Adj. R^2	α	β	φ	Adj. R^2	*Exp. Month*	α	β	Adj. R^2	α	β	φ	Adj. R^2
Dec-00	3.434 **	0.001 **	0.006	-10.560 **	0.001	4.476 **	0.042	Mar-09	9.774 **	**-0.006** **	0.105	3.887	**-0.004** **	1.576 *	0.110
Mar-01	4.307 **	0.000	-0.001	-11.282 **	**0.000**	4.995 **	0.038	Jun-09	9.042 **	**-0.005** **	0.048	-0.607	**-0.001**	2.498 **	0.057
Jun-01	4.928 **	**0.000**	-0.001	-10.095 **	**-0.001** *	4.812 **	0.033	Sep-09	7.496 **	**-0.002** **	0.005	-14.979 **	0.006 **	5.841 **	0.067
Sep-01	4.178 **	0.001 *	0.006	-12.826 **	0.000	5.501 **	0.040	Dec-09	5.946 **	0.001	0.000	-18.499 **	0.007 **	6.564 **	0.097
Dec-01	5.092 **	**0.000**	-0.001	-3.861	0.000	2.735 **	0.006	Mar-10	4.649 **	0.003 **	0.019	-17.822 **	0.007 **	6.351 **	0.116
Mar-02	4.978 **	0.000	-0.001	-9.516 **	0.001	4.459 **	0.018	Jun-10	3.738 **	0.005 **	0.052	-13.344 **	0.006 **	5.102 **	0.115
Jun-02	5.158 **	0.000	-0.001	-10.598 **	0.001	4.943 **	0.025	Sep-10	2.918 **	0.007 **	0.089	-11.205 **	0.007 **	4.300 **	0.132
Sep-02	5.953 **	**-0.001**	0.002	4.675	**-0.001**	0.363	0.000	Dec-10	1.514 **	0.009 **	0.174	-8.866 **	0.008 **	3.291 **	0.199
Dec-02	5.998 **	**-0.001**	0.000	10.372 **	**-0.001**	-1.333	0.001	Mar-11	0.706 **	0.010 **	0.210	-8.135 **	0.008 **	2.951 **	0.232
Mar-03	5.609 **	0.000	-0.001	5.273	0.000	0.106	-0.002	Jun-11	0.145	0.010 **	0.237	-7.832 **	0.008 **	2.820 **	0.253
Jun-03	5.338 **	0.001	0.001	-5.353	0.002 **	3.183 **	0.012	Sep-11	-0.435	0.011 **	0.281	-2.453	0.010 **	0.727	0.282
Sep-03	4.436 **	0.003 **	0.020	-10.966 **	0.003 **	4.777 **	0.049	Dec-11	0.484 *	0.008 **	0.237	-1.461	0.008 **	0.647	0.238
Dec-03	3.059 **	0.005 **	0.077	-13.453 **	0.004 **	5.313 **	0.117	Mar-12	0.521 *	0.008 **	0.230	-1.707	0.007 **	0.731	0.230
Mar-04	3.150 **	0.005 **	0.072	-11.671 **	0.003 **	4.973 **	0.114	Jun-12	0.505 *	0.007 **	0.239	-0.015	0.007 **	0.172	0.236
Jun-04	3.457 **	0.005 **	0.065	-7.136 **	0.003 **	3.696 **	0.083	Sep-12	0.630 **	0.006 **	0.213	2.260	0.006 **	-0.540	0.211
Sep-04	3.805 **	0.004 **	0.056	-1.734	0.003 **	2.024 *	0.058	Dec-12	0.231	0.006 **	0.232	2.552	0.006 **	-0.787	0.230
Dec-04	4.140 **	0.004 **	0.040	-2.596	0.002 *	2.550 **	0.044	Mar-13	-0.570 **	0.008 **	0.301	3.837 **	0.008 **	-1.560 **	0.306
Mar-05	3.574 **	0.005 **	0.059	-0.790	0.003 **	1.783	0.057	Jun-13	-0.901 **	0.007 **	0.316	5.653 **	0.009 **	-2.419 **	0.334
Jun-05	2.713 **	0.006 **	0.101	17.237 **	0.012 **	-5.991 **	0.114	Sep-13	-1.251 **	0.008 **	0.335	4.239 **	0.008 **	-2.050 **	0.349
Sep-05	2.424 **	0.006 **	0.104	13.774 **	0.011 **	-4.760 **	0.112	Dec-13	-1.095 **	0.007 **	0.336	2.094	0.007 **	-1.223 *	0.342
Dec-05	2.101 **	0.007 **	0.119	10.210 **	0.009 **	-3.368 *	0.122	Mar-14	-0.808 **	0.005 **	0.304	-0.464	0.005 **	-0.135	0.304
Mar-06	1.687 **	0.007 **	0.142	0.989	0.007 **	0.319	0.140	Jun-14	-0.807 **	0.005 **	0.291	-2.703	0.005 **	0.774	0.294
Jun-06	1.385 **	0.007 **	0.159	-3.522	0.006 **	2.050	0.160	Sep-14	-0.462 **	0.004 **	0.265	-3.634	0.003 **	1.314 *	0.276
Sep-06	1.944 **	0.005 **	0.115	0.227	0.005 **	0.697	0.117	Dec-14	-0.182	0.003 **	0.225	-1.140	0.003 **	0.387	0.225
Dec-06	1.781 **	0.005 **	0.109	-1.167	0.004 **	1.199	0.113	Mar-15	0.190 *	0.003 **	0.160	-0.273	0.003 **	0.190	0.157
Mar-07	1.749 **	0.004 **	0.102	-3.504	0.004 **	2.156 *	0.110	Jun-15	0.653 **	0.002 **	0.099	-1.009	0.002 **	0.630	0.099
Jun-07	2.133 **	0.003 **	0.068	0.395	0.003 **	0.697	0.069	Sep-15	1.238 **	0.002 **	0.053	-1.465	0.002 **	1.008 *	0.056
Sep-07	2.745 **	0.002 **	0.028	1.930	0.002 **	0.297	0.029	Dec-15	1.433 **	0.002 **	0.060	-1.471	0.003 **	1.042 *	0.064
Dec-07	3.931 **	0.000	-0.001	-0.460	0.001 *	1.543 *	0.007	Mar-16	1.340 **	0.003 **	0.091	-2.759	0.004 **	1.418 *	0.097
Mar-08	5.196 **	**-0.001** *	0.008	-2.923	0.000	2.705 **	0.027	Jun-16	1.022 **	0.004 **	0.142	-5.113 **	0.005 **	2.141 **	0.156
Jun-08	6.143 **	**-0.002** **	0.029	-4.806	0.000	3.518 **	0.057	Sep-16	1.573 **	0.003 **	0.100	-3.302	0.003 **	1.722 **	0.114
Sep-08	6.380 **	**-0.003** **	0.034	-5.071	0.000	3.590 **	0.060	Dec-16	1.394 **	0.003 **	0.119	-5.268 **	0.004 **	2.379 **	0.145
Dec-08	9.253 **	**-0.006** **	0.126	-0.281	**-0.003** **	2.712 **	0.142	Mar-17	1.356 **	0.003 **	0.115	-6.165 **	0.003 **	2.771 **	0.156
								Jun-17	1.1489 **	0.004 **	0.145	-5.8166 **	0.003 **	2.678 **	0.184

	Time to maturity	*Time to maturity*	*Market Volatility*
Positive Relation	49	51	39
Negative Relation	7	3	7
No relation	11	13	21

Table 3. Continues…

Panel B. One year before expiration

	Time to maturity			*Time to maturity & Market Volatility*					*Time to maturity*			*Time to maturity & Market Volatility*			
Exp. Month	α	β	Adj. R^2	α	β	φ	Adj. R^2	*Exp. Month*	α	β	Adj. R^2	α	β	φ	Adj. R^2
Dec-00	0.899 **	0.012 **	0.108	-7.570	0.012 **	2.716	0.119	Mar-09	6.538 **	0.012 **	0.023	-17.249 **	0.031 **	5.775 **	0.069
Mar-01	3.399 **	0.003	0.002	-13.138	0.004	5.199 **	0.033	Jun-09	2.066 **	0.029 **	0.136	-17.209 **	0.037 **	4.906 **	0.175
Jun-01	5.557 **	**-0.005** *	0.012	-7.290	**-0.002**	3.858	0.023	Sep-09	-1.638 *	0.042 **	0.266	11.516	0.051 **	-4.067	0.275
Sep-01	3.621 **	0.005 *	0.008	-24.925 **	0.002	9.133 **	0.086	Dec-09	-0.125	0.021 **	0.198	13.683	0.033 **	-4.620	0.205
Dec-01	3.296 **	0.012 **	0.053	-9.837	0.015 **	3.847 *	0.087	Mar-10	-0.340	0.020 **	0.168	13.960	0.029 **	-4.920 *	0.178
Mar-02	2.584 **	0.014 **	0.073	-6.070	0.014 **	2.660	0.086	Jun-10	0.299	0.017 **	0.203	-14.588 **	0.013 **	4.971 **	0.253
Jun-02	2.797 **	0.013 **	0.060	-1.769	0.011 **	1.536	0.052	Sep-10	1.278 **	0.010 **	0.118	-6.974 **	0.011 **	2.565 **	0.147
Sep-02	1.845 **	0.021 **	0.131	15.483 **	0.020 **	-4.183 **	0.138	Dec-10	0.234	0.013 **	0.283	-4.644	0.013 **	1.544 *	0.297
Dec-02	1.562 **	0.020 **	0.156	-2.356	0.022 **	1.092	0.154	Mar-11	0.288	0.009 **	0.184	1.176	0.009 **	-0.296	0.174
Mar-03	0.401	0.024 **	0.215	-22.255 **	0.032 **	6.336 **	0.266	Jun-11	0.307 *	0.007 **	0.183	2.915	0.009 **	-0.957	0.183
Jun-03	-0.907	0.031 **	0.318	3.316	0.033 **	-1.327	0.315	Sep-11	0.991 **	0.005 **	0.055	-0.195	0.005 **	0.381	0.053
Sep-03	0.215	0.018 **	0.213	6.631	0.023 **	-2.231	0.216	Dec-11	1.244 **	0.005 **	0.052	-7.619 **	0.011 **	2.471 **	0.101
Dec-03	-0.068	0.017 **	0.230	3.392	0.019 **	-1.267	0.230	Mar-12	1.198 **	0.004 **	0.044	-2.652	0.005 **	1.164 **	0.072
Mar-04	0.025	0.018 **	0.229	-4.253	0.016 **	1.593	0.223	Jun-12	0.488 **	0.006 **	0.120	-0.248	0.006 **	0.256	0.116
Jun-04	0.004	0.021 **	0.213	-3.034	0.020 **	1.110	0.211	Sep-12	0.296 *	0.006 **	0.154	-0.950	0.005 **	0.470	0.153
Sep-04	0.954 *	0.016 **	0.121	4.046	0.016 **	-1.110	0.117	Dec-12	0.223 *	0.005 **	0.212	-0.839	0.005 **	0.387	0.211
Dec-04	1.039 *	0.014 **	0.095	-1.283	0.014 **	0.886	0.091	Mar-13	-0.008	0.005 **	0.226	0.151	0.005 **	-0.060	0.224
Mar-05	-0.250	0.021 **	0.189	0.010	0.021 **	-0.095	0.186	Jun-13	0.000	0.004 **	0.190	-1.388	0.003 **	0.545	0.194
Jun-05	0.027	0.017 **	0.162	-8.710	0.015 **	3.438	0.171	Sep-13	0.075	0.003 **	0.145	-2.141	0.002 **	0.842 *	0.169
Sep-05	1.202 **	0.009 **	0.075	-11.577 **	0.007 **	5.119 **	0.101	Dec-13	0.330 **	0.001 **	0.027	-3.509 **	0.001 **	1.449 **	0.081
Dec-05	1.415 **	0.009 **	0.073	-3.793	0.009 **	2.039	0.077	Mar-14	0.191 **	0.002 **	0.076	-5.547 **	0.003 **	2.137 **	0.167
Mar-06	0.789 **	0.013 **	0.147	-0.546	0.013 **	0.555	0.141	Jun-14	-0.382 **	0.006 **	0.289	-3.873 **	0.005 **	1.345 *	0.310
Jun-06	1.443 **	0.009 **	0.090	5.305	0.008 **	-1.505	0.090	Sep-14	-0.207 **	0.003 **	0.212	-0.102	0.003 **	-0.042	0.209
Sep-06	1.878 **	0.006 **	0.050	7.156	0.005 **	-1.974	0.059	Dec-14	-0.151 *	0.003 **	0.241	-0.237	0.003 **	0.033	0.238
Dec-06	0.996 **	0.009 **	0.117	-2.444	0.009 **	1.344	0.127	Mar-15	0.110	0.002 **	0.115	-0.473	0.003 **	0.206	0.114
Mar-07	0.306	0.013 **	0.200	-1.221	0.012 **	0.643	0.196	Jun-15	0.329 **	0.003 **	0.079	-2.089	0.004 **	0.874 *	0.096
Jun-07	0.448	0.012 **	0.150	-0.772	0.012 **	0.479	0.149	Sep-15	0.669 **	0.004 **	0.067	-2.455	0.004 **	1.158 *	0.085
Sep-07	1.371 **	0.009 **	0.068	-17.224 **	0.021 **	6.258 **	0.155	Dec-15	0.715 **	0.006 **	0.094	-2.233	0.006 **	1.039 *	0.106
Dec-07	4.286 **	**-0.002**	-0.002	-20.110 **	0.018 **	7.443 **	0.096	Mar-16	0.863 **	0.005 **	0.090	-2.507	0.007 **	1.086	0.098
Mar-08	6.316 **	**-0.006**	0.012	-22.698 **	0.012 *	8.612 **	0.085	Jun-16	0.528 **	0.007 **	0.171	-2.026	0.007 **	0.896	0.182
Jun-08	6.191 **	**0.000**	-0.004	-18.877 **	0.005	7.847 **	0.060	Sep-16	1.121 **	0.004 **	0.051	-1.465	0.003	1.006	0.057
Sep-08	3.827 **	0.013 **	0.046	-18.207	0.012 **	7.112 *	0.073	Dec-16	0.693 **	0.006 **	0.110	-1.133	0.005 **	0.726	0.112
Dec-08	8.981 **	**-0.003**	-0.002	-4.902	0.006	3.678 **	0.020	Mar-17	0.277	0.008 **	0.167	-2.256	0.007 **	1.024	0.170
								Jun-17	0.4714 **	0.006 **	0.133	-3.1706	0.004 **	1.530	0.149

	Time to maturity	*Time to maturity*	*Market Volatility*
Positive Relation	61	61	25
Negative Relation	1	0	2
No relation	5	6	40

The table reports $\beta$and φ coefficients from regressions $\sigma_F(t,T) = \alpha + \beta(T-t) + u_t$ and $\sigma_F(t,T) = \alpha + \beta(T-t) + \varphi S_{Mt} + u_t$ where *(T – t)* are days to maturity and S_{Mt} is the market volatility (VIX index). We exclude data from 10 days before expiration date. * and ** indicate significance at the 5% and 1% levels, respectively. Bold numbers indicate the presence of maturity effect or negative relation with market volatility. The numbers at the bottom of each panel show the total count of contracts with positive or negative and significant relation with time to maturity and the number of contracts with no relation.

Table 4. Short-Sterling Futures Contracts – Volatility and Time to Maturity

Panel A. Three years before expiration

	Time to maturity			*Time to maturity & Market Volatility*					*Time to maturity*			*Time to maturity & Market Volatility*			
Exp. Month	α	β	Adj. R^2	α	β	φ	Adj. R^2	*Exp. Month*	α	β	Adj. R^2	α	β	φ	Adj. R^2
Dec-00	3.340 **	0.002 **	0.017	4.390	0.013 **	-1.189	0.144	Mar-09	8.615 **	**-0.006** **	0.131	5.233	**-0.005** **	0.928	0.133
Mar-01	3.022 **	0.002 **	0.031	2.461	0.007 **	-0.246	0.067	Jun-09	7.446 **	**-0.004** **	0.057	1.110	**-0.002**	1.700	0.064
Jun-01	2.654 **	0.003 **	0.053	-0.398	0.004 **	0.906	0.038	Sep-09	6.438 **	**-0.003** **	0.019	-8.211 **	0.002	3.956 **	0.064
Sep-01	2.643 **	0.003 **	0.052	0.520	0.002 **	0.714	0.021	Dec-09	5.529 **	**-0.001**	0.001	-9.308 **	0.002 **	4.163 **	0.064
Dec-01	3.334 **	0.002 **	0.023	5.215	**0.000**	-0.402	-0.003	Mar-10	4.506 **	0.001 *	0.003	-8.989 **	0.002 **	3.965 **	0.064
Mar-02	3.647 **	0.002 **	0.015	2.319	**-0.001**	0.711	0.002	Jun-10	3.908 **	0.002 **	0.019	-6.122 **	0.002 **	3.118 **	0.053
Jun-02	4.480 **	0.000	-0.001	-2.012	**-0.002** **	2.345 **	0.024	Sep-10	3.129 **	0.004 **	0.048	-4.741	0.003 **	2.505 **	0.067
Sep-02	5.031 **	**-0.001** *	0.003	5.312 **	**-0.001** **	-0.046	0.005	Dec-10	2.162 **	0.005 **	0.099	-2.409	0.005 **	1.510 *	0.106
Dec-02	5.186 **	**-0.001** **	0.008	6.109 **	**-0.001** **	-0.282	0.006	Mar-11	1.359 **	0.006 **	0.157	-0.572	0.006 **	0.654	0.160
Mar-03	4.922 **	**-0.001** *	0.004	3.518	**-0.001**	0.374	0.001	Jun-11	1.766 **	0.005 **	0.129	-0.117	0.005 **	0.681	0.130
Jun-03	4.758 **	**-0.001**	0.001	-2.302	0.001	1.957 **	0.013	Sep-11	1.609 **	0.005 **	0.140	4.494 **	0.006 **	-1.057	0.143
Sep-03	4.373 **	0.000	-0.001	-3.717	0.001 *	2.357 **	0.027	Dec-11	1.828 **	0.004 **	0.122	4.772 **	0.005 **	-0.994 *	0.126
Dec-03	3.810 **	0.001 **	0.007	-4.282 **	0.001 **	2.476 **	0.043	Mar-12	1.684 **	0.005 **	0.130	2.289	0.005 **	-0.202	0.129
Mar-04	3.693 **	0.002 **	0.012	-2.874	0.001 *	2.145 **	0.040	Jun-12	1.590 **	0.004 **	0.128	2.956	0.004 **	-0.448	0.127
Jun-04	3.571 **	0.002 **	0.014	-1.863	0.001	1.892 **	0.031	Sep-12	1.712 **	0.004 **	0.104	1.350	0.004 **	0.121	0.102
Sep-04	3.448 **	0.002 **	0.016	-0.588	0.001	1.478 **	0.025	Dec-12	1.502 **	0.004 **	0.114	0.327	0.004 **	0.405	0.113
Dec-04	3.259 **	0.002 **	0.015	-1.760	0.000	1.929 **	0.033	Mar-13	0.904 **	0.005 **	0.170	-0.500	0.005 **	0.511	0.173
Mar-05	2.948 **	0.002 **	0.025	-1.604	0.000	1.911 **	0.038	Jun-13	0.550 **	0.005 **	0.200	-1.032	0.005 **	0.606	0.198
Jun-05	2.486 **	0.003 **	0.051	4.868	0.005 **	-1.092	0.054	Sep-13	0.308 *	0.005 **	0.222	-1.558	0.005 **	0.704	0.223
Sep-05	2.351 **	0.003 **	0.053	4.026	0.004 **	-0.773	0.054	Dec-13	0.162	0.005 **	0.244	-1.576	0.005 **	0.678	0.246
Dec-05	1.910 **	0.004 **	0.083	3.680	0.004 **	-0.806	0.084	Mar-14	0.114	0.005 **	0.242	-1.505	0.005 **	0.647	0.245
Mar-06	1.973 **	0.003 **	0.077	3.775	0.004 **	-0.791	0.077	Jun-14	0.101	0.005 **	0.248	-2.508	0.004 **	1.087	0.256
Jun-06	1.791 **	0.003 **	0.078	3.707	0.003 **	-0.812	0.080	Sep-14	0.559 **	0.004 **	0.182	-4.233 **	0.002 **	2.002 **	0.204
Sep-06	2.179 **	0.002 **	0.037	4.722 **	0.002 **	-1.003 *	0.040	Dec-14	0.844 **	0.003 **	0.135	-4.735 **	0.002 **	2.248 **	0.161
Dec-06	2.098 **	0.002 **	0.030	3.700 **	0.002 **	-0.625	0.031	Mar-15	1.124 **	0.003 **	0.098	-3.556	0.002 **	1.836 **	0.119
Mar-07	2.208 **	0.001 **	0.024	1.960	0.001 **	0.098	0.022	Jun-15	1.308 **	0.003 **	0.080	-2.403	0.002 **	1.428 *	0.085
Jun-07	2.122 **	0.001 **	0.027	-0.246	0.002 **	0.872	0.031	Sep-15	1.178 **	0.003 **	0.088	-2.721	0.003 **	1.460	0.093
Sep-07	2.600 **	0.001	0.003	-2.162	0.001 **	1.676 **	0.017	Dec-15	0.889 **	0.004 **	0.135	-3.537	0.004 **	1.596 *	0.143
Dec-07	3.354 **	**-0.001**	0.004	-2.805	0.001	2.043 **	0.025	Mar-16	0.526 **	0.005 **	0.186	-3.515	0.005 **	1.395 *	0.194
Mar-08	3.720 **	**-0.001** **	0.012	-3.049	0.001	2.147 **	0.036	Jun-16	0.403 **	0.005 **	0.220	-3.300	0.005 **	1.269 *	0.226
Jun-08	4.570 **	**-0.002** **	0.050	-5.051 **	0.000	3.001 **	0.094	Sep-16	0.748 **	0.004 **	0.166	-3.941 **	0.005 **	1.589 **	0.180
Sep-08	5.346 **	**-0.003** **	0.066	-4.719	**-0.001**	3.108 **	0.100	Dec-16	0.860 **	0.004 **	0.143	-5.731 **	0.004 **	2.264 **	0.178
Dec-08	8.550 **	**-0.007** **	0.173	-1.932	**-0.004** **	2.998 **	0.197	Mar-17	0.740 **	0.004 **	0.151	-6.656 **	0.004 **	2.631 **	0.210
								Jun-17	0.2746 *	0.004 **	0.192	-6.6296 **	0.004 **	2.614 **	0.249

	Time to maturity	*Time to maturity*	*Market Volatility*
Positive Relation	51	48	32
Negative Relation	10	5	2
No relation	6	14	33

Table 4. Continues…

Panel B. One year before expiration

	Time to maturity			*Time to maturity & Market Volatility*					*Time to maturity*			*Time to maturity & Market Volatility*			
Exp. Month	α	β	Adj. R^2	α	β	φ	Adj. R^2	*Exp. Month*	α	β	Adj. R^2	α	β	φ	Adj. R^2
Dec-00	1.065 **	0.010 **	0.109	4.390	0.013 **	-1.189	0.144	Mar-09	5.874 **	0.011 **	0.019	-6.834	0.021 **	3.170 *	0.030
Mar-01	1.805 **	0.006 **	0.042	2.161	0.006 **	-0.132	0.042	Jun-09	2.291 **	0.021 **	0.107	-9.561	0.025 **	3.149 *	0.126
Jun-01	2.531 **	0.002	0.002	1.663	0.002	0.297	-0.003	Sep-09	-0.045	0.028 **	0.263	11.775	0.038 **	-3.807 *	0.272
Sep-01	3.116 **	0.001	-0.004	7.053	0.002	-1.416	-0.002	Dec-09	0.817 *	0.018 **	0.164	3.668	0.020 **	-0.962	0.161
Dec-01	4.208 **	**0.000**	-0.004	13.508 **	**-0.004**	-2.782 *	0.016	Mar-10	0.170	0.019 **	0.204	6.649	0.022 **	-2.223	0.206
Mar-02	3.449 **	0.007 **	0.020	3.920	0.007 **	-0.158	0.017	Jun-10	0.420	0.016 **	0.210	-8.646 **	0.015 **	3.046 **	0.225
Jun-02	2.702 **	0.014 **	0.074	0.029	0.011 **	0.958	0.063	Sep-10	0.504	0.013 **	0.149	-13.323 **	0.014 **	4.428 **	0.185
Sep-02	1.721 **	0.018 **	0.131	4.451	0.018 **	-0.842	0.132	Dec-10	0.176	0.012 **	0.172	-8.120	0.012 **	2.728 *	0.187
Dec-02	1.946 **	0.014 **	0.118	-7.381	0.019 **	2.526 *	0.122	Mar-11	0.476 *	0.009 **	0.126	-3.587	0.008 **	1.434	0.130
Mar-03	1.940 **	0.011 **	0.090	-14.805 **	0.021 **	4.381 **	0.198	Jun-11	1.541 **	0.004 **	0.033	1.892	0.004 *	-0.129	0.029
Jun-03	1.329 **	0.015 **	0.139	-7.130	0.013 **	2.516 *	0.178	Sep-11	0.986 **	0.008 **	0.106	1.499	0.008 **	-0.169	0.102
Sep-03	2.040 **	0.009 **	0.059	-0.915	0.006	1.027	0.062	Dec-11	0.381	0.012 **	0.184	-8.335 **	0.018 **	2.471 **	0.220
Dec-03	1.623 **	0.011 **	0.071	-0.790	0.008	0.929	0.066	Mar-12	1.036 **	0.006 **	0.062	0.353	0.006 **	0.206	0.058
Mar-04	0.779 *	0.017 **	0.170	-5.524	0.013 *	2.423	0.174	Jun-12	0.912 **	0.006 **	0.077	-0.802	0.005 **	0.598	0.071
Jun-04	1.064 **	0.014 **	0.117	-4.545	0.012 **	2.083	0.117	Sep-12	1.137 **	0.005 **	0.047	-5.128	0.001	2.294 *	0.072
Sep-04	1.101 **	0.012 **	0.114	-1.378	0.011 **	0.940	0.110	Dec-12	1.087 **	0.004 **	0.036	-5.811	0.002	2.564 *	0.063
Dec-04	1.020 **	0.010 **	0.101	-0.288	0.009 **	0.517	0.096	Mar-13	0.259	0.008 **	0.147	-7.529	0.003	3.135 *	0.203
Mar-05	1.186 **	0.008 **	0.081	-5.195	0.004	2.743	0.083	Jun-13	0.146	0.007 **	0.222	-0.784	0.006 **	0.376	0.217
Jun-05	0.949 **	0.010 **	0.134	0.587	0.009 **	0.174	0.125	Sep-13	0.349 *	0.005 **	0.147	-3.551	0.005 **	1.423 *	0.166
Sep-05	1.427 **	0.007 **	0.067	0.537	0.007 **	0.378	0.066	Dec-13	0.456 **	0.004 **	0.085	-5.781	0.004 **	2.333 **	0.157
Dec-05	1.343 **	0.006 **	0.055	8.616	0.005 **	-2.903 *	0.061	Mar-14	0.230 *	0.005 **	0.103	-8.428 **	0.004 **	3.300 **	0.213
Mar-06	1.548 **	0.006 **	0.054	6.883	0.005 **	-2.120	0.059	Jun-14	-0.420 *	0.009 **	0.270	-5.567	0.007 **	2.080	0.291
Jun-06	0.685 **	0.010 **	0.154	0.800	0.010 **	-0.043	0.151	Sep-14	0.386 *	0.004 **	0.093	3.375 **	0.005 **	-1.214 *	0.100
Sep-06	1.177 **	0.007 **	0.096	-0.650	0.008 **	0.633	0.095	Dec-14	0.462 **	0.005 **	0.076	2.062	0.005 **	-0.621	0.076
Dec-06	0.813 **	0.008 **	0.116	-3.370	0.008 **	1.524 *	0.129	Mar-15	0.406 **	0.006 **	0.091	-0.730	0.006 **	0.408	0.091
Mar-07	1.325 **	0.006 **	0.051	-2.015	0.005 **	1.301	0.057	Jun-15	0.152	0.007 **	0.201	-3.301	0.007 **	1.256 *	0.218
Jun-07	1.131 **	0.006 **	0.066	-0.307	0.006 **	0.551	0.063	Sep-15	-0.121	0.008 **	0.252	-2.873	0.008 **	1.001	0.268
Sep-07	2.299 **	0.002	0.001	-12.176 **	0.009 **	4.816 **	0.101	Dec-15	0.340 **	0.005 **	0.140	0.289	0.005 **	0.011	0.149
Dec-07	4.205 **	**-0.006** **	0.042	-8.292	0.002	3.796 **	0.081	Mar-16	0.308 **	0.005 **	0.148	0.452	0.005 **	-0.054	0.157
Mar-08	4.361 **	**-0.004** *	0.013	-12.811 **	0.007 *	4.992 **	0.071	Jun-16	-0.229 *	0.009 **	0.307	-1.017	0.009 **	0.268	0.304
Jun-08	4.364 **	0.001	-0.003	-8.159	0.003	3.885 **	0.044	Sep-16	0.423 *	0.005 **	0.092	-3.547	0.004 **	1.440 *	0.126
Sep-08	3.888 **	0.007 **	0.021	-1.998	0.006 **	1.915	0.019	Dec-16	0.091	0.007 **	0.129	-7.129 **	0.003 *	2.796 **	0.213
Dec-08	9.961 **	**-0.012** *	0.024	0.189	**-0.007**	2.635	0.031	Mar-17	0.031	0.006 **	0.092	-6.741	0.002	2.780 *	0.164
								Jun-17	-0.3795	0.007 **	0.095	-7.4165	0.003 **	3.042	0.149

	Time to maturity	*Time to maturity*	*Market Volatility*
Positive Relation	59	54	24
Negative Relation	3	0	4
No relation	5	13	39

The table reports $\beta$and φ coefficients from regressions $\sigma_F(t,T) = \alpha + \beta(T-t) + u_t$ and $\sigma_F(t,T) = \alpha + \beta(T-t) + \varphi S_{Mt} + u_t$ where *(T – t)* are days to maturity and S_{Mt} is the market volatility (FTSE 100 volatility index). We exclude data from 10 days before expiration date. * and ** indicate significance at the 5% and 1% levels, respectively. Bold numbers indicate the presence of maturity effect or negative relation with market volatility. The numbers at the bottom of each panel show the total count of contracts with positive or negative and significant relation with time to maturity and the number of contracts with no relation.