Maturity effects in the Mexican interest rate futures market

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Abstract

This study investigates the relation between volatility and contract expiration for the case of Mexican interest rate futures. Specifically, it examines the hypothesis that futures volatility should increase as contract approaches expiration ("maturity effect"). The analysis includes panel data techniques which permit to assess the existence of cross-sectional individual effects through a set of contracts with different maturities. The results show that, although the maturity effect was sometimes present, in the last years there is an inverse effect: volatility decreases as expiration approaches. An explanation of this behavior can be found in the term structure dynamics and in changes in monetary policy transmission.

1 Introduction.

Understanding the dynamics of futures price volatility is important for all market participants. This study focuses on a specific aspect of these dynamics: the relation between volatility and time to expiration. Samuelson (1965) was the first to investigate theoretically this relation, providing a model that postulates that the volatility of futures prices should increase as the contract approaches expiration. This effect, more commonly known as Samuelson hypothesis or maturity effect, occurs because, as the contract approaches maturity, the futures price is forced to converge to the spot price and so it tends to respond more strongly to new information. As time to maturity increases, less is known about the future spot price of the underlying. Numerous studies have investigated the Samuelson hypothesis empirically, yielding mixed results. In general, the maturity effect has been supported for commodities, while it has not appear to be significant for financial assets.

The study of the behavior of volatility of futures prices near the maturity date has important implications for risk management, for hedging strategies, and for derivatives pricing, among others. First, clearinghouses set margin requirements on the basis of futures price volatility. Therefore, if there is any relation between volatility and time to maturity, these requirements should be adjusted accordingly. Matching margins with price variability in an efficient way is the aim of an adequate margin policy and, although exchanges monitor price variability for different assets, they do not usually consider differences among contracts over the same underlying. In the case of hedging strategies, depending on the positive or negative relation between volatility and maturity, hedgers should choose between futures contracts with different time to maturity to minimize price variability. For example, Low, Muthuswamy, Sajar and Terry (2001) propose a multiperiod hedging model that incorporates the maturity effect. Their empirical results show that their model outperforms other hedging strategies that do not account for maturity. Thirdly, volatility and time to maturity relation is also essential for speculators in the futures markets. If Samuelson hypothesis holds, speculators may find beneficial to trade in futures contracts close to expiration, as greater volatility implies greater short time profit opportunities. Finally, since volatility is central to derivatives pricing, the relation between maturity and volatility should also be taken into consideration when pricing derivatives on futures.

The aim of this article is to study the presence of maturity effects in the Mexican interest rate futures market. Specifically, the study considers the Mexican TIIE futures contracts. These contracts settle to the 28-day Interbank Equilibrium Interest Rate (Tasa de Interes Interbancaria de Equilibrio, or TIIE), which is the yield implied by a 28-day deposit. The 28-day TIIE is calculated daily by the Central Bank (Banco de Mexico) and is a benchmark to measure the average cost of funds in the Mexican interbank money market.

The main motivation for studying this market lies in its growing importance: the Mexican Derivatives Exchange (MexDer) reached during 2006 a volume of 274.65 million contracts, making it the eighth largest exchange worldwide. Its leading contract, the 28-day TIIE interest rate future, experienced during the same period the largest increase in volume in any futures contract, becoming the third most actively traded futures contract in the world after CME's Eurodollar and Eurex' Eurobond contracts (Holz, 2007). With such impressive growth, the behavior and characteristics of this emerging market are certainly important to many participants, including non-Mexican investors.

Relative to previous literature, the contribution of this study is threefold. First, it shows that, in the case of interest rates futures, understanding the relation between volatility and maturity requires considering the dynamics of the term structure. Previous studies have empirically tested Samuelson hypothesis on interest rate futures but, to the best of our knowledge, none of them provide a theoretical intuition. Second, this study also expands upon previous research by considering a panel of contracts where observations are arranged not according to calendar day, but according to days to maturity. This arrangement permits to perform a panel data analysis to assess the existence of cross-sectional individual effects. In addition, it avoids the problem of having to rollover contracts in order to construct longer series, a procedure that can potentially generate biases on the statistical properties of the series (Ma, Mercer and Walker, 1992) and obscures the individual particularities of each contract. Finally, the analysis documents the existence of maturity effect in a market for which, in spite of its growing importance, there are almost no previous studies.

Our findings show that, while the usual maturity effect is occasionally present in contracts maturing in 2003 and 2004, an inverse maturity effect is significantly predominant in contracts maturing after 2004. In addition, this situation remains unchanged when the spot volatility is included as a proxy of information flow. Moreover, since the switching between a maturity effect and its inverse coincide with a drop in spot rate volatility induced by a change in the way the Central Bank transmits its monetary policy, it appears that an explanation of this behavior should be looked in the dynamics of the term structure.

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

2 Literature review

Samuelson (1965) was the first to provide a theoretical model for the relation between the futures price volatility and time to maturity. This model predicts that volatility of futures prices rises as maturity approaches, a behavior which is known as the Samuelson hypothesis or the maturity effect. The intuition 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 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 and so it tends to respond more strongly to new information.

The example used by Samuelson to present the hypothesis relies on the assumptions that 1) futures price equals the expectation of the delivery date spot price, and 2) 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). Later, Samuelson (1976) showed that a spot generating process that includes higher order autoregressive terms can result in temporary decreases in a generally increasing pattern of price variability. Hence a weaker result is obtained: if delivery is sufficiently distant then variance of futures prices will necessary be less than the variance very near to delivery.

Numerous studies have investigated the Samuelson hypothesis empirically, with different sets of data and different methodologies, obtaining mixed results. Since the hypothesis was originally formulated in the context of commodity markets, most of the studies have been centered in commodity futures, and only tangentially consider other underlyings. In general, the effect appears to be stronger for commodities futures, while for financial futures the effect is frequently statistically nonsignificant or non existent at all.

For commodity markets, early empirical work by Rutledge (1976) finds support for the maturity effect in silver and cocoa but not for wheat or soybean oil. In line with Samuelson's arguments, Milonas (1986) derives a theoretical model for the maturity effect and provides empirical evidence. He calculates price variability as variances over daily price changes within a month and adjusts these variances for month, year and contract month effects. He tests for significant differences in variability among the different time to maturity groups of variances and finds general support for the maturity effect in ten out of the eleven future markets examined, which included agricultural, financial and metal commodities.

Grammatikos and Saunders (1986), investigating five currency futures, find no relation between time to maturity and volatility for currency futures prices. Khoury and Yourougou (1993) analyzed the case of agricultural futures in the Winnipeg Commodity Exchange, concluding that besides time to maturity, there are other factors, such as year, calendar month or trading session effects, that influence the volatility of prices.

Galloway and Kolb (1996) examined a set of 45 commodities futures contracts, including twelve financial contracts. Using monthly variances, they investigated the maturity effect both in an univariate setting, searching for maturity effect patterns, and performing ordinary least squares (OLS) regressions. They found strong maturity effect in agricultural and energy commodities, concluding that time to maturity is an important source of volatility in contracts with seasonal demand or supply, but they did not found the effect in commodities for which the cost-of-carry model works well (precious metals and financial). In particular, T-Bill, T-bond and Eurodollar futures showed no evidence of any significant maturity effect. A similar result for currency futures was reported in Han, Kling and Sell (1999).

Anderson and Danthine (1983) offered an alternative explanation of the time pattern of futures price volatility by incorporating time-varying rate of information flow. The hypothesis, named state variable hypothesis, establishes that 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, Samuelson's hypothesis is a special case in which the resolution of uncertainty is systematically greater as the contract nears maturity. Under this perspective, the maturity effect reflects a greater rate of information flow near maturity as more traders spend time and resources to uncover new information.

Some studies have applied the state variable hypothesis to test the existence of maturity effect. Anderson (1985) studies volatility in nine commodity futures for the period 1966 to 1980. Using both nonparametric and parametric tests he finds that on six of these markets there is strong evidence of maturity effects. However, he also reports that seasonality is more important in explaining the patterns in the variance of futures price changes. A similar conclusion is found by Kenyon, Kenneth, Jordan, Seale, and McCabe (1987) in the study of corn, soybean and wheat futures. Barnhill, Jordan and Seale (1987) apply the state variable hypothesis to the Treasury bond futures market during the period 1977-1984 and find evidence supportive of the maturity effect.

Chen, Duan and Hung (1999) focus on index futures and propose a bivariate GARCH model to describe the joint dynamics of the spot index and the futures basis. They use the Nikkei-225 index spot and futures prices to examine empirically the Samuelson effect and study the hedging implications under both stochastic volatility and time-varying futures maturities. Their finding of decreasing volatility as maturity approaches contradicts the Samuelson hypothesis.

Bessembinder, Coughenour, Seguin and Monroe Smoller (1996) present a different analysis of the economic issues underlying the maturity effect. With respect to the state variable hypothesis, they note that there is an absence of satisfactory explanations of why information should cluster towards a contract expiration date. 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 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 changes in net carry costs. Since financial assets do not provide service flows, they predict that the Samuelson hypothesis will not hold for financial futures. To test their predictions they consider data from agricultural, crude oil, metals and financial futures. Performing regressions on days to expiration, spot volatility and monthly indicators they obtain supportive evidence for their model.

Hennessy and Wahl (1996) propose an explanation of futures volatility based not on information flow or time to expiration, but on production and demand inflexibilities arising from decision making. Their results on CME commodity futures support the maturity effect.

More recently, Aragó and Fernández (2002) study the expiration and maturity effects in the Spanish market index using a bivariate error correction GARCH model (ECM-GARCH). Their results show that during the week of expiration conditional variance increases for the spot and futures prices, in agreement with Samuelson hypothesis. Duong and Kalev (2008), using intraday data and realized volatility estimations from 20 futures markets, find strong support for the Samuelson hypothesis in agricultural futures. However, they conclude the hypothesis does not hold for other futures contracts.

3 Data and Methodology

3.1 The TIIE spot rate

Since March 1995, Banco de Mexico determines and publishes the short-term interest rate benchmark known as Tasa de Interés Interbancaria de Equilibrio, or TIIE. There are two variants for the TIIE: 28- and 91-day. The 28-day TIIE is the rate implied by 28-day deposits and is based on quotations submitted daily by full-service banks using a mechanism designed to reflect conditions in the Mexican peso money market. The participating institutions submit their quotes to Banco de Mexico by 12:00 p.m. Mexico City time. Following the receipt of the quotes, Banco de Mexico determines the TIIE applying an algorithm based on the average between bid and ask quotes weighted by the size of the positions, with the purpose of locating the equilibrium rate at which supply and demand of funds are equated. In the case that less than six quotes are received, Banco de Mexico determines the TIIE rate according to the prevailing money market conditions on that day.

Rates quoted by institutions participating in the survey are not indicative rates for informational purposes only; they are actual bids and offers by which these institutions are committed to borrow from or lend to Banco de Mexico. In case Banco de Mexico detects any collusion among participating institutions or any other irregularity, it may deviate from the stated procedure for determination of the TIIE rates.

To help set the macroeconomic context during the period to be studied, Figures 1 and 2 show the evolution of the TIIE spot rate and of its volatility (measured as the absolute value of daily returns) from January 2003 to the end of 2007. It can be seen how the TIIE spot rate's volatility and tendency suffered abrupt changes which permit to identify distinct phases. In March 2003 the 28-day TIIE rate reached a maximum of almost 11%, declining after that until August 2003, when it reached the historic minimum (4.745%). A period of uncertainty started after September that year and prevailed throughout the first quarter of 2004 when movements of almost 150 bps within very short periods (2 weeks) were present. After this, more stable patterns appear, either increasing or decreasing, until the rate stabilizes with very low volatility during the second half of 2006 and 2007.

To explain this behavior there are two factors which must be considered. First, the evolution of inflation rates. As Figure 3 shows, during the first three years of the period under study, inflation rates tend to decrease (ignoring seasonality), while in 2007 they stabilize in a range between 3.7% and 4.3%, and show much lesser volatility. The second factor to consider has to do with monetary policy transmission. In April 2004 there was a change in the way Banco de Mexico communicated its monetary policy intentions. Before that date, the monetary policy was defined through a target level for banks current account balances at the Central Bank. Normally the target level was a negative balance that restrained funds available at market rates for banking institutions. Institutions with negative balances could still borrow money from the Central Bank but they were charged twice the market rate. This action pressured interest rates upwards as banks would borrow money at the interbank market, and interest rates would move freely as there were no clear signals from the Central Bank about target rates. To remove that uncertainty and considering the more stable conditions of the market, in April 2004 Banco de Mexico started to communicate the target for the 1-day interbank rate together with the negative balances target. The consequence was the progressive reduction in short-term interest rates volatility.

3.2 The TIIE futures contracts

The TIIE futures contracts are traded in the Mexican Derivatives Exchange (MexDer). These are cash-settled contracts with a face value of \$100,000 Mexican pesos (approximately \$9,400 U.S. dollars) each. MexDer lists and makes available for trading different series of the 28-day TIIE futures contracts on a monthly basis for up to ten years. It is important to observe that, in contrast with analogous instruments like CME's Eurodollar futures or LIFFE's Short Sterling futures, TIIE futures are quoted by annualized future yields and not by prices. The relation between the quoted future yields on day t and the corresponding futures price F_t is determined by MexDer by the formula

$$F_t = \frac{100,000}{1 + Y_t(28/360)} \tag{1}$$

where Y_t is the quoted yield divided by 100.

Daily settlement rates are calculated in accordance with the following order of priority and methodology: 1) In the first instance, the daily settlement rate will be the weighted average of the rates agreed upon in trades executed in the last five minutes of the trading session. 2) If no trades were executed during the period mentioned above, the settlement rate will be the volume weighted average of the firm bids or offers at the end of the trading session. 3) If at the end of the session, there is not at least one bid or one offer quote, the settlement rate will be the future rate agreed upon the last trade executed during the auction session. 4) If none of the above holds, the settlement yield will be the theoretical yield derived from the forward curve.

The last trading day and the maturity date for each series of 28-day TIIE futures contracts is the bank business day after Banco de Mexico holds the primary auction of government securities in the week corresponding to the third Wednesday of the maturity month. Since these primary auctions are usually held every Tuesday, in general the expiration day for TIIE futures corresponds to the third Wednesday of every month.

3.3 Sample Data

The study considers daily 28-day TIIE spot and futures rates between January 2003 and December 2007. Futures data include daily settlement yields and trading volume data for all 28-day TIIE futures contracts with maturities between the months mentioned above. These data were obtained from the Mexican Derivatives Exchange (MexDer). Since, for the majority of contracts, open interest is low and trading volume is thin in periods long before maturity, the sample used for each futures contract includes only the thirteen months preceding its expiration. The result is a data set of 15,780 observations corresponding to 60 TIIE futures contracts with 263 daily settlement rates each.

As mentioned before, other analogous instruments, like CME Eurodollar, are quoted in terms of prices and not of yields. Hence, to facilitate the comparison with previous studies, like Barnhill et al. (1987) or Bessembinder et al. (1996), in this study we will use the series of daily settlement prices obtained applying equation (1) to the original daily settlement yields provided by the MexDer.[1]

If S_t is the spot price implied by the 28-day TIIE spot rate at time t, then we will consider the logarithmic changes

$$\Delta S_t = \ln(S_{t+1}/S_t). \tag{2}$$

Analogously, logarithmic changes for futures prices are defined as

$$\Delta F_{T\,t} = \ln(F_{T,\,t+1}/F_{T,\,t}) \tag{3}$$

where $F_{T,\,t}$ denotes the settlement price on calendar day t for the contract with maturity T. We will refer to these logarithmic price changes simply as price changes.

As for the expiration month itself, it will be excluded from the analysis, considering that trading volume decreases as the contract enters its final month, inducing abnormal price variability. Hence, we have a set of 60 series of logarithmic price changes, corresponding to contracts with expiration dates ranging from January 2003 to December 2007, and with 242 observations each.

Table I presents summary statistics for the price changes ΔF_{Tt}. Few of the mean estimates are significantly different from zero. Most contracts are leptokurtic (kurtosis greater than 3), negatively skewed and, with the exception of seven of the contracts maturing in 2005, in all cases Bera-Jarque statistic rejects the hypothesis of normality. Standard deviation tends to diminish over time, with contracts expiring in 2006 and 2007 being the less volatile. The Ljung-Box Q-statistic for autocorrelation (with 20 lags) shows little evidence of autocorrelation in the series. The table also includes the results for the Engle (1982) LM-test for an autoregressive conditional heteroscedasticity (ARCH) effect. Contracts maturing between April 2004 and December 2005 show significant ARCH effects, while for the rest of the contracts there is no trace of such effects.

With respect to trading volume, taking the 60 series that mature from January 2003 until December 2007, daily volume is tracked since the day the contract first appeared. Then the average traded volume across the 60 contracts and relatively to the days to expiration is obtained. Since 2005, contracts with maturity up to 10 years are available; however, trading volume is almost negligible for contracts with expiration longer than 3 years. Figure 4 presents the average number of contracts traded daily according to months before expiration. The plot shows that, from nine up to two months before expiration, traded volume increases quickly as the contract approaches maturity. The peak in trading volume is reached around two months before expiration while in the last four weeks of the contract volume declines. This pattern justifies the decision of considering for the analysis only the thirteen months previous to the expiration of the contract.

Finally, Figure 5 reports the number of TIIE futures contracts traded every month from January 2003 to December 2007. It is noticeable the significant drop in volume during 2005 as compared to previous years. According to MexDer, this fact is explained by some tax issues that induced participants to switch their hedging positions to swaps traded over the counter (Alegría, 2006).

3.4 Methodology

Previous studies have employed different approaches to test Samuelson hypothesis. Some studies, like Milonas (1986) or Galloway and Kolb (1996), calculate price variability as variances over daily price changes within a month, record the number of months left to maturity of the contract, and then perform OLS regressions using these monthly variances. In Bessembinder et al. (1996) daily volatility is estimated as the absolute value of future returns and regressions are performed on days to expiration, spot volatility and monthly indicators. Other studies build long term future series by rolling over contracts and apply different GARCH-type models with time to maturity as an exogenous variable.

In this study, the focus is on extending the usual OLS regressions by applying panel estimation techniques.[2] Hence, from the 60 series of price changes a panel data set is constructed by aligning the data by days to expiration instead of calendar day. This implies rearranging subindexes to express the cross-sectional and time dimensions.[3]

Specifically, if the contracts are labeled with the variable i ($i = 1, ..., 60$), $T(i)$ is the maturity date defining the i-th contract, and $\tau = T(i) - t$ is the number of days to maturity, then all data can be defined in terms of the pair (i, τ) instead of the previous (T, t). For example, in terms of time to maturity, price changes for contract i are expressed as

$$\Delta F_{i\tau} = \ln(F_{i,\tau}/F_{i,\tau+1}). \tag{4}$$

Recall that the expiration month has been excluded from the analysis. Hence, the time variable τ ranges from the 20-th day before the contract expires ($\tau = 20$) to 262 days before expiration ($\tau = 262$).

For each futures series i there is a corresponding series of contemporaneous spot rates and, applying relation (1), a series of contemporaneous notional spot prices. To maintain coherence with the panel data structure, each of these spot price series is subsequently aligned in terms of the days to maturity τ defined by contract i. The logarithmic spot price changes are then expressed as

$$\Delta S_{i\tau} = \ln(S_{i,\tau}/S_{i,\tau+1}) \tag{5}$$

where, for the i-th contract, $S_{i,\tau}$ is the notional price S_t implied by the TIIE spot rate on calendar day $t = T(i) - \tau$.

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

$$\sigma(F)_{i\tau} = |\ln(F_{i,\tau}/F_{i,\tau+1})| \tag{6}$$

for the case of futures contracts. Analogous expressions hold for spot changes volatility $\sigma(S)_{i\tau}$.[4]

The first step in the analysis consists, for each individual contract i, of a linear regression of the contract's volatility $\sigma(F)_{i\tau}$ on time to maturity τ. Next, we extend the analysis by grouping the contracts as a whole and by year of expiration and performing an analysis of variance for panel data. The analysis of variance of the disturbances will give information on the presence of individual effects, time effects or both. The last stage of the analysis consists of panel regressions both with fixed and random effects. In order to test for the effects of information flow, the above analysis is also performed including spot volatility as a regressor, as in Bessembinder et al. (1996).

All the coefficient estimates were obtained using Rats v.5.0 software package and all the time series regressions were obtained using heteroscedasticity consistent covariance estimation (White, 1980).

4 Empirical Results

4.1 Estimates of time-to-maturity effects on volatility

The maturity effect will first be investigated by performing individual OLS regressions. For each contract i, consider the unrestricted model

$$\sigma(F)_{i\tau} = \alpha_i + \beta_i \tau + u_{i\tau} \tag{7}$$

corresponding to linear regressions of the daily futures volatility on the number τ of days until the contract expires, and with disturbances $u_{i\tau}$. If the maturity effect is present, the coefficient β_i should be negative and statistically significant.[5]

Table II reports results of the above regressions (7). Only for some contracts that matured between January 2003 and October 2004 the estimated coefficients on the time to expiration variable are negative, as predicted by Samuelson hypothesis, and, among these, only five are statistically significant. On the other hand, from February 2005 to the end of 2007 almost all coefficients are positive and significant, contrary to Samuelson hypothesis. This means that for all these contracts there is strong evidence of an inverse maturity effect, with volatility decreasing as maturity approaches. The last two columns of Table II report the adjusted R^2 and the Durbin-Watson statistics. Durbin-Watson test results indicate in general there is no significant first order autocorrelation of the residuals.

Next, we consider if a single statistical model can reflect the behavior of the contracts, either on the whole period or grouping them according to the year of maturity. Imposing on (7) the restrictions $\alpha_i = \alpha$ and $\beta_i = \beta$, for all $i \in \{1, ..., N\}$, yields the restricted model

$$\sigma(F)_{i\tau} = \alpha + \beta\tau + u_{i\tau} \tag{8}$$

After estimating coefficients, analysis of variance tests of the residuals will give information on the presence of individual effects, time effects or both. The analysis uses the decomposition of the regression model disturbances $u_{i\tau}$ as

$$u_{i\tau} = \mu_i + \lambda_\tau + \eta_{i\tau} \tag{9}$$

where μ_i denotes the unobservable individual effect, λ_τ the unobservable time effect, and $\eta_{i\tau}$ is the remainder stochastic disturbance term. λ_τ is individual invariant and accounts for any time specific effect that is not included in the regression.

Table III reports the estimated coefficients for the restricted regression (8) for contracts grouped by year and for the whole set, together with the F-tests (analysis of variance) for the presence of individual effects, time effects or both, and a likelihood ratio test for the equality of variances across cross-sections. The analysis for the existence of individual or time effects (or both) shows the presence of individual effects in all periods, but no evidence of time effects.

The last stage of the analysis consists of panel regressions both with fixed and random effects (see Baltagi (1995) for a general reference). The fixed and random effects estimators are designed to handle the systematic tendency of $u_{i\tau}$ to be higher for some individuals than for others (individual effects) and possibly higher for some periods than for others (time effects). Table IV reports the results of panel regression of daily volatility on days to expiration. The estimated regression coefficients β are negative for contracts expiring in 2003 and 2004 but are positive and significant for contracts expiring in 2005, 2006 and 2007. Moreover, when the whole period is considered, β is positive and significant, indicating that the inverse maturity effect prevails. These results confirm the maturity effect was present in the early contracts but turned into an inverse effect in contracts expiring from 2005 onwards. It is also worth noting that for the whole set of contracts, the adjusted R^2 indicates the model has considerable explanatory power.

4.2 Effect of controlling for variation in information flow

As mentioned earlier, recent studies on the Samuelson hypothesis suggest that increased volatility prior to a contract expiring is directly due to the rate of information flow into the futures market. The significance of information effects is therefore investigated by following the testing procedure used in Bessembinder et al. (1996) which involves including spot price variability as an independent variable in the regression outlined above. If information flow is not the main explanation of the Samuelson hypothesis, the coefficient on the days to expiry variable should remain negative and significant despite the inclusion of the spot volatility variable.

Table V reports results of individual regressions of the daily volatility estimates on the number of days until the contract expires and on spot volatility. Compared with the results obtained previously, the inclusion of the spot price volatility has little effect on the estimates and significance of the coefficients of the time to maturity variable. This result indicates that changes in the rate 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). On the other hand, the TIIE spot volatility is only statistically significant in very few cases, showing that, in general, futures volatility is not being affected by spot volatility.

It should be noted that spot volatility is negative (and significant) in some contracts maturing in 2005 and 2007. At first sight this result is in contradiction with theory, specifically with the cost-of-carry model in which it is usually assumed that the only source of futures volatility is the volatility of the underlying. This assumption makes sense in the case of commodities or equity, since the volatility of the underlying is usually much higher than the volatility of the net cost of carry (volatility which is frequently assumed to be zero). However, in the case of interest rate futures, the volatility of the cost of carry is of the same order of magnitude as the volatility of the underlying. In fact, both volatilities must be correlated, since they are tied by the dynamics of the term structure. Since TIIE spot volatility is only one of the components contributing to futures volatility, it is theoretically possible to see spot volatility increasing while futures volatility decreases (or the other way around), depending on the sign and magnitude of the correlation between the underlying and the cost of carry. In fact, the significant negative γ coefficients indicate this actually happens.

Table VI reports the results of the tests for individual and time effects when spot volatility is introduced as a control variable to account for the effects of information flow. The first columns depict the results of the restricted model regression

$$\sigma(F)_{i\tau} = \alpha + \beta\tau + \gamma\sigma(S)_{i\tau} + u_{i\tau} \tag{10}$$

where $\sigma(S)_{i\tau}$ is the spot price volatility. The analysis for the presence of individual effects, time effects or both shows the presence of individual effects partially disappears in 2003 and 2004 when the spot volatility is included as regressor.

Table VII reports the results of the panel regression of daily volatility on days to expiration and spot volatility. As before, the results support Samuelson hypothesis for contracts with expiration in 2004, while the results for contracts with expiration in 2005, 2006 and 2007, and for the whole period, show evidence of the inverse effect. In 2003, 2004 and 2005 the significance of the spot volatility coefficient indicates that, when contracts are grouped and individual effects are captured, spot volatility has more weight explaining futures volatility. However, it still has almost no effect on the estimates and significance of the time-to-maturity coefficients, confirming that changes in the rate of information flow are not relevant in explaining the maturity effect.

4.3 Seasonality tests

In the case of some commodities, mostly agricultural, both Anderson (1985) and Kenyon et al. (1987) found that seasonality is more important than maturity as a factor for the variance of price changes, supporting the state variable hypothesis. Since financial assets are not dependent on harvest cycles, seasonality effects on financial futures should be less relevant. However, for the robustness of the results, it is convenient to control the potential effects of seasonality on the relation between futures price volatility and time to maturity. To do this, we estimate the following regression

$$\begin{aligned} \sigma(F)_{i\tau} &= \alpha + \beta\tau + \gamma_1 \mathrm{Jan}_\tau + \gamma_2 \mathrm{Feb}_\tau + \gamma_3 \mathrm{Mar}_\tau + \gamma_4 \mathrm{Apr}_\tau + \\ &\quad + \gamma_5 \mathrm{May}_\tau + \gamma_6 \mathrm{Jun}_\tau + \gamma_7 \mathrm{Jul}_\tau + \gamma_8 \mathrm{Aug}_\tau + \gamma_9 \mathrm{Sep}_\tau + \gamma_{10} \mathrm{Oct}_\tau + \gamma_{11} \mathrm{Nov}_\tau \end{aligned} \tag{11}$$

where Jan_τ, Feb_τ, Mar_τ, Apr_τ, May_τ, Jun_τ, Jul_τ, Aug_τ, Sep_τ, Oct_τ, Nov_τ are the monthly dummy variables. An F-test is then performed to examine the null hypothesis of joint significance of all seasonal coefficients. The results obtained (not reported here, but available from the authors) indicate that there is no significant seasonality in the majority of the futures contracts. More precisely, with a 1% significance, in 65% of the contracts we cannot reject the null hypothesis that all seasonal coefficients γ_i are simultaneously zero. And even in those cases where seasonality is significant, only in eight contracts there is a change in the significance of the maturity coefficient β. Therefore we conclude that the results obtained are robust even after controlling for seasonality.

4.4 Maturity effect and term structure

Most of the theories explaining the maturity effect, including the papers of Samuelson (1965), the state variable hypothesis of Anderson and Danthine (1983) or the theory of Bessembinder et al. (1996), are focused on the particularities of commodities futures. However, the results obtained here indicate that, in the case of interest rate futures, the rationale should be different.

There is a clear coincidence between the presence of an inverted maturity effect with the period when the TIIE spot rate volatility became damped by the Central Bank policy. This seems to indicate that, in the case of interest rates, any explanation of the relation between volatility and maturity should be looked, not in information flow rates or supply and demand as in the case of commodities, but in the dynamics of the term structure. Under this perspective, the inverse maturity effect can be explained as follows: for these contracts, as the short end of the zero curve is more controlled by the Central Bank, the forward rates continue to be determined to a larger extent by trading activities and are subject of greater uncertainty. As maturity approaches, uncertainty reduces and futures volatility decreases as it converges to spot volatility.

5 Conclusions

This article analyzed the volatility of TIIE futures contracts in relation with their maturity, i.e. the existence of maturity effect. The study complements and expands previous research using panel data techniques that permit cross-sectional and temporal analysis. In fact, descriptive statistics show that volatility has been consistently diminishing over time, indicating changes in return patterns and a possible reduction in information asymmetry in the Mexican futures markets.

Results show that the usual maturity effect, as defined by Samuelson hypothesis, was present in some TIIE futures but only until 2004. For contracts expiring later there is evidence of the inverse effect: volatility decreases as maturity approaches. When the spot volatility is included as a proxy for information flow the results are qualitatively the same, indicating that information arrival is not the main component neither of the maturity effect nor of its inverse. In fact, spot volatility appears in general to have little relation with futures volatility. However, in some contracts there is evidence of an inverse relation between spot and futures volatility. Since this inverse relation cannot be entirely explained under the cost-of-carry model when the volatility of the cost of carry is ignored, the result suggests that, in the case of interest rates futures, the cost of carry volatility and the covariance between underlying and cost of carry must be taken into account. Finally, panel data results show the same conclusions: maturity effect in 2003 and 2004, and the inverse effect for 2005, 2006, 2007, and for the whole period (2003-2007). Under the panel data analysis, the coefficient for the spot rate volatility becomes significant in 2003, 2004 and 2005 contracts, but the inclusion of the spot volatility regressor has still no effect on the time-to-maturity coefficients, confirming information flow is not a main component of the relation between futures volatility and maturity.

Previous studies have failed to analyze to possible causes of the presence of maturity effects in interest rates futures. This research provides evidence showing that, in the case of interest rate futures, relations between volatility and maturity do not correspond to Samuelson hypothesis (1965) nor to Anderson and Danthine (1983) theories. Instead, the inverse maturity effect seems to be inherent to this type of contracts and locked to the dynamics of the term structure of interest rates. Futures price volatility should decrease over time as futures converge to spot prices. This motivates further research using prices from other futures markets.

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Footnotes:

[1] For the sake of robustness, all the calculations were also performed over the original yield series. The results obtained are qualitatively the same.

[2] A GARCH(1,1) model with time to maturity as exogenous variable was also tested for each contract. However, in agreement with the results of the LM-test reported in Table I, only in few cases the model appeared to be appropriate.

[3] Clearly, individual regressions yield identical results regardless of whether the data is organized by calendar day, as is done in prior literature, or by days to maturity. But the arrangement by days to maturity is necessary for a panel data analysis.

[4] Other studies examine Samuelson hypothesis based on alternative volatility measures like daily range or more efficient estimators based on intraday data (Moosa and Bollen, 2001; Duong and Kalev, 2008). In the case of the TIIE futures contracts, the required data was not available from the Mexder or appeared to be incomplete.

[5] Similar regressions were performed considering, instead of days to maturity, the squared root and the natural logarithm of days to maturity. The results obtained are qualitatively the same.

List of figure captions:

Figure 1. Daily 28-day TIIE spot rate from January 2003 to December 2007. Source: Banco de México.

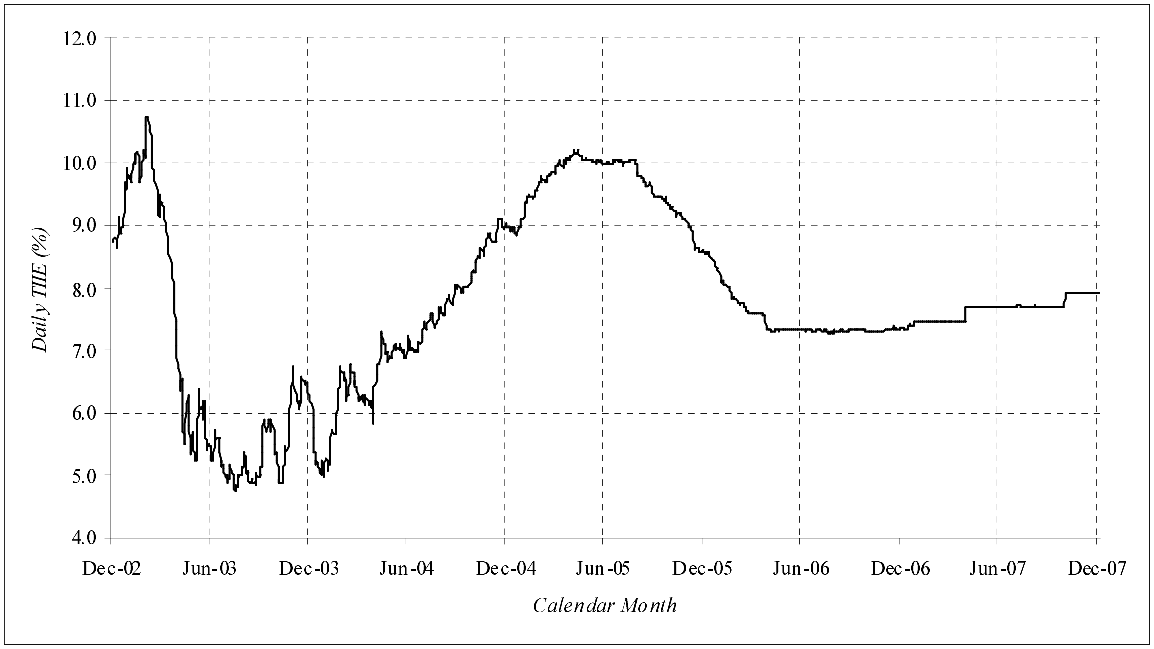
Figure 2. Absolute value of daily TIIE spot returns from January 2003 to December 2007. Source: Banco de México.

Figure 3. Annual inflation rates reported monthly from January 2003 to December 2007. Source: Banco de México.

Figure 4. Monthly average (in thousands) of TIIE futures contracts traded daily relative to the number of months remaining to maturity.

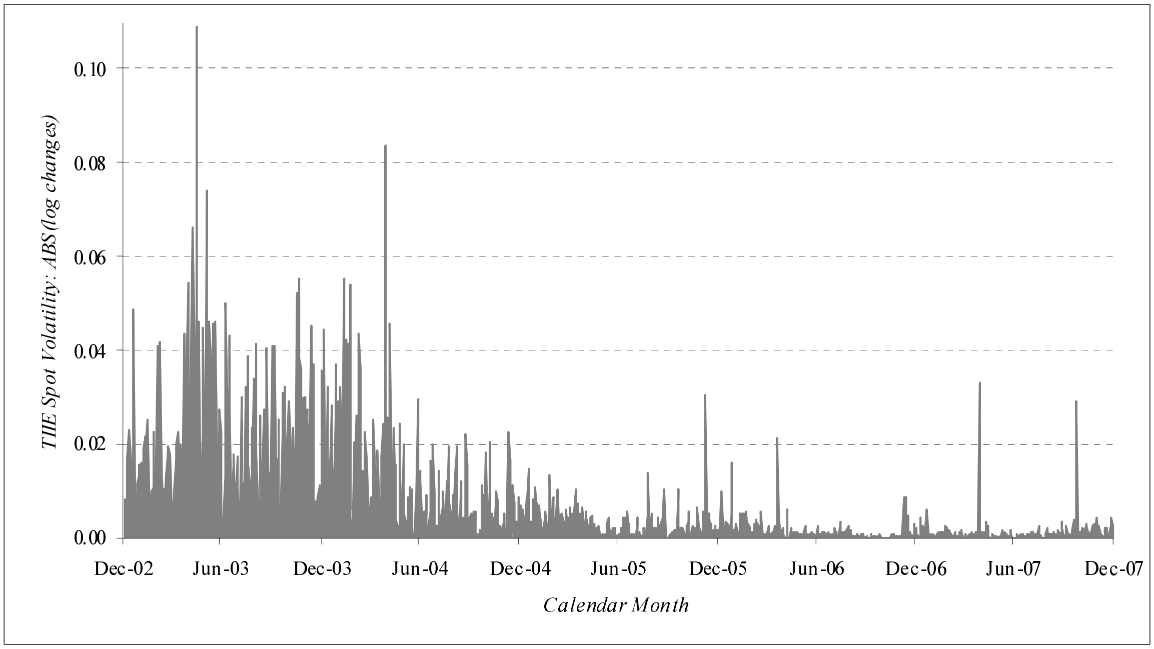
Figure 5. Volume of TIIE futures contracts traded monthly from January 2003 to December 2007. Source MexDer.

Figure 1: 28-day TIIE spot rate during the period 2003-2007



Daily TIIE spot rate from January 2003 to December 2007. Source: Banco de México.

Figure 2: 28-day TIIE spot volatility during the period 2003-2007



Absolute value of daily TIIE spot returns from January 2003 to December 2007. Source: Banco de México.

Figure 3: Annual inflation rates during the period 2003-2007

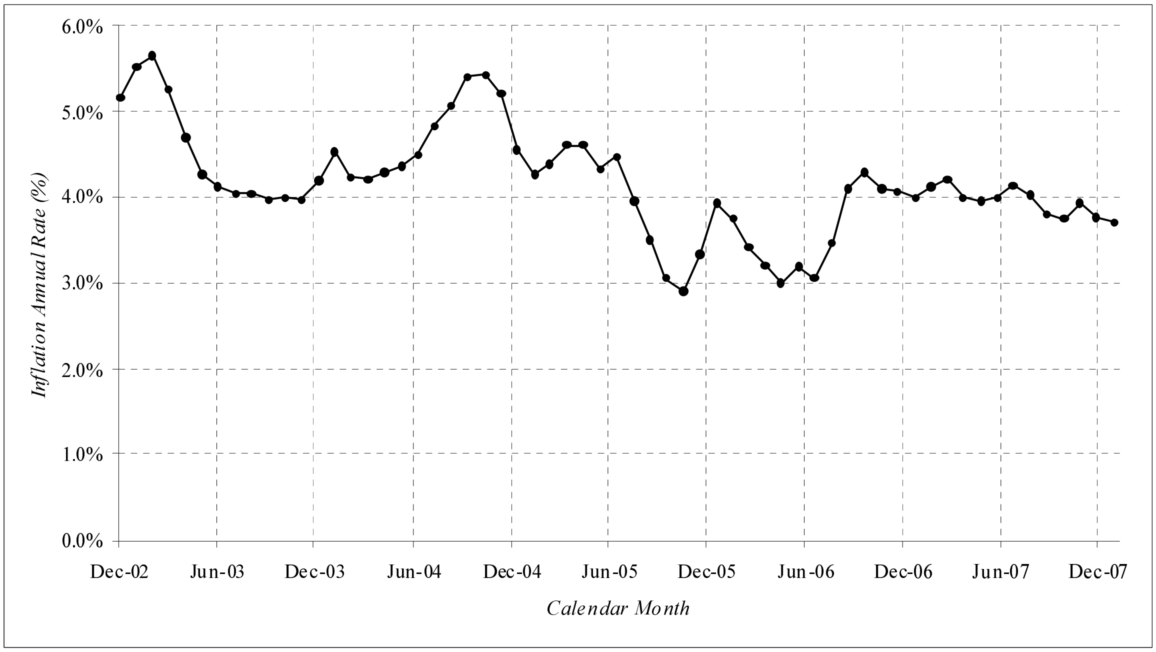
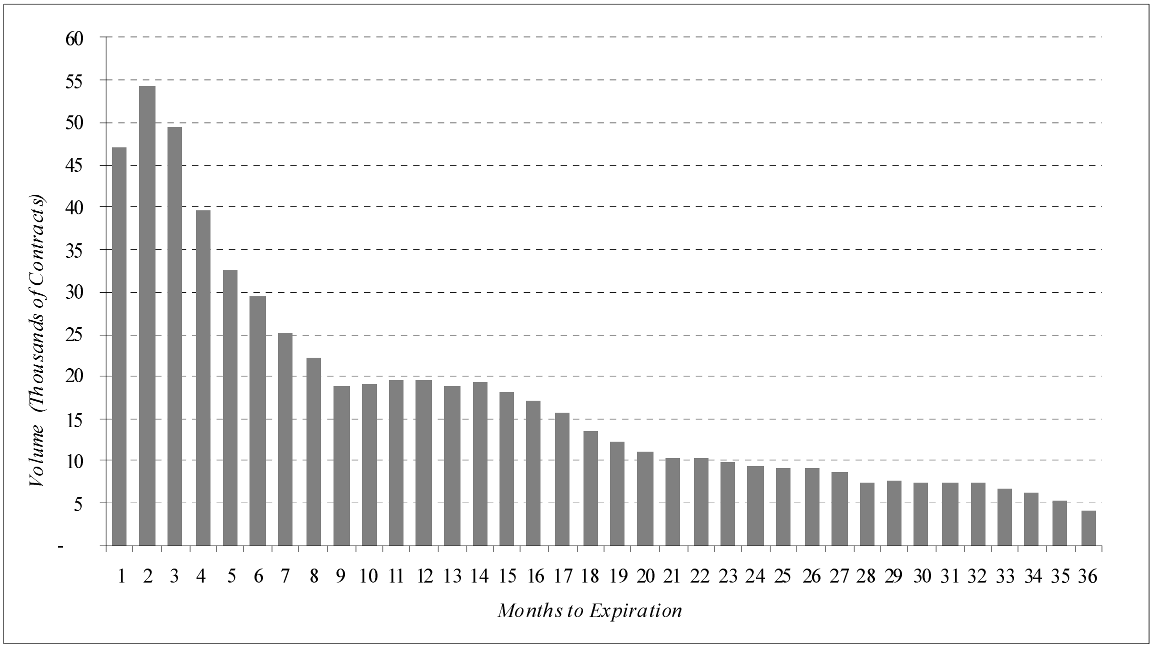
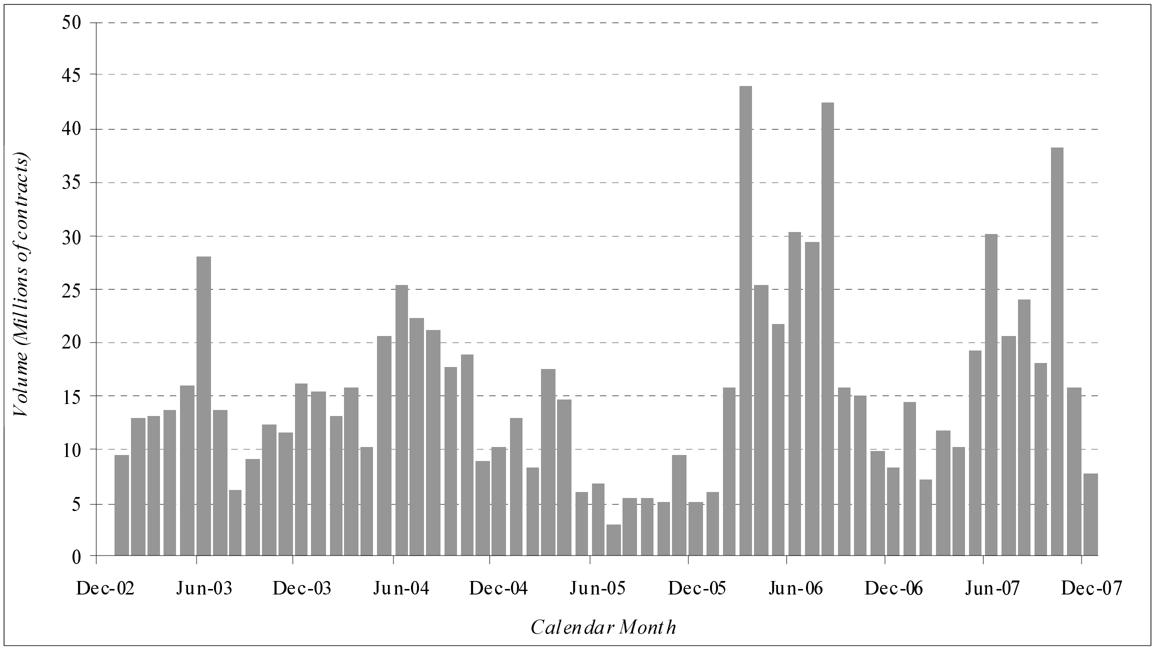


Figure 4: Number of TIIE Futures contracts traded per month relative to contract expiration



Numbers are millions of contracts traded during each month before the expiration date.

Figure 5: Volume of TIIE Futures contracts traded during the whole period



Numbers are millions of contracts traded monthly during the period.

Table I: Descriptive statistics for TIIE futures contracts daily price changes

Contract	Mean	s.d.	Skewness	Kurtosis	BJ	$Q(20)$	p-value	$ARCH$	p-value
Jan03	0.0021	0.0023	-2.05	16.71	2064.49*	26.81	0.1408	8.09	0.9912
Feb03	0.0000	0.0024	-1.99	16.80	2080.46*	27.70	0.1168	6.76	0.9974
Mar03	0.0004	0.0023	-1.74	14.44	1442.10*	25.37	0.1877	6.13	0.9987
Apr03	0.0002	0.0024	-1.00	10.99	683.74*	18.53	0.5523	20.01	0.4571
May03	0.0007	0.0023	-1.39	14.63	1441.17*	35.73*	0.0165	20.22	0.4440
June03	0.0018	0.0021	-0.27	7.60	216.49*	22.42	0.3184	25.35	0.1882
July03	0.0030	0.0020	-0.65	8.05	274.03*	24.98	0.2024	38.40*	0.0079
Aug03	0.0031	0.0019	-0.43	7.20	185.32*	25.64	0.1782	23.29	0.2748
Sept03	0.0032	0.0018	-0.77	7.94	269.55*	32.58*	0.0375	21.35	0.3770
Oct03	0.0043*	0.0015	-0.29	4.21	18.03*	24.04	0.2408	18.06	0.5834
Nov03	0.0037*	0.0014	-0.40	4.33	24.11*	38.50*	0.0077	29.33	0.0815
Dec03	0.0036*	0.0015	-0.43	5.14	53.39*	19.17	0.5107	27.90	0.1118
Jan04	0.0023	0.0014	-0.47	6.62	140.85*	21.39	0.3744	14.62	0.7978
Feb04	0.0035*	0.0014	-0.48	4.59	34.69*	28.77	0.0925	25.39	0.1871
Mar04	0.0031*	0.0013	-0.32	4.81	37.15*	25.49	0.1835	24.87	0.2064
Apr04	0.0021	0.0014	-0.39	4.56	30.57*	21.97	0.3423	31.84*	0.0450
May04	0.0016	0.0013	-0.17	3.77	7.15*	27.06	0.1335	24.53	0.2200
June04	0.0005	0.0013	-0.28	6.36	117.06*	24.36	0.2272	35.99*	0.0154
July04	0.0002	0.0013	0.11	6.07	95.83*	30.99	0.0553	33.50*	0.0297
Aug04	0.0001	0.0012	-0.09	4.29	17.17*	39.46*	0.0058	32.06*	0.0427
Sept04	−0.0002	0.0012	-0.06	4.11	12.51*	40.35*	0.0045	47.91*	0.0004
Oct04	−0.0006	0.0012	-0.32	4.66	32.00*	35.70*	0.0167	40.77*	0.0040
Nov04	−0.0011	0.0013	-0.30	4.46	25.11*	32.81*	0.0354	45.96*	0.0008
Dec04	−0.0015	0.0012	-0.29	4.33	21.18*	40.82*	0.0039	62.34*	0.0000
Jan05	−0.0016	0.0011	-0.20	4.18	15.55*	26.00	0.1660	57.13*	0.0000
Feb05	−0.0015	0.0011	-0.17	4.23	16.31*	27.61	0.1189	54.66*	0.0000
Mar05	−0.0020	0.0011	-0.17	3.91	9.36*	27.41	0.1241	42.44*	0.0024
Apr05	−0.0022*	0.0011	-0.19	3.88	9.26*	22.14	0.3329	36.56*	0.0132
May05	−0.0012	0.0010	0.15	3.26	1.63	24.81	0.2089	42.57*	0.0023
June05	−0.0008	0.0010	0.07	3.40	1.80	29.28	0.0824	48.25*	0.0004
July05	−0.0010	0.0008	0.02	3.12	0.16	22.61	0.3084	31.96*	0.0438
Aug05	−0.0005	0.0008	-0.04	3.27	0.82	28.85	0.0907	36.31*	0.0141
Sept05	−0.0006	0.0007	-0.10	3.53	3.21	28.40	0.1003	35.36*	0.0183
Oct05	−0.0003	0.0007	-0.11	3.72	5.70	35.93*	0.0157	46.78*	0.0006
Nov05	0.0005	0.0007	0.06	3.73	5.51	33.68*	0.0284	37.06*	0.0115
Dec05	0.0005	0.0007	-0.02	4.26	15.91*	38.43*	0.0078	33.19*	0.0321

(Continued)

Table I. Descriptive statistics for TIIE futures contracts daily price changes (*Continued*)

Contract	Mean	s.d.	Skewness	Kurtosis	BJ	$Q(20)$	p-value	$ARCH$	p-value
Jan06	0.0005	0.0007	-0.08	3.87	7.94*	30.93	0.0561	11.05	0.9448
Feb06	0.0011	0.0007	-0.15	3.94	9.90*	36.72*	0.0126	15.83	0.7272
Mar06	0.0016*	0.0007	0.04	4.03	10.73*	32.72*	0.0362	20.37	0.4347
Apr06	0.0023*	0.0006	0.30	4.39	23.16*	24.45	0.2231	23.93	0.2453
May06	0.0022*	0.0006	0.54	4.89	47.47*	21.87	0.3474	13.58	0.851
June06	0.0020*	0.0006	0.36	4.51	28.22*	28.63	0.0954	12.27	0.9064
July06	0.0016*	0.0006	0.14	4.47	22.65*	38.65*	0.0074	14.02	0.8295
Aug06	0.0018*	0.0006	0.01	4.16	13.45*	38.58*	0.0075	18.99	0.5222
Sept06	0.0014*	0.0006	-0.27	4.60	28.78*	42.73*	0.0022	18.39	0.5615
Oct06	0.0014*	0.0006	-0.55	6.21	116.09*	28.72	0.0934	19.74	0.4744
Nov06	0.0013	0.0007	-0.38	6.55	133.05*	29.59	0.0767	24.59	0.2174
Dec06	0.0010	0.0007	-0.81	11.07	683.06*	22.64	0.3068	19.13	0.5133
Jan07	0.0008	0.0007	-1.12	12.19	901.63*	33.77*	0.0277	13.36	0.8615
Feb07	0.0005	0.0008	-0.82	9.20	415.01*	43.36*	0.0018	18.72	0.5402
Mar07	0.0003	0.0009	-1.19	11.47	779.97*	53.18*	0.0001	18.20	0.5742
Apr07	0.0007	0.0009	-0.88	9.32	434.33*	26.04	0.1644	23.05	0.2865
May07	0.0005	0.0009	-0.89	10.05	532.58*	32.20*	0.0413	29.96	0.0705
Jun07	0.0004	0.0009	-0.78	11.18	699.68*	49.88*	0.0002	41.40*	0.0033
Jul07	0.0006	0.0007	-0.90	11.47	755.94*	32.40*	0.0392	45.32*	0.0010
Aug07	0.0004	0.0006	-0.62	6.82	162.62*	29.74	0.0741	5.39	0.9995
Sep07	0.0002	0.0006	-0.87	8.50	335.68*	43.37*	0.0018	9.10	0.9817
Oct07	0.0002	0.0006	-0.91	9.40	445.88*	33.45*	0.0301	10.83	0.9505
Nov07	−0.0001	0.0005	-0.82	9.11	403.94*	37.53*	0.0101	16.96	0.6554
Dec07	−0.0004	0.0005	-0.31	7.24	185.27*	39.68*	0.0055	23.11	0.2833

This table reports the statistics of the daily log-price changes of each of the futures contracts along 242 days before expiration month. Mean and standard deviation (s.d.) are annualized. BJ is the Bera-Jarque statistic for testing the null hypothesis of normal distribution. $Q(20)$ is the Ljung-Box Q-statistic for autocorrelation (20 lags). ARCH is the LM-statistic of autoregressive conditional heteroscedasticity effect with 20 lags. * indicates significance at 5%.

Table II: Regression of daily volatility on days to expiration

Contract (i)	$\alpha_i \times 10^3$	t-stats	$\beta_i \times 10^4$	t-stats	$AdjR^2$	DW
Jan03	0.1175	7.18^{*}	-0.00203	-2.33^{*}	0.011	1.72
Feb03	0.1263	8.22^{*}	-0.00257	-3.08^{*}	0.018	1.83
Mar03	0.1211	8.92^{*}	-0.00206	-2.58^{*}	0.012	1.88
Apr03	0.1154	8.00^{*}	-0.00134	-1.53	0.002	1.92
May03	0.0892	7.27^{*}	-0.00030	-0.35	-0.004	1.89
June03	0.0969	7.09^{*}	-0.00066	-0.71	-0.002	1.74
July03	0.0962	7.36^{*}	-0.00069	-0.80	-0.002	1.70
Aug03	0.0908	7.71^{*}	-0.00034	-0.42	-0.003	1.79
Sept03	0.0632	5.85^{*}	0.00132	1.58	0.008	1.97
Oct03	0.0477	6.83^{*}	0.00165	3.30^{*}	0.028	1.81
Nov03	0.0478	6.90^{*}	0.00144	2.82^{*}	0.023	1.64
Dec03	0.0481	6.77^{*}	0.00135	2.43^{*}	0.017	1.83
Jan04	0.0588	5.91^{*}	0.00028	0.42	-0.003	1.60
Feb04	0.0619	6.69^{*}	0.00006	0.09	-0.004	1.76
Mar04	0.0649	7.21^{*}	-0.00017	-0.29	-0.004	1.65
Apr04	0.0726	8.35^{*}	-0.00060	-1.11	0.001	1.53
May04	0.0625	8.02^{*}	0.00008	0.15	-0.004	1.67
June04	0.0714	7.67^{*}	-0.00093	-1.60	0.008	1.75
July04	0.0716	8.46^{*}	-0.00098	-1.66	0.011	1.62
Aug04	0.0767	9.83^{*}	-0.00155	-3.40^{*}	0.042	1.84
Sept04	0.0758	9.50^{*}	-0.00138	-3.02^{*}	0.032	1.91
Oct04	0.0661	8.69^{*}	-0.00061	-1.37	0.002	1.82
Nov04	0.0558	7.87^{*}	0.00020	0.46	-0.003	2.00
Dec04	0.0527	8.47^{*}	0.00021	0.55	-0.003	2.03
Jan05	0.0480	9.23^{*}	0.00031	0.91	-0.002	2.03
Feb05	0.0389	7.62^{*}	0.00088	2.36^{*}	0.013	1.92
Mar05	0.0353	6.61^{*}	0.00120	2.90^{*}	0.029	2.02
Apr05	0.0223	4.04^{*}	0.00209	4.79^{*}	0.097	2.05
May05	0.0240	5.36^{*}	0.00183	5.18^{*}	0.097	2.16
June05	0.0197	4.58^{*}	0.00196	5.49^{*}	0.117	2.15
July05	0.0176	5.07^{*}	0.00161	5.92^{*}	0.107	2.13
Aug05	0.0198	6.04^{*}	0.00125	4.68^{*}	0.073	2.10
Sept05	0.0147	5.10^{*}	0.00140	5.76^{*}	0.099	1.95
Oct05	0.0121	3.58^{*}	0.00148	5.47^{*}	0.114	1.80
Nov05	0.0134	3.83^{*}	0.00131	4.75^{*}	0.088	1.86
Dec05	0.0131	3.75^{*}	0.00123	4.43^{*}	0.084	1.88

(Continued)

Table II: Regression of daily volatility on days to expiration (*Continued*)

Contract (i)	$\alpha_i \times 10^3$	t-stats	$\beta_i \times 10^4$	t-stats	$AdjR^2$	DW
Jan06	0.0254	6.40*	0.00054	2.11*	0.015	1.89
Feb06	0.0189	5.44*	0.00086	3.54*	0.044	1.90
Mar06	0.0169	4.79*	0.00099	4.03*	0.057	1.92
Apr06	0.0175	5.20*	0.00090	3.61*	0.049	1.92
May06	0.0198	5.80*	0.00065	2.61*	0.025	1.97
June06	0.0197	5.71*	0.00065	2.66*	0.026	1.81
July06	0.0208	6.26*	0.00047	2.11*	0.012	1.80
Aug06	0.0236	6.23*	0.00038	1.49	0.006	1.77
Sept06	0.0200	5.64*	0.00052	2.23*	0.016	1.68
Oct06	0.0197	5.11*	0.00051	2.05*	0.012	1.63
Nov06	0.0251	6.57*	0.00029	1.36	0.000	1.61
Dec06	0.0210	6.09*	0.00058	2.81*	0.012	1.66
Jan07	0.2030	6.43*	0.00828	4.00*	0.026	1.57
Feb07	0.1625	5.19*	0.01307	5.09*	0.062	1.61
Mar07	0.0528	1.94	0.02255	8.06*	0.154	1.66
Apr07	0.0472	1.33	0.02319	6.73*	0.156	1.71
May07	0.0350	0.79	0.02404	5.86*	0.155	1.72
Jun07	0.0543	0.99	0.02117	4.68*	0.122	1.76
Jul07	0.0748	1.50	0.01616	4.02*	0.097	1.59
Aug07	0.1322	3.94*	0.00890	4.01*	0.053	1.61
Sep07	0.1042	3.79*	0.01025	5.75*	0.071	1.45
Oct07	0.0737	3.07*	0.01174	6.40*	0.098	1.60
Nov07	0.0900	3.78*	0.00997	5.13*	0.072	1.54
Dec07	0.0914	3.43*	0.00989	4.54*	0.077	1.74

The table reports the estimates of the regression model $\sigma(F)_{i\tau} = \alpha_i + \beta_i \tau + u_{i\tau}$ where τ represents days to maturity. $AdjR^2$ is the adjusted R^2. DW is the Durbin-Watson test for first-order serial correlation of the residuals. There are 242 observations (expiration month is excluded). Estimation with heteroscedasticity-consistent standard errors. * indicates significance at 5%.

Table III: Test for individual and time effects in futures volatility series

Year	**Regression coefficients**				**Analysis of variance**			**Equality of variances**	
		estimate	t-stat	p-value	Source	F-test	p-value	χ^2	p-value
2003	$\alpha \times 10^3$	0.08768	24.15	0.0000	Individual	2.400	0.0058	324.94	0.0000
	$\beta \times 10^4$	-0.00035	-1.36	0.1739	Time	0.908	0.8347	(df=11)	
					Joint	0.977	0.5864		
2004	$\alpha \times 10^3$	0.06505	31.28	0.0000	Individual	1.930	0.0048	1225.93	0.0000
	$\beta \times 10^4$	-0.00045	-3.02	0.0025	Time	0.800	0.9889	(df=11)	
					Joint	0.900	0.8721		
2005	$\alpha \times 10^3$	0.02585	18.34	0.0000	Individual	3.021	0.0000	3329.14	0.0000
	$\beta \times 10^4$	0.00138	13.71	0.0000	Time	0.782	0.9943	(df=11)	
					Joint	1.069	0.2090		
2006	$\alpha \times 10^3$	0.02190	21.47	0.0000	Individual	2.893	0.0000	5951.56	0.0000
	$\beta \times 10^4$	0.00061	8.41	0.0000	Time	0.815	0.9829	(df=11)	
					Joint	1.158	0.0355		
2007	$\alpha \times 10^3$	0.12180	10.05	0.0000	Individual	16.047	0.0000	22315.68	0.0000
	$\beta \times 10^4$	0.01493	17.27	0.0000	Time	1.174	0.0342	(df=11)	
					Joint	4.171	0.0000		
All	$\alpha \times 10^3$	0.06445	20.37	0.0000	Individual	106.853	0.0000	27276.38	0.0000
	$\beta \times 10^4$	0.00322	14.28	0.0000	Time	0.597	1.0000	(df=59)	
					Joint	21.653	0.0000		

This table reports the coefficients of the restricted regression $\sigma(F)_{i\tau} = \alpha + \beta\tau + u_{i\tau}$, where α and β are assumed to be constant across contracts and τ represents days to maturity. Analysis of variance is an analysis of variance test for common means, across individuals, across time, or both. The last two columns report the results of a likelihood ratio test for equal variances across cross-sections. df = degrees of freedom.

Table IV: Panel regression of daily volatility on time to expiration

Year	**Regression coefficients**				
		Estimate	**t-stat**	**p-value**	$AdjR^2$
2003	$\alpha \times 10^3$	0.08768	21.47	0.0000	0.0056
	$\beta \times 10^4$	-0.00035	-1.36	0.1728	
	Panel Regression - Estimation by Fixed Effects				
2004	$\alpha \times 10^3$	0.06505	31.84	0.0000	0.0016
	$\beta \times 10^4$	-0.00045	-3.02	0.0025	
	Panel Regression - Estimation by Random Effects				
2005	$\alpha \times 10^3$	0.02585	8.35	0.0000	0.1584
	$\beta \times 10^4$	0.00138	10.47	0.0000	
	Panel Regression - Estimation by Random Effects				
2006	$\alpha \times 10^3$	0.02190	18.74	0.0000	0.0588
	$\beta \times 10^4$	0.00061	7.33	0.0000	
	Panel Regression - Estimation by Random Effects				
2007	$\alpha \times 10^3$	0.12180	5.14	0.0000	0.1688
	$\beta \times 10^4$	0.01493	11.99	0.0000	
	Panel Regression - Estimation by Random Effects				
All	$\alpha \times 10^3$	0.06445	4.57	0.0000	0.3207
	$\beta \times 10^4$	0.00322	11.87	0.0000	
	Panel Regression - Estimation by Random Effects				

This table reports the coefficients of the panel regression $\sigma(F)_{i\tau} = \alpha + \beta\tau + u_{i\tau}$, where τ is the variable for days to maturity. $AdjR^2$ is the adjusted R^2.

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

Contract	$\alpha \times 10^3$	t-stats	$\beta \times 10^4$	t-stats	γ	t-stats	$AdjR^2$	DW
Jan03	0.1118	6.91*	-0.00213	−2.41*	0.068	0.95	0.012	1.77
Feb03	0.1179	7.65*	-0.00289	−3.48*	0.131	1.73	0.032	1.92
Mar03	0.1098	7.49*	-0.00227	−2.95*	0.148	1.78	0.033	1.99
Apr03	0.1089	6.62*	-0.00139	−1.63	0.076	0.92	0.004	1.96
May03	0.0769	5.00*	-0.00049	−0.61	0.159	1.66	0.016	2.02
June03	0.0854	5.40*	-0.00075	−0.83	0.124	1.64	0.015	1.83
July03	0.0778	4.60*	-0.00039	−0.43	0.148	1.89	0.016	1.71
Aug03	0.0790	5.05*	-0.00019	−0.23	0.102	1.28	0.005	1.78
Sept03	0.0536	3.89*	0.00130	1.57	0.105	1.37	0.019	1.93
Oct03	0.0364	4.21*	0.00170	3.43*	0.121	2.10*	0.043	1.81
Nov03	0.0413	4.97*	0.00140	2.77*	0.081	1.49	0.030	1.71
Dec03	0.0399	4.55*	0.00124	2.29*	0.111	1.75	0.029	1.90
Jan04	0.0523	4.73*	0.00017	0.26	0.087	1.22	0.003	1.65
Feb04	0.0601	6.65*	0.00001	0.02	0.027	0.57	-0.007	1.76
Mar04	0.0615	7.17*	-0.00027	−0.44	0.054	1.10	-0.004	1.64
Apr04	0.0648	7.43*	-0.00082	−1.48	0.123	2.22*	0.019	1.65
May04	0.0586	7.26*	-0.00007	−0.13	0.072	1.33	-0.001	1.73
June04	0.0694	6.92*	-0.00094	−1.62	0.027	0.46	0.005	1.76
July04	0.0707	8.33*	-0.00098	−1.65	0.014	0.24	0.007	1.60
Aug04	0.0703	8.39*	-0.00169	−3.71*	0.122	2.00*	0.058	1.95
Sept04	0.0715	8.37*	-0.00156	−3.46*	0.103	1.96	0.042	2.01
Oct04	0.0648	8.16*	-0.00074	−1.66	0.049	0.95	0.001	1.86
Nov04	0.0553	7.59*	0.00011	0.25	0.030	0.55	-0.007	1.98
Dec04	0.0525	8.26*	0.00018	0.44	0.012	0.21	-0.007	2.02
Jan05	0.0486	9.15*	0.00039	1.07	-0.034	−0.65	-0.005	1.98
Feb05	0.0401	7.75*	0.00100	2.54*	-0.062	−1.16	0.013	1.84
Mar05	0.0375	6.86*	0.00138	3.24*	-0.114	−1.92	0.037	1.92
Apr05	0.0246	4.35*	0.00229	5.16*	-0.131	−2.05*	0.106	2.01
May05	0.0285	6.03*	0.00196	5.45*	-0.182	−2.53*	0.113	2.08
June05	0.0238	5.11*	0.00209	5.84*	-0.182	−2.31*	0.131	2.10
July05	0.0200	5.56*	0.00176	6.12*	-0.148	−1.96*	0.118	2.07
Aug05	0.0208	6.24*	0.00133	4.64*	-0.082	−1.08	0.074	2.05
Sept05	0.0150	5.14*	0.00145	5.22*	-0.034	−0.40	0.096	1.92
Oct05	0.0123	3.61*	0.00150	5.16*	-0.026	−0.32	0.111	1.80
Nov05	0.0135	3.85*	0.00132	4.27*	-0.015	−0.16	0.084	1.85
Dec05	0.0131	3.69*	0.00124	4.13*	-0.010	−0.10	0.080	1.89

(Continued)

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

(*Continued*)

Contract	$\alpha \times 10^3$	t-stats	$\beta \times 10^4$	t-stats	γ	t-stats	$AdjR^2$	DW
Jan06	0.0258	6.46*	0.00056	2.10*	-0.034	−0.43	0.011	1.88
Feb06	0.0181	5.17*	0.00084	3.35*	0.062	0.51	0.043	1.92
Mar06	0.0170	4.55*	0.00099	4.04*	-0.010	−0.13	0.053	1.92
Apr06	0.0170	4.67*	0.00090	3.61*	0.032	0.46	0.045	1.96
May06	0.0193	5.36*	0.00066	2.62*	0.036	0.53	0.022	2.02
June06	0.0196	5.32*	0.00065	2.66*	0.011	0.16	0.022	1.85
July06	0.0210	6.18*	0.00047	2.11*	-0.018	−0.27	0.008	1.81
Aug06	0.0238	6.24*	0.00039	1.50	-0.025	−0.32	0.002	1.77
Sept06	0.0201	5.66*	0.00054	2.20*	-0.023	−0.30	0.012	1.69
Oct06	0.0197	5.12*	0.00054	2.08*	-0.043	−0.51	0.009	1.61
Nov06	0.0251	6.58*	0.00032	1.41	-0.027	−0.35	-0.003	1.60
Dec06	0.0208	6.10*	0.00061	2.76*	-0.036	−0.44	0.008	1.63
Jan07	0.2213	6.22*	0.00919	4.35*	-1.589	−1.88	0.034	1.61
Feb07	0.1705	4.91*	0.01327	5.15*	-0.607	−0.82	0.059	1.63
Mar07	0.0917	3.11*	0.02294	8.27*	-2.589	−2.82*	0.170	1.68
Apr07	0.0773	2.15*	0.02327	6.78*	-1.929	−1.95	0.162	1.71
May07	0.0655	1.54	0.02392	5.92*	-2.000	−1.76	0.160	1.72
Jun07	0.0776	1.46	0.02120	4.72*	-1.674	−2.03*	0.126	1.77
Jul07	0.0868	1.80	0.01654	4.05*	-1.245	−1.48	0.098	1.59
Aug07	0.1342	4.00*	0.00908	4.02*	-0.347	−0.51	0.050	1.61
Sep07	0.1041	3.76*	0.01022	5.63*	0.043	0.06	0.067	1.45
Oct07	0.0737	3.07*	0.01169	6.16*	0.065	0.09	0.094	1.60
Nov07	0.0943	3.61*	0.00841	2.67*	1.723	0.58	0.083	1.54
Dec07	0.0891	3.35*	0.01035	4.36*	-0.471	−0.33	0.074	1.73

The table reports the estimates of the unrestricted regression $\sigma(F)_{i\tau} = \alpha_i + \beta_i \tau + \gamma_i\, \sigma(S)_{i\tau} + u_{i\tau}$, where τ represents days to maturity and $\sigma(S)_{i\tau}$ is the spot volatility. $AdjR^2$ is the adjusted R^2. There are 242 observations (expiration month is excluded). Estimation with heteroscedasticity-consistent standard errors. * indicates significance at 5%.

Table VI: Test for individual and time effects in futures volatility series with TIIE spot variance as control variable

Year	**Regression coefficients**				**Analysis of variance**			**Equality of variances**	
		Estimate	t-stat	p-value	Source	F-test	p-value	χ^2	p-value
2003	$\alpha \times 10^3$	0.0775	19.78	0.0000	Individual	2.190	0.0126	323.07	0.0000
	$\beta \times 10^4$	-0.0004	-1.58	0.1132	Time	0.953	0.6814	(df=11)	
	γ	0.1147	6.64	0.0000	Joint	1.012	0.4410		
2004	$\alpha \times 10^3$	0.0612	27.28	0.0000	Individual	1.695	0.0203	1208.50	0.0000
	$\beta \times 10^4$	-0.0006	-3.80	0.0001	Time	0.832	0.9707	(df=11)	
	γ	0.0708	4.49	0.0000	Joint	0.909	0.8496		
2005	$\alpha \times 10^3$	0.0263	18.12	0.0000	Individual	2.895	0.0000	3293.45	0.0000
	$\beta \times 10^4$	0.0014	13.59	0.0000	Time	0.805	0.9873	(df=11)	
	γ	-0.0251	-1.25	0.2128	Joint	1.074	0.1947		
2006	$\alpha \times 10^3$	0.0219	20.99	0.0000	Individual	2.774	0.0000	5888.61	0.0000
	$\beta \times 10^4$	0.0006	8.32	0.0000	Time	0.842	0.9631	(df=11)	
	γ	-0.0005	-0.02	0.9834	Joint	1.161	0.0331		
2007	$\alpha \times 10^3$	0.1230	10.00	0.0000	Individual	8.238	0.0000	302.41	0.0000
	$\beta \times 10^4$	0.0150	17.28	0.0000	Time	0.825	0.9743	(df=11)	
	γ	-0.0301	-0.64	0.5203	Joint	1.167	0.0431		
All	$\alpha \times 10^3$	0.0602	18.47	0.0000	Individual	105.586	0.0000	27229.00	0.0000
	$\beta \times 10^4$	0.0031	13.86	0.0000	Time	0.593	1.0000	(df=59)	
	γ	0.0980	5.40	0.0000	Joint	21.395	0.0000		

This table reports the coefficients of the restricted regression $\sigma(F)_{i\tau} = \alpha + \beta\tau + \gamma\sigma(S)_{i\tau} + u_{i\tau}$, where α and β are assumed to be constant across contracts, τ is the variable for days to maturity and $\sigma(S)_{i\tau}$ is spot volatility. Analysis of variance is an analysis of variance test for common means, across individuals, across time, or both. The last two columns report the results of a likelihood ratio test for equal variances across cross-sections. df = degrees of freedom.

Table VII: Panel regression of daily volatility on time to expiration and spot rate volatility

Year	Regression coefficients				
		Estimate	t-stat	p-value	$AdjR^2$
2003	$\alpha \times 10^3$	0.07763	17.76	0.0000	0.0214
	$\beta \times 10^4$	-0.00041	-1.59	0.1129	
	γ	0.11290	6.55	0.0000	
	Panel Regression - Estimation by Random Effects				
2004	$\alpha \times 10^3$	0.06096	28.03	0.0000	0.0116
	$\beta \times 10^4$	-0.00058	-3.77	0.0002	
	γ	0.07510	4.83	0.0000	
	Panel Regression - Estimation by Random Effects				
2005	$\alpha \times 10^3$	0.02737	8.14	0.0000	0.1675
	$\beta \times 10^4$	0.00149	10.73	0.0000	
	γ	-0.08910	-4.29	0.0000	
	Panel Regression - Estimation by Random Effects				
2006	$\alpha \times 10^3$	0.02190	18.38	0.0000	0.0587
	$\beta \times 10^4$	0.00061	7.25	0.0000	
	γ	0.00102	0.04	0.9677	
	Panel Regression - Estimation by Random Effects				
2007	$\alpha \times 10^3$	0.12348	5.19	0.0000	0.1687
	$\beta \times 10^4$	0.01495	12.00	0.0000	
	γ	-0.03451	-0.72	0.4688	
	Panel Regression - Estimation by Random Effects				
All	$\alpha \times 10^3$	0.06368	4.52	0.0000	0.3207
	$\beta \times 10^4$	0.00321	11.83	0.0000	
	γ	0.01754	1.08	0.2815	
	Panel Regression - Estimation by Random Effects				

This table reports the estimated coefficients of the panel regression $\sigma(F)_{i\tau} = \alpha + \beta\tau + \gamma\sigma(S)_{i\tau} + u_{i\tau}$, where τ is the variable for time to maturity and $\sigma(S)_{i\tau}$ is the spot rate volatility. $AdjR^2$ is the adjusted R^2.