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Abstract

This study examines the information conveyed by options, and examines their implied volatility at the time of the 1997 Hong Kong stock market crash. The paper determines the efficiency of implied volatility as a predictor of future volatility by comparing it to other candidate leading indicators. These include volume and open interest of index options and futures, as well as the arbitrage basis of index futures. Using monthly, non-overlapping data, the study reveals that implied volatility is superior to those variables in forecasting future realized volatility. The paper also demonstrates that a simple signal extraction model could have produced useful warning signals prior to periods of extreme volatility.

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1. Introduction

The Asian financial crisis rocked the Hong Kong markets on October 23, 1997. The Hang Seng Index futures plummeted 1,300 points in an hour from 11,300 at the open. Measured by the annualized standard deviation of the minute-by-minute index futures returns, volatility on that day was 148% (Draper and Fung, 2003). In contrast, the volatility figure had not exceeded 25% prior to the outbreak of the crisis.

A number of studies have tested potential early warning systems following the outbreak of the Asian financial crisis. These systems focus on macroeconomic variables from the banking and real economic sectors.[1] The current paper, in contrast, analyzes prices, volume and open interest of index options and futures at the time of the crisis to examine whether certain abnormalities or "signals" could have been observed from these market variables.

Compared to cash market positions index options and futures are highly leveraged speculative instruments. They allow traders who possess superior market-wide information to magnify their investment returns. Bullish traders who expect a market rise may go long index futures, buy call and/or short put index options. On the other hand, bearish speculators would short futures, buy put and/or short call. Hence, volumes, open interest and prices of these instruments could impound information on the probability, potential magnitude and direction of impending market movements. This study especially focuses on the implied volatility of index options since this is widely regarded as an agglomeration of market opinions on future volatility.

The paper examines the forecast quality of the implied volatility index compiled by the HKEx for the period March 1993 to October 2000. The prediction efficiency of implied volatility is compared to the use of volume and open interest information for index derivatives, and the lagged realized volatility and arbitrage basis of index futures.

The study finds that option implied volatility subsumes measures based on past realized volatility, volume and open interest of index options and index futures, and the arbitrage basis of index futures in forecasting future volatility. The result indicates that implied volatility is an efficient predictor of future volatility. The study shows that signal extraction based on implied volatility provides early-warning signals for 7 out of 11 of the most volatile monthly periods surrounding the crisis episode. Early signals appeared in May and June of 1997. The simple model had correctly signaled the extreme volatility observed in August. The results suggest that option implied volatility could be incorporated into an early warning system against impending large market movements or crisis events.

The paper contributes to the literature in a number of ways. Past studies have examined the efficiency of estimates based on implied volatility relative to realized volatility in predicting future volatility. This paper shows that implied volatility encompasses other potential indicators of volatility - open interest and volume of options and futures, as well as the arbitrage basis of index futures, in predicting future market volatility. This study also provides preliminary evidence to support the incorporation of estimates

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1 See for example, Kaminsky (1999), Berg and Patttillo (1999), and Goldfajn and Valdes (1998).

of implied volatility in an early warning system designed to provide information on potential financial crisis.

2. Background of research

Index options and futures are highly leveraged speculative instruments. Bullish traders expecting a rise in the market can go long futures, buy call, and/or short put. Bearish traders who expect the opposite would short futures, short call and/or buy put. However, options have finite lives and their values are subject to time decay. Successful option players have to be right both about market direction and volatility forecasts for a specific time horizon (by the time period preceding the option's expiration date).[2] Traders increase their exposure and pay higher prices only if they expect the returns to be large and imminent. Therefore, trading volumes and the prices of options contracts may impound the probability, potential magnitude, direction, and most importantly, the timing of prospective market movements.

In their seminal paper, Black and Scholes (1973) show that the price of an option is determined by (1) value of the underlying asset, (2) payouts or leakage from the asset, (3) time-to-maturity of the contract, (4) risk-free interest rate, (5) exercise price of the option, and (6) expected future volatility of the asset. Given the first five factors, implied volatility is monotonic over option price and it is common for option traders to quote option prices in units of (implied) volatility. Implied volatility summarizes the supply and demand condition in the options market and can be interpreted as an agglomeration of the market's anticipation of future volatility between the initiation and expiration day of the contract. It is a natural choice for forecasting future volatility.

Rapport and White (1994) postulate that the brokers' loan in the 1920s was actually a call option contract. Based on this insight, they find that the implied volatility inferred from the brokers' loans rose sharply in early 1929 well in advance of the October 1929 crash. They also find that implied volatility continued to build up until the crash occurred. Schwert (1990) and Bates (1991) show that the volatility implied by the S&P 500 index options signaled the 1987 crash. Moreover, prior to the crash, the implied volatility of the out-of-the-money put was significantly higher than that of the out-of-the-money call although the phenomena subsided in the two months leading to the crash. These results are consistent with the general finding of Fleming, Ostdiek, and Whaley (1995) and Christensen and Prabhala (1998) that implied volatility can predict future "realized" market volatility.

Canina and Figlewski (1993) find that the implied volatility from the S&P 100 index options (OEX) provides a poor forecast of volatility. However, a number of recent studies show that implied volatility outperforms past volatility and provides an efficient forecast of future volatility. Examples of these studies include Jorion (1995) on foreign currency options, Christensen and Prabhala (1998) on OEX options, Poteshman (2000) on S&P 500 index options, and Corrado and Miller (2003) on CBOE VIX and VXN volatility index. This paper extends these studies and explores whether implied volatility encompasses other volatility indicators in forecasting future volatility.

[2] Futures can be rolled over indefinitely. The strategy, however, is subject to the basis risk between the expiring spot and deferred month contracts.

To avoid arbitrage, the futures price must be close to its "fair" or arbitrage-free value that depends largely on the value of the underlying asset. The cost-of-carry condition of Modest and Sundaresan (1983) and Cornell and French (1983) provide a formula to calculate the fair futures price. If the futures price is above (below) its fair value there is an index arbitrage opportunity; an arbitrageur may buy (short or sell) the underlying asset and short (buy) the futures.

However, there are significant transactions costs associated with index arbitrage operation. Fung and Draper (1999, 2003) show that, for the Hong Kong market, arbitrage opportunities have rarely exceeded transaction costs and rapidly disappear if they are spotted. Fung's (2003) study on the relationship between order imbalance and index futures price shows that arbitrage opportunities are associated with excessive buying or selling in the cash stock market, and the arbitrage opportunity is a price for liquidity borne by speculators. It is possible that large and persistent index arbitrage opportunities reveal information on the size and direction of expected future market movements.

Admati and Pfleiderer (1988) demonstrate theoretically that the significance of a piece of information imbedded in a trade is positively related to the size of the transaction. Hence, volume can be used as a measure of the size of information flow. Empirical evidence has shown that trading volume is significantly related to price changes. This is consistent with the empirical evidence in general, in Karpoff (1987), indicating that there is a positive relationship between volume and absolute value of returns (a proxy for volatility) in both stock and futures markets. Cornell (1981) finds that the positive relationship between changes in volatility and commodities futures volume is contemporaneous although Chan and Chung (1993) examine the Major Market index futures and find that increases in arbitrage spread are followed by rises in cash and futures volatility[3] as well as cash trading volume. Possibly due to restrictions against short-selling, they find that the relationship is weaker when the futures are under-priced. Bessembinder and Seguin (1992) decompose futures volume into expected and unexpected components and find that stock price volatility is positively related to the volume shock (i.e., unexpected volume) but is negatively related to expected volume.

A number of studies have examined the behavior of the options and futures prices surrounding the 1997 Hong Kong financial crisis period. Draper and Fung (2003) show that despite record volatility the prices of index futures were mostly in line with the no-arbitrage bounds during the pre-intervention period. However, pricing efficiency was breached when and after the government intervened in both stock and futures markets.[4] Cheng, Fung and Chan's (2000) study on the relative pricing efficiency between index options and futures during the crisis period shows that prices of the derivatives remained closely aligned during the stressful market period.

A number of papers have tested different early warning systems following the outbreak of the Asian financial crisis - for example, Kaminsky (1999), Berg and Pattillo (1999), and Goldfajn and Valdes (1998). These studies have mainly focused on potential early warning signals that are derived from

[3] Their results also show that an increase in market volatility does not lead to higher potential arbitrage profit.

[4] The Hong Kong government also transacted in the options market. Goodhart and Dai (2003) provide a detailed account of the extent of government intervention and market statistics for the period surrounding the event.

macroeconomic variables such as changes in exports, exchange rates, foreign exchange reserve, and national products.

3. Data and methodology

Data

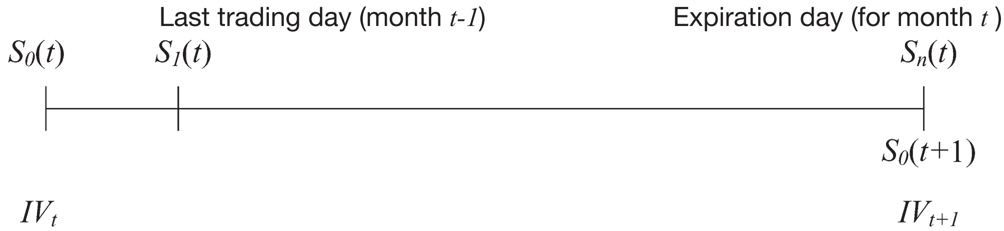
The study uses the implied volatility index provided by HKEx for the period March 5, 1993 to October 31, 2000. Since the inception of index options trading, the exchange has determined the daily settlement prices of index options by using the implied volatilities of the outstanding options polled from major market makers. The volatility index is calculated as a simple average of the six nearest to the money HS index call and put options. Daily data on trading volume and open interest of Hang Seng Index options and futures are also obtained from the exchange. Time-stamped tick-by-tick Hang Seng Index futures prices are employed for the calculation of intraday arbitrage basis for the period May 1996 to December 1998. The arbitrage basis is measured as the difference between the actual futures price and the fair futures value implied by the mid-quote cash index. The mid-quote index is an average of the bid and ask index prices estimated from the quote records of all index stocks. Dividend information on all index stocks and interest rates that match the time period of the futures price data is provided by Hang Seng Index Services. Trading in index options and futures is concentrated on spot month contracts except on the expiration day. Hence, we limit the prediction horizon to be one month.

Sampling procedure

Regressions using daily data of implied and realized volatility typically produce serial correlation in the forecasting error. This occurs when the prediction horizons of consecutive implied volatilities and the periods for calculating realized volatilities overlap. Serial correlation in the errors introduces downward bias in the standard error of the ordinary least square estimates. Following Christensen and Prabhala (1998), we adopt the following sampling procedure (as shown in Exhibit 1 below) to produce non-overlapping monthly sample data. On the option expiration day, (in month t-1), of the spot month contract, HKEx uses option contracts that expire at the end of the next month (i.e., month t) to calculate the volatility index. The volatility index reported on the last trading day of the spot month contract includes the expected market volatility until the next expiration day in month t. To match the forecast horizon of the implied volatility, the (future) realized volatility AV_t is measured by the standard deviation of the daily close-to-close index returns observed between the two consecutive expiration days for month t-1 and month t. The procedure is repeated for the next expiration day (i.e., for month t), and so on.

Exhibit 1

Expiration day (for month t-1)



Realized volatility is represented by the annualized standard deviation of the continuously compounded, daily, close-to-close index return. Let AV_t be the realized or actual volatility for month t.

$$AV_t = \sqrt{\frac{N}{n_t - 1}\sum_{i=1}^{n_t}\left[u_i(t) - \frac{1}{n_t}\sum_{j=1}^{n_t}u_j(t)\right]^2} \tag{1}$$

where

AV_t is the annualized standard derivation of the continuously compounded daily index return for month t.

n_t is the number of trading days in month t

N is the number of trading days for the year

$u_i(t)$ is the continuously compounded daily index return on day i in month t

$u_i(t) = \ln S_i(t) - \ln S_{i-1}(t)$

$S_i(t)$ is the index price at market close on day i in month t.

Calculation of the arbitrage spread

To control for the measurement error of the cash index due to bid ask bounce and non-synchronous trading in underlying stocks,[5] the bid ask index prices used in Draper and Fung (2003) are adopted in this study. These indexes are estimated from simultaneous and active quotes of every component stock of the index. Since the quotes are directly retrieved from a screen-trading system data problems associated with floor trading - for instance, delay in trade reporting are largely eliminated. The arbitrage spread is measured as the difference between the actual futures price and the fair futures value implied by the mid-quote index. The mid-quote index is the average of the concurrent bid and ask indexes. Controlling for the actual (ex-post) dividend payments accrued to the index during the remaining life of the contract, the fair futures value $F^*_{t_\tau}$ is calculated as follows:

5 Note that the bid ask spread of the cash index could amount to 70 basis points of the index level in Fung and Draper (2003).

$$F_{t_\tau}^{*} = S_{t_\tau}^{m}(1+r)^{T-t} - \sum_{j=t}^{T-t-1} W_{it} D_{ij} (1+r_j)^{T-j} \tag{2}$$

where $S_{t_x}^{m}$ is the mid-quote index - an average of bid and ask index prices; *r* is the riskless rate for the holding period between day *t* and *T*; *t* and *T* (as fractions of a year) denote the current and expiration day of the contract, respectively; W_{it} is the market value weight for security *i* on day *t*; D_{ij} is the per share cash dividend for stock *i* at time *j*; and r_j is the overnight interest rate. The arbitrage spread at a particular time point is equal to *F-F*/ F**. We examine the aggregate of the intraday basis for each monthly period defined between two consecutive expiration days.

Methodology

To test the predictive power and information content of implied volatility relative to other measures, IV_t is compared to other variables in the following 'encompassing' multiple regression model.

$$AV_t = \alpha_0 + \alpha_1 IV_t + \sum_{i=1}^{k} \beta_{it} X_{it} + e_t \tag{3}$$

Variables excluding the implied volatility are denoted by X_{it}. OLS is adopted to estimate the model since non-overlapping sample data is used. If IV_t encompasses all other variables in predicting future volatility, then β_{it} are all equal to zero.

A signal extraction process

Consider the following model for the determination of implied volatility or option price where implied volatility is determined in the market according to a simple auto-regressive process with an adjustment for the latest error represented by AV_t - IV_t.

$$IV_t = \gamma_0 + \gamma_1 IV_{t-1} + \gamma_2 \left(AV_{t-1} - IV_{t-1}\right) + v_t \tag{4}$$

The deviation of IV_t from its predicted value $\hat{IV}_t$ reflects information on future volatility that is not imbedded in the current information set. For simplicity, it is assumed here that the current information set can be largely described by two parameters - i.e., the currently observed market volatility and the previous implied volatility.[6] Controlling for the error in the model for the IV_t process, the standardized error is the variable of potential interest here.

Focusing on positive deviations, a significant deviation from the norm (or the predicted value given the current market information) may indicate that option prices have incorporated information of a potential future volatility shock. Hence, a potential signal for an impending large market movement is when the standardized error exceeds a positive threshold number; that is

6 Note that these two parameters together explain over 78% of the variation in the current implied volatility. This supports the hypothesis that market participant price options according to the currently observed market volatility and a component that corrects for past pricing error. Please refer to the section on empirical findings.

$$Signal_t = IV_t - I\hat{V}_t / \sqrt{MSE} > threshold \qquad (5)$$

Where $$IV_t - I\hat{V}_t = IV_t - \left[\hat{\gamma}_0 + \hat{\gamma}_1 IV_{t-1} + \hat{\gamma}_2 \left(AV_{t-1} - IV_{t-1}\right)\right] \qquad (6)$$

4. Empirical findings

Table 1 summarizes descriptive statistics of the monthly observations of realized volatility (AV_t) , implied volatility index (IV_t), options open interest (OOI_t), option trading volume ($OVOL_t$), futures open interest (FOI_t), and futures trading volume ($FVOL_t$) on the common expiration day of both contracts. The mean of the options volume is around 6% of future volumes. However, the mean of the options open interest is close to 70% of futures.

Figure 1 graphs the implied volatility (IV_t) and realized volatility (AV_t) for the study period March 1993 to October 2000. The two metrics closely track each other. Figure 2 shows the time series plot of the option volume ($OVOL_t$) and open interest (OOI_t) against the realized volatility (AV_t). A build up of open interest occurred as far back as the second half of 1996 well before volatility dramatically increased in the third quarter of 1997.

Table 2 provides the results from ordinary least square univariate and multivariate regressions of realized volatility (AV_t) on lagged realized volatility (AV_{t-1}), implied volatility (IV_t), option volume ($OVOL_t$) and option open interest (OOI_t). For the period March 1993 to October 2000, we obtain 92 non-overlapping monthly samples of implied and realized volatilities. The results provide evidence of the forecasting efficiency of implied volatility relative to realized volatility, option volume, and option open interest

The R^2 for the univariate regression with implied volatility is 42.8%, higher than the 39% obtained with lagged realized volatility AV_{t-1}. Expiration day option volume and open interest have no explanatory power on the next-month market volatility. By comparing implied against lagged realized volatility, the multivariate regression result shows that implied volatility easily outperforms lagged realized volatility in forecasting future volatility. The slope coefficient for the lagged realized volatility is insignificant and including lagged volatility only increases the adjusted R^2 by a fraction of a percent. This result is consistent with recent literature that implied volatility is an efficient forecast estimator of future volatility. The estimated values are comparable to those in Christensen and Prahala (1998). The coefficient estimates for IV_t and AV_t, in their one-month ahead forecast with non-overlapping sample, are 0.76 (R^2=39%) and 0.57 (R^2=32%), respectively although they use the natural logarithms of the variables. These findings are consistent with those of Chan, Chung, and Fong (2002) who find that net trading volume of CBOE stock options is only weakly related to the future return of the corresponding stocks but that revisions of options' price quotes are informative.

Figure 3 plots volume ($FVOL_t$) and open interest (FOI_t) of the futures contract. The volume and open interest of the futures appears to better track volatility than the corresponding option statistics. Table 3 summarizes the results of regressions of realized volatility (AV_t) on implied volatility, futures volume and futures open interest. Both univariate regressions using futures volume, and open interest are significant with R^2 of 14.4% and 14.2%, respectively. However, comparing either one of them against implied volatility shows that both are subsumed by implied volatility in predicting volatility. These results show that implied volatility is an efficient forecaster relative to volume and open interest information from index futures.

The arbitrage basis of index futures data is only available for the 24-month period between May 1996 and April 1998. Table 4 provides descriptive statistics of implied and realized volatility and the two measures of basis. We adopt the aggregate of the intraday basis for each monthly period defined between two consecutive expiration days as well as the absolute value of the aggregate. Figure 4 plots the two basis measures against the realized volatility. It is seen that the aggregate basis is mostly negative for the period.

Table 5 summarizes the results of ordinary least square univariate and multivariate regressions of realized volatility (AV_t) on implied volatility (IV_t), absolute value of the basis and the basis. The regressions are run with a 24 non-overlapping monthly sample for the period. Regressions with either basis measure are significant with R^2 above 15%. However, implied volatility easily outperforms both measures in predicting volatility. Adjusted R^2 drops after including the basis measures in the implied volatility regression.

The model for the determination of implied volatility has high explanatory power. Table 6 summarizes the estimation results. The error correction coefficient is positive as expected, and significant. R^2 for the regression is over 78%. To produce an out-of-sample forecast of $I\hat{V}_t$, we use rolling regressions with the 24 non-overlapping month data. The prediction error is standardized using the root mean squared error of the respective regression.

To test whether the variable is a potential signaling device, we define an event as occurring when the (annualized) realized volatility exceeds 40%, and a signal if the standardized error exceeds unity.[7] Table 7 summarizes the correspondence between the event and the signal. Ten signals arise from the 68 out-of-sample forecasts. A total of 11 months occur with volatility in excess of 40%. The date denotes the date when the signal occurs. It is also the date for the reported implied volatility index. AV_t is the realized volatility of the following month. Following Kaminsky (1999), Table 8 summarizes type I and type II errors associated with the signal extraction framework. A signal is counted as a good signal (A) only if the volatility realized in the subsequent month exceeds 40%. This definition of a good signal can be overly restrictive. For example, the signals produced in May and June of 1997 could be seen as good early warning signals of impending volatility that was subsequently realized in the September. Based on the definition, the framework produced 10 signals, 7 of them good signals. Conditional on events, the probability of a correct signal is 7/11, and 70% of the signals issued are good signals.

A signal is a bad signal or “noise” (B) if the realized volatility in the following month does not exceed 40%. Of the 10 signals issued, 3 are bad signals. C denotes the number of times the framework fails to produce a signal before an event. On this count, the system failed 4 times to produce a signal prior to an

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7 Note that both the threshold level for classifying a signal and the definition of an event are arbitrarily determined without calibration. They are chosen as ballpark figures to demonstrate the potential value of incorporating option implied volatility in an early warning system.

event. D shows the number of times the framework correctly refrains from issuing a bad signal. Out of 57 non-events, the system has correctly avoided making a signal in 54 of these cases.

5. Conclusion

This study provides a test of the efficiency of implied volatility in forecasting future volatility at the time of the 1997 Hong Kong financial crisis period. Using monthly non-overlapping data, the paper shows that implied volatility outperforms a number of candidate predictors of volatility in forecasting future volatility. The widely cited volatility predictors include volume and open interest of index options and futures, lagged realized volatility and the arbitrage basis of index futures. The paper also demonstrates that a simple signal extraction model could have produced reasonably accurate warning signals prior to periods of extreme volatility. These results provide support for the incorporation of implied volatility into an early warning system against impending large market movement in order to enhance crisis or risk management ability of various entities.

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Table 1. Summary statistics for the monthly measures of realized volatility, implied volatility index, option open interest, option trading volume, futures open interest, and futures volume for the period March 1993 to October 2000

	N	Mean	Std Dev	Min	Median	Max
AV_t	92	26.88	13.94	9.89	23.78	97.23
IV_t	92	32.21	12.15	15.80	30.75	81.00
OOI_t	92	34069	20584	2326	28159	89507
$OVOL_t$	92	3280	1796	194	2834	7871
FOI_t	92	51724	19756	15238	47618	150935
$FVOL_t$	92	21055	7583	6409	20073	44351

AV_t realized volatility is the standard deviation of daily close-to-close index returns from the expiration day of the spot month contract in month t-1 to the next expiration day one month after.
IV_t implied volatility index inferred from options that mature in month *t*.
OOI_t open interest of all options contracts on the expiration day in month *t-1*.
$OVOL_t$ volume of all options contracts on the expiration day in month *t-1*.
FOI_t open interest of all futures contracts on the expiration day in month *t-1*.
$FVOL_t$ volume of all futures contracts on the expiration day in month *t-1*.

Table 2. Regression results with non-overlapping monthly samples for the period Mar 1993 to Oct 2000 (N=92)

OLS univariate and multivariate regressions of realized volatility (AV_t) on lagged realized volatility (AV_{t-1}), implied volatility (IV_t), option volume ($OVOL_t$) and option open interest (OOI_t).

	Independent variables					F-stat	R^2	Adj R^2	Root MSE
	Intercept	IV_t	AV_{t-1}	OOI_t	$OVOL_t$				
Estimates	2.697	0.751				67.38	0.428	0.422	10.598
(p-value)	(0.3936)	(<.0001)				(<.0001)			
	10.142		0.624			56.93	0.390	0.383	11.001
	(0.0001)		(<.0001)			(<.0001)			
	25.459			0.00004		0.34	0.004	-0.007	14.060
	(<.0001)			(0.5696)		(0.5596)			
	27.016				-0.00004	0.00	0.000	-0.011	14.014
	(<.0001)				(0.9596)	(0.9596)			
	3.931	0.523	0.229			34.75	0.441	0.429	10.590
	(0.2306)	(0.0056)	(0.1584)			(<.0001)			
	0.813	0.753		0.00005		33.81	0.435	0.422	10.653
	(0.8277)	(<.0001)		(0.3302)		(<.0001)			
	0.757	0.759			0.00051	33.90	0.432	0.420	10.617
	(0.8481)	(<.0001)			(0.4141)	(<.0001)			
	1.761	0.529	0.228	0.00003	0.00025	17.38	0.447	0.421	10.656
	(0.6652)	(0.0056)	(0.1666)	(0.6881)	(0.8015)	(<.0001)			

Table 3. Regression results with non-overlapping monthly samples (Period: Mar 1993-Oct 2000) - Monthly (N=92)

OLS univariate and multivariate regressions of realized volatility (AV_t) on implied volatility (IV_t), futures volume ($FVOL_t$) and futures open interest (FOI_t).

	Independent variables				F-stat	R^2	Adj R^2	Root MSE
	Intercept	IV_t	$FVOL_t$	FOI_t				
Estimates	2.697	0.751			67.38	0.438	0.422	10.598
(p-value)	(0.3936)	(<.0001)			(<.0001)			
	12.204		0.001		15.12	0.144	0.134	12.967
	(0.0031)		(0.0002)		(0.0002)			
	13.110			0.000	14.95	0.142	0.133	12.978
	(0.0009)			(0.0002)	(0.0002)			
	2.109	0.731	0.000		33.41	0.429	0.416	10.650
	(0.5622)	(<.0001)	(0.7406)		(<.0001)			
	-0.286	0.688		0.000	35.54	0.444	0.432	10.508
	(0.9374)	(<.0001)		(0.1144)	(<.0001)			
	0.362	0.729	-0.000	0.000	23.95	0.450	0.431	10.515
	(0.9224)	(<.0001)	(0.3503)	(0.0724)	(<.0001)			

Table 4. Summary Statistics (Period: May 1996 - Apr 1998) - Monthly Data (N=24)

	N	Mean	Std Dev	Min	Median	Max
AV_t	24	28.25	21.06	9.89	19.09	97.23
IV_t	24	29.91	16.82	15.80	22.15	81.00
Basis	24	-7.7111	9.1457	-26.5728	-8.0216	5.7997
|Basis|	24	9.38	7.35	0.36	8.02	26.57

Basis is equal to the aggregate of the intraday basis for a monthly period between two consecutive expiration day.
|Basis| is the magnitude of the arbitrage basis (|Basis|)

Table 5. Regression results with non-overlapping monthly samples (Period: May 1996-Apr 1998; N=24)

OLS univariate and multivariate regressions of realized volatility (AV_t) on implied volatility, magnitude of the arbitrage basis (|Basis|), and the basis (Basis). Basis is equal to the aggregate of the intraday basis for the previous month including the expiration day.

	Independent variables				F-stat	R^2	Adj R^2	Root MSE
	Intercept	IV_t	*|Basis|*	*Basis*				
Estimates	5.930	0.746			12.13	0.355	0.326	17.292
(p-value)	(0.4264)	(0.0021)			(0.0021)			
	17.849		1.110		3.88	0.150	0.111	19.859
	(0.0137)		(0.0617)		(0.0617)			
	21.311			-0.901	3.97	0.153	0.114	19.823
	(0.0006)			(0.0589)	(0.059)			
	4.432	0.662	0.428		6.25	0.373	0.314	17.454
	(0.5679)	(0.0124)	(0.4491)		(0.0074)			
	5.737	0.659		-0.365	6.32	0.376	0.316	17.419
	(0.4453)	(0.012)		(0.419)	(0.0071)			
	5.707	0.659	0.010	-0.358	4.01	0.376	0.282	17.849
	(0.534)	(0.015)	(0.995)	(0.781)	(0.0219)			

Table 6. (Period: Mar 1993 – Oct 2000) – Monthly (N=92)

Dependent variable: Implied Volatility (IV_t)

	Independent variables				F-stat	R^2	Adj R^2	Root MSE
	Intercept	IV_{t-1}	AV_{t-1}	AV_{t-1} - IV_{t-1}				
Estimates	9.727	0.698			84.75	0.4878	0.4820	8.790
(p-value)	(0.0003)	(<.0001)			(<.0001)			
	11.875		0.757		273.03	0.7542	0.7514	6.090
	(<.0001)		(<.0001)		(<.0001)			
	8.034	0.855		0.627	159.52	**0.7838**	0.7789	5.743
	(<.0001)	(<.0001)		(<.0001)	(<.0001)			

Table 7. Signal and Extreme Volatility

Date	IV_t	AV_t	$IV_t - I\hat{V}_t / \sqrt{MSE}$
19970529	22	27.5464	1.1884
19970626	29.3	16.0049	4.0918
19970828	33.3	44.7967	4.3834
19970929	33.5	97.2258	-1.7425
19971030	81	46.9317	9.9107
19971230	45.3	66.7979	1.4175
19980126	63.5	56.2003	1.3282
19980429	38.5	28.7233	4.0785
19980528	57.1	52.0147	5.0900
19980730	47.5	50.824	1.4850
19980828	69	55.6143	2.4483
19980929	45.8	46.0227	-1.3797
19991229	35.2	40.5227	-0.1204
20000330	37.3	40.9276	-0.4392

Table 8. The performance of the signal extraction model

		Event		No Event	
Signal was issued	A	7	B	3	10
No signal was issued	C	4	D	54	58
		11		57	

An event is defined if the realized volatility in that particular month exceeds 40% (p.a.). A signal is defined as when the actual implied volatility deviates from the predicted value by over 1 standard deviation of errors. A signal is counted as a good signal (A) only if the volatility realized in the subsequent month exceeds 40%. A signal is a bad signal or “noise” (B) if the realized volatility in the month following the signal does not exceed 40%. C denotes the number of times the framework fails to produce a signal before an event. D shows the number of times the framework correctly refrains from issuing a bad signal.

Figure 1. Implied volatility (IV_t) and realized volatility (AV_t) for the period March 1993 to October 2000

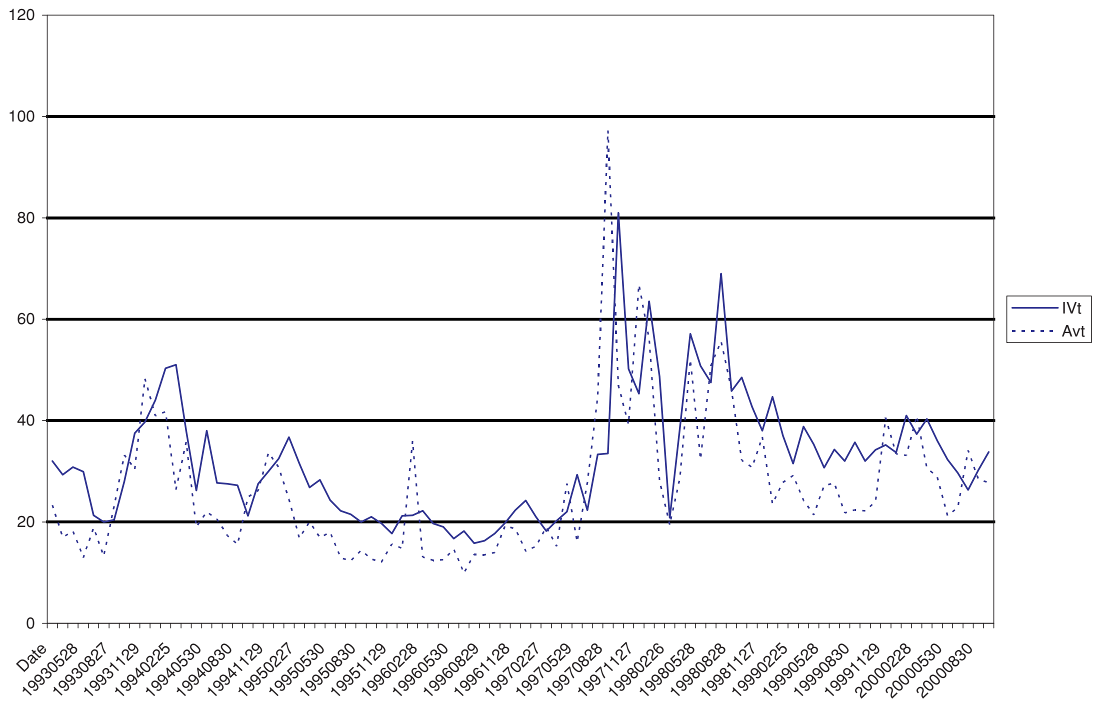

Figure 2. Realized volatility (AV_t), option volume ($OVOL_t$) and option open interest (OOI_t) for the period March 1993 to October 2000

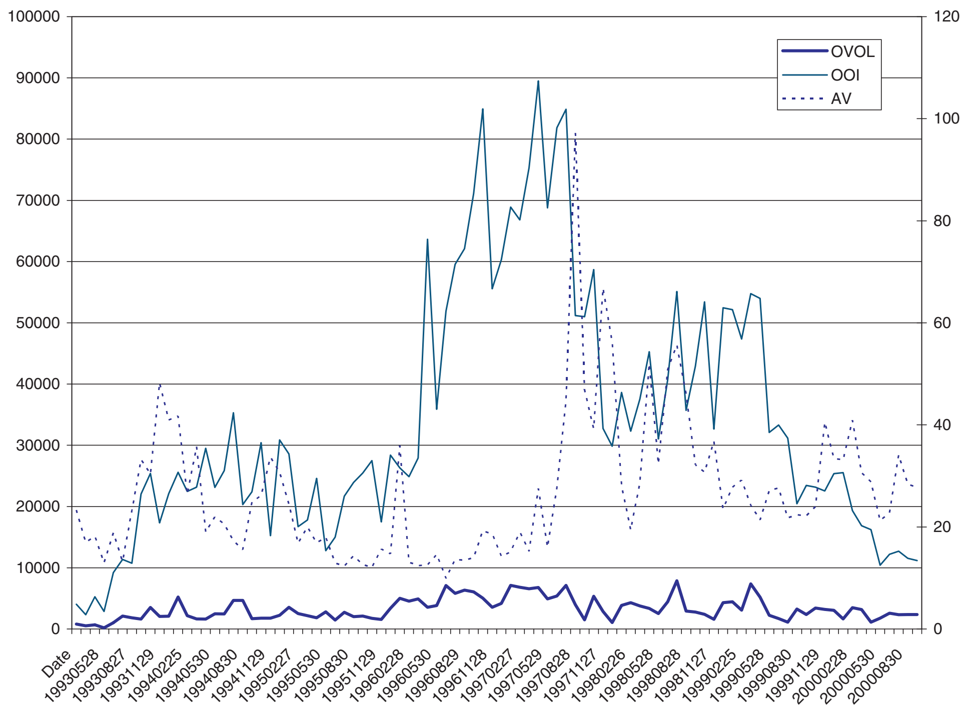

Figure 3. Realized volatility (AV_t), futures volume ($FVOL_t$) and futures open interest (FOI_t) for the period March 1993 to October 2000

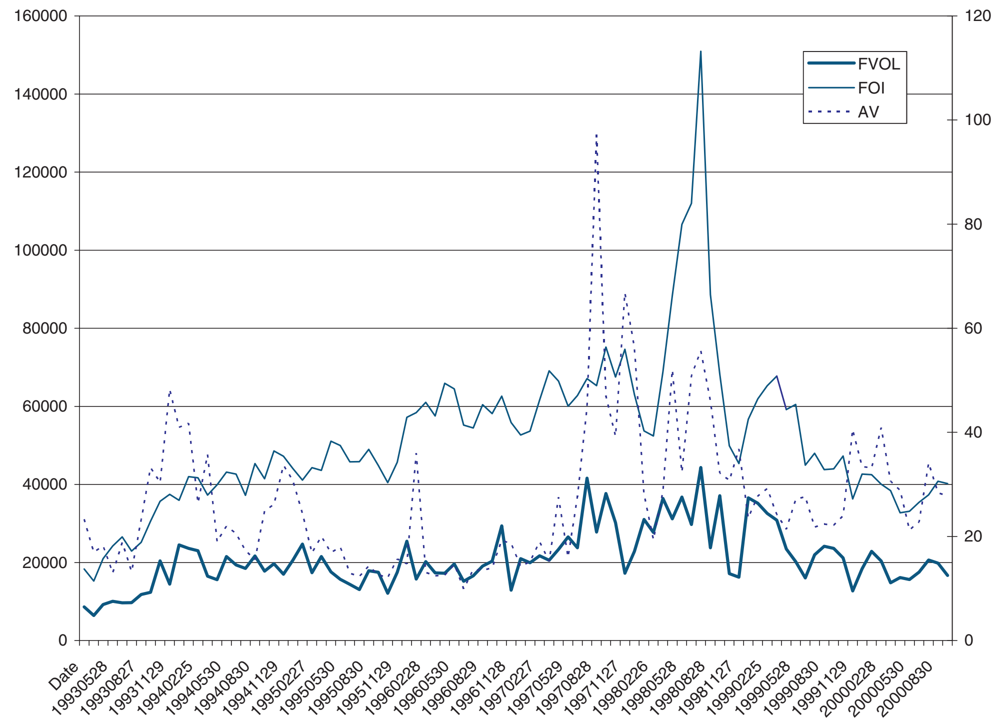

Figure 4. Realized volatility (AV_t), arbitrage basis (Basis), and absolute value of the basis (|Basis|) for the period May 1996 and April 1998