THE INFORMATION CONTENT OF IMPLIED VOLATILITY WITH JUMP:

EVIDENCE FROM THE 2008 GLOBAL FINANCIAL CRISIS

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Abstract

This study tests whether information derived from Bates's option pricing model that incorporates a jump component (IV_{JD}) provides incremental information on future market volatility surrounding crisis events. The model is empirically tested using the Hang Seng Index Futures and Options. The findings indicate that the model outperforms the implied volatility derived from Black's (1977) model (IV_B) derived in predicting future volatility and return. The paper also assesses the usefulness of the IV_{JD} in generating early warnings for future extreme events. Our empirical results document the superiority of IV_{JD} in the crisis signaling test.

1. Introduction

Along with the Asian financial crisis of 1997 that caused severe slumps of currencies and the devaluation of stock markets in Asian countries, the global financial crisis that occurred in 2007 represents one of the serious financial crises that triggered extreme volatility in capital markets of both developed and developing countries. It led to the collapse of banks, financial institutions and conglomerates, bringing serious loss to creditors and investors. In response to these events, regulators have become more concerned about the protection of financial institutions against these catastrophic market risks. Researchers and practitioners strive at devising possible mechanisms to anticipate the outbreak of extreme events. Tool, like Value-at-Risk (VaR), has become a standard measure for risk management.

To account for the heavily tailed distribution in financial returns, researchers have developed VaR models that incorporate either asymmetric distributions or the extreme value theory. For instance, Bali and Theodossiou (2005) derived a conditional VaR with a skewed generalized t.

Researchers such as Maheu and McCurdy (2004) demonstrated that the unusual events like stock crash may be better captured by jumps. Ze-To (2010) derived a model that incorporates extreme value theory with jump process to enhance the forecast performance of extreme events.

Fung (2007), on the other hand, devised a signal extraction model using implied volatility to produce early warning signals to forthcoming extreme volatility.

The asset return volatility could be forecasted by option implied volatility or econometric modeled volatility. The predictability and information contents of Black-Scholes implied volatility have been extensively researched because it has been widely documented that volatility implied by options contains incremental information of the future volatility. Researchers including Day and Lewis (1992), Lamoureux and Lastrapes (1993), Jorion (1995) and Fleming (1998) validated the predictability of implied volatility for future volatility. Yet, most of the researches on the information content of implied volatility focus on the use of implied volatility derived by Black's model using at-the-money options. The major problem of using at-the-money option alone is that it ignores the information content of options of other strike prices. To tackle this problem, researchers like Fung (2007) uses the average of Black's implied volatilities derived from six nearest to the money options to test the information content of implied volatility.

In addition to the Black's implied volatility, Britten-Jones and Neuberger (2000) developed a model-free implied volatility. Jiang and Tian (2005) implemented this model-free implied volatility to test the information content efficient of the option market. It is shown that the model-free implied volatility subsume information of the

Black's implied volatility.

The information content of jump process in price is also investigated. While Fleming (1998) and Jiang and Tian (2003) indicated the superiority of implied volatility to reflect information that econometric modeled volatility forecast could not, Becker (2009) evidenced that these studies fail to consider the fact that the future volatility composes both the components due to diffusion and jump process in asset price. Becker (2009) identified that the VIX index subsumes information both relating to past jump and future jump activity.

Pan (2002) examined the S&P 500 index and options and evidenced that the jump risk premia implicit in options responds quickly to market volatility, especially during the extreme events. In addition, Giot and Laurent (2007) examined the information content of jump and continuous component of historical volatility using S&P100 and S&P500 indexes. They documented that the implied volatility still has very high information content of future volatility even in the presence of the jump and continuous components.

In addition to the prediction of future volatility, researchers also examine return predictability of implied volatility. Bali and Hovakimian (2009) examine if the realized and implied volatilities of individual stocks are capable of predicting the cross sectional variation in expected return. The results show a significantly positive relationship between expected returns and implied volatility spread. Goyal and Saretto (2009) conducted a study of the cross-section of stock option returns by ranking the stocks based on the difference between their realized volatility and implied volatility. They find that a profitable trading strategy by buying (selling) portfolio with largest (lowest) positive differences between the two volatility measures.

There are a number of motivations for this paper. First, as it has been widely documented the discontinuous jump component carries important information for option valuation, we question whether a model for the option implied volatility incorporated with asset price jumps can provide better predictability of future volatility. This model has two advantages over the Black's implied volatility. First, it is believed that the jump can extract further information from the options about future volatility. Second, the volatility and jump factors are implied using options across different strike prices at one time. This can integrate information across options with different prices and the derived implied volatility is more information efficient.

We compare the predictability of the two implied volatilities by running regression with future volatility. The results show that implied volatility with jump has stronger predictive power on future volatility. This paper further validates the predictive power of jump component on future volatility by running regression on the future volatility against jump and diffusion variables of implied volatility with jump.

Second, Fung (2007) showed that the Black's implied volatility can signal the future extreme event. We hypothesize that the implied volatility incorporated with jump should perform better in acting as an early warning system for future extreme volatility. The result supports our hypothesis.   Finally, this paper also examines the return predictability of implied volatility and realized volatility. We find that the future return is associated with the changes of the two lagged volatilities.

The rest of this paper is organized as follows. The next section explains the model for implied volatility estimation. Section 3 presents the data, implementation and the empirical results as well as the analysis. Section 4 concludes the study.

2.0 Model

We derive the implied volatility with the price jump process under the framework of Bate (1991) model. The Hang Seng Index Futures is assumed to follow a stochastic differential equation with asymmetric and random price jumps. The jump diffusion model is risk neutral and expressed as:

$$\frac{dS}{S} = [\theta - \lambda \bar{k}]dt + \sigma dB + kdq \qquad (1)$$

where θ is the drift which is set to zero with our transformation of index option to futures option and σ is the diffusion volatility of the process. λ represents the frequency of the Poisson events while k stands for random jump size with ln(1+k) ~ N($\gamma - 0.5\delta^2$, δ^2). $E(k) \equiv \bar{k} = e^{\gamma} - 1$ is the expected proportional jump size. dB is the geometric Brownian motion while dq is a Poisson process which represents the random increment corresponding to the occurrence of a jump. Prob(dq=1) = λdt and Prob(dq=0) = 1-λdt.

The Bates' (1991) jump-diffusion process allows the implied volatility, skewness and kurtosis measures of ln (S_{t+T}/S_t) to be easily computed as follows:

$$Implied \quad Volatility = IV_{JD} = \sqrt{\lambda(\omega^2 + \delta^2) + \sigma^2} \tag{2}$$

$$Skewness = \frac{\lambda\omega\,(\omega^2 + 3\delta^2)}{(\sigma_{JD})^3\sqrt{T}} \tag{3}$$

$$Kurtosis = 3 + \frac{\lambda(\omega^4 + 6\omega^2\delta^2 + 3\delta^4)}{(\sigma_{JD})^4 T} \tag{4}$$

where $\omega = \gamma - \frac{\delta^2}{2}$

We follow the methodology proposed by Arnold et al. (2007) to estimate the model call and put option prices. Since the HSI option contracts matures at the same time as the HSI futures contracts, the model can be further simplified using the modified Back's model. The HSI options are priced like the options on the futures (Chan, Cheng and Fung, 2010; Duan and Zhang, 2001). The value of call and put options of maturity T at a strike price X can be expressed in the form of:

$$C(S,T) = \sum_{n=0}^{\infty} \frac{e^{-\lambda T}(\lambda T)^n}{n!}[Se^{\theta(n)T} N(d_{1n}) - XN(d_{2n})] \quad (5)$$

$$P(S,T) = \sum_{n=0}^{\infty} \frac{e^{-\lambda T}(\lambda T)^n}{n!}[XN(-d_{2n}) - Se^{\theta(n)T} N(-d_{1n})] \quad (6)$$

$$d_{1n} = \frac{\ln(\frac{S}{X}) + \theta(n)T + \frac{1}{2}(\sigma^2 T + n\delta^2)}{\sqrt{\sigma^2 T + n\delta^2}} \quad (7)$$

$$d_{2n} = d_{1n} - \sqrt{\sigma^2 T + n\delta^2} \quad (8)$$

where originally, $\theta(n) = (\theta - \lambda\bar{k}) + \frac{n\gamma}{T}$ but is adjusted to $\theta(n) = -\lambda\bar{k} + \frac{n\gamma}{T}$ after setting θ as zero.

3.0 Empirical Analysis

3.1 Data

Daily data on the HKEx Hang Seng Index futures are collected for the period from July 28, 2000 to November 27, 2009. In addition, data on the options prices, strike prices of the corresponding Hang Seng Index options are obtained from the exchange. To reduce the noise of microstructure effects, the mid quote index estimated as the average of the closing bid and ask prices of the index is used for the calculation of realized volatility. In addition, the bid prices of the call options are used for the calculation of implied volatilities. At month t, the realized volatility RV_t is the annualized standard deviation of the continuously daily close to close index return, expressed in the following form.

$$RV_t = \sqrt{\frac{N}{n_t - 1}\sum_{i=1}^{n_t}[R_i(t) - \frac{1}{n_t}\sum_{j=1}^{n_t} R_j(t)]^2} \quad (9)$$

where n_t is number of trading days in month t. N is the total number of trading days for the year. $R_i(t)$ is the daily return on day i in month t.

3.2 Calculation of Implied Volatility and Jump

The paper computed the implied volatility IV_{JD} using equation (1). For each month, the bid rates of eight index call options of one month maturity with different strike prices are selected. The model call option prices of index option of each component stock is expressed using equations (5). The parameters of σ and jump are unobservable and calculated by minimizing the sum of squared differences between the model and market option prices of the eight index options at various strike prices with equal times to maturity in the following form:

$$MSE = \sum_{j=1}^{Q}[c(K_j) - C(K_j \mid \Omega)]^2 , \quad (10)$$

where Q stands for total number of strike prices available for HS Index option. Ω is the set of parameters while c and C represent the market and model call option prices of index option at a strike price of K_j respectively. We repeat the same procedure for the implied volatility estimation of put options using equation (6).

In addition, the implied volatilities of the call and put options are estimated using the modified Black's model. The implied volatilities $IV_{B,C}$ (Call) and $IV_{B,P}$ (Put) are respectively constructed by averaging all these implied volatilities of call options and put options during the last five minutes before the close of the market. The procedure is repeated for the rest of the sample data.

Panel A of Table 1 presents the summary statistics of the monthly measures of Hang Seng index return, realized volatility, Black's implied volatility and parameters estimates from Jump Diffusion model. The monthly data are collected from July 2000 to November 2009.

- Table 1 Here -

It is shown that the implied volatilities by Black's model are close to the realized volatility of 23.9 percent. $IV_{B,C}$ and $IV_{B,P}$ are respectively 25.4 percent and 26.2 percent . The finding is consistent with that from previous study by Driessen, Maenhout and Vikov (2009). The implied volatility, however, is more volatile with higher standard deviation and positively skewed. The implied volatility has a high kurtosis value indicating the existence of infrequent extreme deviations. The monthly index return also exhibits a wide fluctuation ranging from 18.8 percent to -22.7 percent. The distribution of return is obviously not normally distributed. Panel B of Table 1 reports the parameter estimates and their standard errors for the Jump-diffusion model.

The jump component J has higher skewness and kurtosis than the diffusion sigma σ, as expected.

- Figure 1 Here -

Figure 1 illustrates the movement of Black's implied volatility ($IV_{t,B,C}$) using call options, realized volatility (RV_t) and implied volatility $IV_{t,JD,C}$ using Jump Diffusion model over the study period from July 2001 to November 2009. It is shown that the realized volatility fluctuates within a narrow range and gradually decline from 46.6 percent in August 2001 to 6.7 percent in May 2005. The realized volatility then increases sharply to 58.4 percent in December 2007 due to the outbreak of financial crisis and moves up continuously to 109.8 percent in September 2008. The Black's implied volatility, as a good predictor of the future volatility, increases from 18.1 percent in end June 2007, almost four months ahead of outbreak of crisis, to 58.8 percent in January 2008. The implied volatility, however, exhibits a wide fluctuation during the crisis period. It declines to 24.7 percent in April 2008 but rockets to 84.7 percent in October 2008 and then decreases continuously to 26.1 percent in September 2009.

The implied volatility ($IV_{t,JD,C}$) also moves closely with the realized volatility. The implied volatility exhibits a good predictive power of future volatility and moves up or down ahead of the realized volatility. The implied volatility increases from 21.9 percent in end April 2007 (one month ahead of the realized volatility) and fluctuate tightly with the realized volatility. The $IV_{t,JD,C}$ line reaches the peak of 61.1 percent in August 2008 (one month ahead of the peak of realized volatility) and then declines together with the RV_t line. Similar pattern is found for implied volatilities using put options in Figure 2.

- Figure 2 Here -

- Figure 3 Here -

Figure 3 compares the variations of the realized volatility (RV_t) with that of derived jump and diffusion volatility over the study period. Both the jump and diffusion volatility exhibit predictive power and move closely in line with the realized volatility. The diffusion volatility reaches its bottom on April 2005 (one month ahead of realized volatility) and rises to the top on August 2008 (again one month before realized volatility reaches its peak). The jump process fluctuates in similar pattern with that of realized volatility. The jump component generates surges when the extreme movements of realized volatility occur.

3.3 Predictability Test of Implied Volatility and Jump

The predictability of implied volatility and Jump factors are examined in this section. The paper conducts three sets of predictability tests. 1) multivariate regression is run on the diffusion volatility and jump factor of Bates' Jump Diffusion model for testing their predictabilities on future volatility; 2) regression is run on the implied volatility against the lagged implied volatility and difference between realized volatility and implied volatility. It aims to identify the determinants of the implied volatility. The findings using the two implied volatilities are compared and 3) the signaling test of future extreme events using implied volatility.

3.3.1 Predictive power on future volatility

3.3.2 Predictability of jump

This paper adopted the methodology of Fung (2007) to conduct regression on the realized volatility against the lagged implied volatility. Table 2 exhibits the regression of log realized volatility on lagged implied volatility derived by the two models. The regression is in the form of

$$Log\ (RV_t) = a_0 + a_1 Log\ (IV_{t-1,*}) + \varepsilon_t \tag{11}$$

where Log($IV_{t-1,*}$) stands for the log implied volatility derived by model * (* stands for Black's model and Bates model) of t - 1 month before.

- Table 2 Here -

Panel A of Table 2 indicates that the Black's implied volatility $IV_{t-1,B,C}$ is a good predictor of the future volatility. The coefficient value of the one month lagged implied volatility is 0.832. The result is consistent with the previous finding by Fung (2007). There is a strong positive association between the lagged implied volatility and realized volatility. Panel B describes the regression of log realized volatility against the lagged log implied volatility incorporated with price jump. The result indicates that the implied volatility with jump is superior to the Black's implied volatility in the short run predictability of future volatility. The one month lagged implied volatility with jump has a slope coefficient value of is 1.002 while the slope coefficient value for Black's implied volatility with jump is 0.832. We find similar results for implied volatility using put options. The $IV_{t-1,JD,P}$ give a coefficient of 0.880 while $IV_{t-1,B,P}$'s slope value is 0.815. The findings the implied volatility with jump give higher predictability of future volatility.

- Table 3 Here -

Table 3 illustrates the regression of the log realized volatility of time t against the independent variables of jump and diffusion volatility of t- 1 month. Since the first twelve monthly data are used for calculating the initial realized volatility, the period for regression is from July 2001 to November 2009. Two regressions are conducted and expressed as:

Regression with log diffusion volatility and Jump variables

$$Log\ (RV_t) = a_0 + a_1 Log\ (\sigma_{t-1,*}) + a_2 J_{t-1,*} + \varepsilon_t \tag{12}$$

Regression with log Black's implied volatility and Jump variables

$$Log\ (RV_t) = a_0 + a_1 Log\ (IV_{t-1,B,*}) + a_2 J_{t-1,*} + \varepsilon_t \tag{13}$$

where Log(RV_t) represents the realized volatility at time t. Log(σ_{t-1}) stands for the log diffusion volatility of t - 1 month before. J_{t-1} represents the jump variable of t - 1 month before. * denotes call and put options. The forecasting variables are the jump and diffusion volatility derived by Bates' model. Log($IV_{t-1, BS}$) stands for the log Black's implied volatility of t - 1 month before.

Panel A and C of table 3 indicate that both the diffusion volatility and the jump factors have significant predictive power of future volatility. The coefficient values of jump and diffusion volatility variable derived by call options are respectively 0.825 and 0.701 and positively associated with the future volatility. Compared with the diffusion volatility, the jump factor has higher coefficient value.

Panel B and D summarize the regression results using Black's implied volatility and lagged jump. The findings indicate that both the coefficient values of lagged jump and log Black's implied volatility are significantly positive. Comparing with the results of Panel A and B, it is shown that the squared R values of the regressions are higher.

The results show that while the Black's implied volatility has taken up some explanatory power of the jump risk, the Jump risk is a still highly efficient forecast estimator of future volatility in the presence of Black's implied volatility.

3.3.3 Predictability of implied volatility with jump

To give further robustness check of predictability of implied volatility with jump, we conduct regression of log realized volatility against implied volatility with jump with Black's implied volatility as control. Two regressions are conducted and expressed as follows:

Regression with log BS implied volatility and log diffusion volatility and Jump variables

$$Log(RV_t) = a_0 + a_1 Log(IV_{t-1,B,*}) + a_2 Log(\sigma_{t-1,*}) + a_3 J_{t-1,*} + \varepsilon_t \tag{14}$$

Regression with log BS implied volatility and log BJD implied volatility

$$Log(RV_t) = a_0 + a_1 Log(IV_{t-1,B,*}) + a_2 Log(IV_{t-1,JD,*}) + \varepsilon_t \tag{15}$$

where $Log(IV_{t-1, JD})$ stand for the Bates' implied volatility of t - 1 month before. * denotes call or put options

- Table 4 Here -

The results are summarized in Table 4. Panel A and C show the predictability power of Jump and diffusion volatility in the presence of Black's implied volatility. It is shown that the coefficients of the two variables are significantly positive. The R-squared values of Panel A and C are respectively 0.558 and 0.605. The result is further supported by the regression in Panel B and D. The implied volatility with jump is significantly associated with the future volatility with the Black's implied volatility as control. The coefficients of $IV_{t-1,JD,C}$ and $IV_{t-1,JD,P}$ are respectively 0.403 and 0.394. The results evidence that implied volatility with jump exhibit predictive power of future volatility that cannot be fully explained by Black's implied volatility.

3.4 Determinants of Implied Volatility

The paper examines the determinants of implied volatility using the methodology proposed by Fung (2007). The implied volatility is regressed against the lagged implied volatility and the differences between lagged realized volatility and implied volatility. The regression is expressed as:

$$Log(IV_{t,B,*}) = a_0 + a_1[Log(RV_{t-1}) - Log(IV_{t-1,B,*})] + a_2 Log(IV_{t-1,B,*}) + \varepsilon_t \quad (16)$$

where $Log(RV_t)$ - $Log(IV_{t-1,B,*})$ stands for the difference of log realized volatility and log implied volatility of time of t - 1 months. * denotes call and put options. This variable could indicate how the implied volatility interacts with realized volatility. If the implied volatility increases (decreases) when lagged realized volatility is larger (smaller) than the lagged implied volatility, the error correction coefficient a_1 will be significantly positive.

Panel A and C of Table 5 represents the results of the regression of implied volatility derived by Black's model against the independent variables of lagged log implied volatility and differences of log realized volatility and log implied volatility using call and put options. It is shown that the lagged implied volatility is positively associated with the current implied volatility as expected. The error correction coefficient a_1 is also positive. The model shows a high explanatory power of the implied volatility with a R^2 value of 0.865 and 0.933 for Panel A and C.

- Table 5 Here -

We conduct the same regression using the implied volatility with jump. The regression is in the form of

$$Log\ (IV_{t,JD,*}) = a_0 + a_1[Log\ (RV_{t-1}) - Log\ (IV_{t-1,JD,*})] + a_2 Log\ (IV_{t-1,JD,*}) + \varepsilon_t \quad (17)$$

The findings summarized in panel B and D of table 5. The results indicate that in addition to the positive coefficient value of lagged implied volatility, the error correction coefficient a_1 is also significantly positive across all horizons. The R^2 value are respectively 0.865 and 0.911 for panel B and D, suggesting that both the implied volatility with jump and difference of realized volatility and implied volatility with jump have high predictive power of implied volatility.

3.5 Signaling of Extreme Event

3.5.1 Signaling using implied volatility

The paper investigates the performance of implied volatility as a device for signaling the extreme event. We first conduct the regression for implied volatility estimated by Black's model in the form of

$$IV_{t,B,*} = a_0 + a_1[RV_{t-1} - IV_{t-1,B,*}] + a_2 IV_{t-1,B,*} + \varepsilon_t \tag{18}$$

where * denotes call and put options.

The coefficient values are found using the above regression. The extreme event is defined as the occurrence of annualized realized volatility at time t (RV) exceeding the twelve month average of realized volatility by three standard deviation.

Then, a signal occurs if the difference between the actual and modeled implied volatility is larger than one root mean squared error as expressed in the form of

$$Signal_t = \frac{[Log(IV_{t,B,*}) - Log(I\hat{V}_{t,B,*})]}{\sqrt{MSE}} > 1 \tag{19}$$

where $I\hat{V}_{t,B,*} = \hat{a}_0 + \hat{a}_1[RV_{t-1} - IV_{t-1,B,*}] + \hat{a}_2 IV_{t-1,B,*}$ represents the calculation of modeled implied volatility using the coefficient values estimated by equation (18).

Table 6 and 7 present the results of the signaling test of extreme event using implied volatility derived by Black's model using call and put options respectively. The last two columns of the table indicate the corresponding occurrences of the extreme event and the signal generated in the period from January 2007 to September 2008 during which the financial tsunami broke out.

- Table 6 Here -

- Table 7 Here -

In table 6, there are six extreme events occurred during the period. Five signals are triggered by the Black's implied volatility. Two extreme events (September 2007 and October 2007) are accurately captured by the signals in one or two months ahead. There is one signal triggered in April 2007 and is three months ahead of the extreme volatility (July 2007). The result is consistent with the findings of Fung (2007). Yet, it is shown that the implied volatility using Black's model cannot signal the very extreme shock occurred in September 2008. In Table 7, again 5 signals are triggered by Black implied volatility using put options. Only two extreme events (July 2007 and September 2007) are accurately captured by the signals in two or three months ahead.

We conduct the same regression on the implied volatility with jump derived by Bates' Jump-Diffusion model. The regression is expressed as

$$IV_{t,JD,*} = a_0 + a_1[RV_{t-1} - IV_{t-1,JD,*}] + a_2 IV_{t-1,JD,*} + \varepsilon_t \quad (19)$$

- Table 8 Here -
- Table 9 Here -

The results are summarized in Table 8 and 9 for implied volatility using call and put options. Table 8 indicates that six signals are triggered by the implied volatility with jump during the crisis period. Three of the signals have accurately generated one month ahead of the three extreme events occurred in 2007 (January, September and October 2007). In addition, the extreme stock crash event of Hang Seng Index in September 2008 is also accurately warned by the signaling tool. Similarly, the results in table 9 shows that three extreme events occurred in 2007 (September, October and December 2007) are accurately signaled by implied volatility $IV_{t,JD,P}$.

By comparing the results of Table 6 to 9, it is shown that signaling framework induced by the implied volatility with jump can outperform the traditional Black's implied volatility in providing early warning signals of the extreme event. The study provides evidence that the implied volatility with underlying price incorporated with jump is a more efficient tool to forecast the future realized volatility.

3.5.2 Signaling using implied skewness

We develop a device using implied skewness (ISkew) for the Jump-diffusion model for signaling the extreme event. Again, the extreme event is defined as the occurrence of annualized realized volatility (RV) exceeding the mean of realized volatility by three standard deviation.

A signal occurs if there is a change of sign in implied skewness (ISkew) expressed in the form of

$$ISkew = \frac{\lambda\omega\,(\omega^{2} + 3\delta^{2})}{(\sigma_{JD,*})^{3}\sqrt{T}} \qquad (20)$$

where * denotes call and put options.

Table 10 and 11 present the performance of ISkew derived by call and put options respectively in signaling the extreme event. Table 10 exhibits the result using ISkew derived by call options. It is shown that two extreme events (February and July 2007) are accurately by ISkew. Only the extreme events occurred in July of 2007, however, is captured by ISkew derived by put options as indicated in Table 11.

- Table 10 Here -

- Table 11 Here -

4.0 Conclusion

This paper contributes to the literature in four respects. First, the study derives the implied volatility incorporated with price jump process and examines its predictability on future volatility. The result evidences that the implied volatility with jump is superior to the traditional Black' implied volatility in predictability of the future volatility. The new approach provides a high R^2 value in the volatility predictability regression. We further conduct regression on future volatility against the components of implied volatility with price jump. The findings show that both the jump and diffusion components exhibit high predictive power of future volatility.

Second, this paper investigates the determinants of both implied volatilities. It is shown that while the lagged implied volatility is positively associated with the current implied volatility, the difference of the lagged realized volatility and lagged implied volatility has greater explanatory power of the current implied volatility incorporated with jump. The variable has positive and significant slope coefficient value across all lagged months. Therefore, it is expected that a widening of the difference between the past realized volatility and implied volatility will be accompanied by an increase of implied volatility in the future.

Third, most regulators and practitioners are anxious for having some effective mechanisms to anticipate the outbreak of extreme events, like stock crashes. It has been documented that Black's implied volatility can be used as a warning model to signal for the future extreme volatility. This paper examines the performance of this implied volatility with jump as a device for signaling the future crisis. We follow the same procedure to conduct the signaling test using the data of recent global financial crisis and compare the results with the one using Black's model. The results indicate that out of the four extreme events incurred during the crisis period, only three of them are successfully captured by model using Black’s implied volatility. However, it is shown that in addition to the three events captured by the Black’s implied volatility, the proposed model using implied volatility with jump can further anticipate the extreme crash of Hang Seng Index in late 2008 accurately. Therefore, the signaling model using the implied volatility with jump outperforms the one using Black’s implied volatility and provide efficient forecast of the future volatility.

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Table 1

Descriptive Statistics for Monthly Returns, Realized Volatility, Implied Volatility and Jump Variable and Parameter Estimation of Jump Diffusion Model

Panel A presents the summary statistics of the monthly measures of Hang Seng index return, realized volatility, implied volatility and jump variable. The monthly data are collected from July 2000 to November 2009. The realized volatility RV_t is the standard deviation of 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. The standard deviation is estimated in a window of 12 months. The implied volatility IV_{BS} is derived as a simple average of the eight implied volatilities nearest to the money Hang Seng index Call options that mature in month t. Panel B illustrates the parameters of the Bates' Jump Diffusion Model estimated for the Hang Seng index options. The standard errors are presented below each parameter value. The fitting performances of the models is examined using the Jarque-Bera values where Jarque-Bera = (Number of observations) x [skewness^2 /6 + (kurtosis^2 -3)/24].

Panel A: Descriptive Statistics

	Index Return	Realized Volatility RV_t	Implied Volatility (Call) $IV_{B,C}$	Implied Volatility (Put) $IV_{B,P}$
Mean	0.0019	0.2387	0.2544	0.2625
SD	0.0669	0.1406	0.1154	0.1286
Max	0.1885	1.0981	0.8472	0.9161
Min	-0.2273	0.0678	0.1107	0.1076
Median	0.0086	0.1965	0.2291	0.2314
Skew	-0.5353	2.8852	2.1289	2.2159
Kurt	1.2518	13.2796	6.7054	6.7738

Panel B: Parameter Estimation of Jump Diffusion Model (Call)

	ω	Jump J	Jump size k	Intensity λ	γ	δ	Diffusion sigma σ
Estimate	-0.2567	-0.0238	-0.1651	0.2445	-0.2022	0.3004	0.2053
Std error	0.0223	0.0102	0.0384	0.0144	0.0234	0.0129	0.0081
Skew	0.5687	2.2397	3.1231	0.9226	0.5830	0.6932	0.7815
Kurt	-1.0707	8.2614	16.6607	-0.1836	-0.9107	-0.3506	-0.0613
Jarque-Bera	-2.6359	401.69	1476.50	2.0642	-3.8195	-4.4965	-2.6042

Panel C: Parameter Estimation of Jump Diffusion Model (Put)

	ω	Jump J	Jump size k	Intensity λ	γ	δ	Diffusion sigma σ
Estimate	0.0370	0.0073	0.0262	0.3034	0.0786	0.2188	0.2330
Std error	0.0079	0.0092	0.0264	0.0065	0.0069	0.0178	0.0064
Skew	-0.8651	1.9858	1.4059	0.2426	0.3706	1.2740	1.0702
Kurt	1.3728	11.0369	7.3354	-0.8783	0.5111	0.3465	1.7789
Jarque-Bera	8.8427	633.684	276.44	-9.3848	-10.308	17.008	22.345

Table 2

Regression of Log Realized Volatility on Lagged Implied Volatility

The table illustrates the regression of the log realized volatility of time t against the independent implied volatility variable of t- 1 month before. Panel A to D describes the regression using implied volatilities derived by Black's model and Bates Jump Diffusion (BJD) model. The implied volatilities in panel A and B are derived by using call options while panel C and D are from put options. The monthly data are collected from July 2000 to November 2009. The regression is in the form of

$$Log\ (RV_t) = a_0 + a_1 Log\ (IV_{t-1,*}) + \varepsilon_t$$

$Log(RV_t)$ represents the realized volatility at time t. $Log(IV_{t-1,*})$ stands for the log implied volatility derived by model * (* stands for Black's model and Bates model) of t - 1 month before. The t-statistics of the independent variables are listed below the coefficient estimates.

Panel A: Implied volatility $IV_{t-1,B,C}$ (Call)				
Implied Volatility	Intercept	F-stat	R^2	Root square MSE
0.832	-0.334	107.500	0.523	0.322
10.368	-2.736			
Panel B: Implied volatility $IV_{t-1,JD,C}$ (Call)				
Implied Volatility	Intercept	F-stat	R^2	Root square MSE
1.002	-0.306	83.484	0.460	0.343
9.137	-2.174			
Panel C: Implied volatility $IV_{t-1,B,P}$ (Put)				
Implied Volatility	Intercept	F-stat	R^2	Root square MSE
0.815	-0.372	123.965	0.558	0.310
11.134	-3.374			
Panel D: Implied volatility $IV_{t-1,JD,P}$ (Put)				
Implied Volatility	Intercept	F-stat	R^2	Root square MSE
0.880	-0.358	108.364	0.525	0.321
10.410	-3.009			

Table 3

Multivariate Regression of Log Realized Volatility on Lagged Jump and Volatility Variables

The table illustrates the regression of the log realized volatility of time t against the independent variables of jump and diffusion volatility of t- 1 month before. The monthly data are collected from July 2000 to November 2009. Panel A to D describes the regression using implied volatilities derived by Black's model and Bates Jump Diffusion (BJD) model. The implied volatilities in panel A and B are derived by using call options while panel C and D are from put options. There are two regressions in discussion

Panel A and C: regression with log diffusion volatility and Jump variables

$$Log\ (RV_t) = a_0 + a_1 Log\ (\sigma_{t-1,*}) + a_2 J_{t-1,*} + \varepsilon_t$$

Panel B and D: regression with log Black's implied volatility and Jump variables

$$Log\ (RV_t) = a_0 + a_1 Log\ (IV_{t-1,B,*}) + a_2 J_{t-1,*} + \varepsilon_t$$

$Log(RV_t)$ represents the realized volatility at time t. $Log(\sigma_{t-1})$ stands for the log diffusion volatility of t - 1 month before. J_{t-1} represents the jump variable of t - 1 month before. * denotes call and put options. The forecasting variables are the jump and diffusion volatility derived by Bates' model. $Log(IV_{t-1, BS})$ stands for the log Black's implied volatility of t - 1 month before. The t-statistics of the independent variables are listed below the coefficient estimates.

Panel A: diffusion volatility and Jump variables (Call)					
Jump	Log Diffusion Volatility σ	Intercept	F-stat	R^2	Root square MSE
0.825	0.701	-0.372	44.008	0.476	0.339
2.582	8.183	-2.569			

Panel B: Implied volatility $IV_{t-1,B,C}$ and Jump variables (Call)					
Jump	Log Implied Volatility $IV_{t-1,B,C}$	Intercept	F-stat	R^2	Root square MSE
0.640	0.784	-0.390	57.932	0.544	0.316
2.124	9.573	-3.181			

Panel C: diffusion volatility and Jump variables (Put)					
Jump	Log Diffusion Volatility σ	Intercept	F-stat	R^2	Root square MSE
0.641	1.061	0.049	37.718	0.437	0.352
1.819	8.527	0.256			

Panel D: Implied volatility $IV_{t-1,B,P}$ and Jump variables (Put)					
Jump	Log Implied Volatility $IV_{t-1,B,C}$	Intercept	F-stat	R^2	Root square MSE
0.770	0.825	-0.364	68.667	0.586	0.302
2.542	11.559	-3.388			

Table 4

Multivariate Regression of Log Realized Volatility on Log Black's Implied Volatility and Implied Volatility with Jump Variables

The table illustrates the regression of the log realized volatility of time t against the independent variables of jump and diffusion volatility of t- 1 month before. The monthly data are collected from July 2000 to November 2009. Panel A to D describes the regression using implied volatilities derived by Black's model and Bates Jump Diffusion (BJD) model. The implied volatilities in panel A and B are derived by using call options while panel C and D are from put options. There are two regressions in discussion

Panel A and C: regression with log BS implied volatility and log diffused volatility and Jump variables

$$Log\ (RV_t) = a_0 + a_1 Log\ (IV_{t-1,B,*}) + a_2 Log\ (\sigma_{t-1,*}) + a_3 J_{t-1,*} + \varepsilon_t$$

Panel B and D: regression with log BS implied volatility and log BJD implied volatility

$$Log\ (RV_t) = a_0 + a_1 Log\ (IV_{t-1,B,*}) + a_2 Log\ (IV_{t-1,JD,*}) + \varepsilon_t$$

Log(RV_t) represents the realized volatility at time t. Log($IV_{t-1, BS}$) and Log($IV_{t-1, JD}$) stand for the log Black's implied volatility and Bates' implied volatility of t - 1 month before. Log(σ_{t-1}) stands for the log diffusion volatility of t - 1 month before. J_{t-1} represents the jump variable of t - 1 month before. * denotes call and put options. The forecasting variables are the jump and diffusion volatility derived by Bates' model. The t-statistics of the independent variables are listed below the coefficient estimates.

Panel A: Log Implied Volatility $IV_{t-1,B,C}$, diffusion volatility and Jump variables (Call)

Log Diffusion Volatility σ	Jump	Log Implied Volatility $IV_{t-1,B,C}$	Intercept	F-stat	R^2	Root square MSE
0.235	0.634	0.588	-0.287	40.431	0.558	0.313
1.737	2.128	4.234	-2.123			

Panel B: Log Implied volatility $IV_{t-1,B,C}$ and Log Implied Volatility $IV_{t-1,JD,C}$ (Call)

Log Implied Volatility $IV_{t-1,B,C}$	Log Implied Volatility $IV_{t-1,JD,C}$	Intercept	F-stat	R^2	Root square MSE
0.579	0.403	-0.202	59.095	0.549	0.315
4.382	2.371	-1.541			

Panel C: Log Implied Volatility $IV_{t-1,B,P}$, diffusion volatility and Jump variables (Put)

Log Diffusion Volatility σ	Jump	Log Implied Volatility $IV_{t-1,B,P}$	Intercept	F-stat	R^2	Root square MSE
0.331	0.751	0.661	-0.099	48.979	0.605	0.296
2.136	2.524	6.376	-0.606			

Panel D: Log Implied volatility $IV_{t-1,B,P}$ and Log Implied Volatility $IV_{t-1,JD,P}$ (Put)

Log Implied Volatility $IV_{t-1,B,P}$	Log Implied Volatility $IV_{t-1,JD,P}$	Intercept	F-stat	R^2	Root square MSE
0.515	0.394	-0.271	69.349	0.588	0.301
3.864	2.658	-2.386			

Table 5

Regression Test of Determinants of Implied Volatility

The table represents the regression of the log implied volatility of time t against the independent variables of lagged log implied volatility and differences of log realized volatility and log implied volatility. The implied volatility is derived as a simple average of the eight implied volatilities nearest to the money Hang Seng index Call options. The monthly data are collected from July 2000 to November 2009. Panel A to D describes the regression using implied volatilities derived by Black's model and Bates Jump Diffusion (BJD) model. The implied volatilities in panel A and B are derived by using call options while panel C and D are from put options.

There are two regressions in discussion

Panel A and C: regression with log BS implied volatility and the difference of realized and implied volatility

$$Log\ (IV_{t,B,*}) = a_0 + a_1[Log\ (RV_{t-1}) - Log\ (IV_{t-1,B,*})] + a_2 Log\ (IV_{t-1,B,*}) + \varepsilon_t$$

Panel B and D: regression with log BJD implied volatility and the difference of realized and implied volatility

$$Log\ (IV_{t,JD,*}) = a_0 + a_1[Log\ (RV_{t-1}) - Log\ (IV_{t-1,JD,*})] + a_2 Log\ (IV_{t-1,JD,*}) + \varepsilon_t$$

$Log(IV_{t,*})$ represents the implied volatility of model * (* stands for BS model and BJD model) at time t. $Log(RV_t)$ - $Log(IV_{t-1,*})$ stands for the difference of log realized volatility and log implied volatility of time t - 1 month before. The t-statistics of the independent variables are listed below the coefficient estimates.

Panel A: Implied volatility $IV_{t-1,B,C}$ and the volatility difference (Call)					
$Log(RV_{t-1})$ - $Log(IV_{t-1,B,C})$	$Log(IV_{t-1,B,C})$	Intercept	F-stat	R^2	Root square MSE
0.585	0.884	-0.119	309.475	0.865	0.150
10.453	23.495	-2.054			

Panel B: Implied volatility $IV_{t-1,JD,C}$ and the volatility difference (Call)					
$Log(RV_{t-1})$ - $Log(IV_{t-1,JD,C})$	$Log(IV_{t-1,JD,C})$	Intercept	F-stat	R^2	Root square MSE
0.135	0.926	-0.045	312.081	0.865	0.119
3.437	24.182	-0.909			

Panel C: Implied volatility $IV_{t-1,B,P}$ and the volatility difference (Put)					
$Log(RV_{t-1})$ - $Log(IV_{t-1,B,P})$	$Log(IV_{t-1,B,P})$	Intercept	F-stat	R^2	Root square MSE
0.634	0.946	-0.010	671.221	0.933	0.112
14.090	35.456	-0.253			

Panel D: Implied volatility $IV_{t-1,JD,P}$ and the volatility difference (Put)					
$Log(RV_{t-1})$ - $Log(IV_{t-1,JD,P})$	$Log(IV_{t-1,JD,P})$	Intercept	F-stat	R^2	Root square MSE
0.151	0.970	-0.007	499.275	0.911	0.116
3.854	31.586	-0.151			

Table 6

Signaling Test of Extreme Event using Black's Implied Volatility (Call)

The table presents the performance of implied volatility derived by Merton model in signaling the extreme event. The implied volatility is derived as a simple average of the eight implied volatilities nearest to the money Hang Seng index Call options. The extreme event is defined as the occurrence of annualized realized volatility (RV) exceeding the mean of realized volatility by three standard deviation. The regression is in the form of

$$IV_{t,B,C} = a_0 + a_1[RV_{t-1} - IV_{t-1,B,C}] + a_2 IV_{t-1,B,C} + \varepsilon_t$$

A signal occurs if the difference between the actual and modeled implied volatility is larger than one root mean squared error as expressed in the form of

$$Signal_t = \frac{[Log(IV_{t,B,C}) - Log(I\hat{V}_{t,B,C})]}{\sqrt{MSE}} > 1$$

$$\text{where } I\hat{V}_{t,B,C} = \hat{a}_0 + \hat{a}_1[RV_{t-1} - IV_{t-1,B,C}] + \hat{a}_2 IV_{t-1,B,C}$$

The last two columns of the table indicate the corresponding occurrences of the extreme event and the signal generated during the period from January 2007 to October 2008 are studied.

Date	$IV_{B,C}$	RV	Signal	E(RV) + 3σ	Extreme Event	Signal>1
20070130	0.1925	0.1740	0.84	0.2413		
20070227	0.1824	0.2599	0.37	0.2444	Y	
20070329	0.1855	0.1447	-1.17	0.2708		
20070427	0.1828	0.1570	1.30	0.2708		Y
20070530	0.1754	0.1565	0.43	0.2709		
20070628	0.1809	0.1711	0.90	0.2702		
20070730	0.2178	0.4119	2.32	0.2618	Y	Y
20070830	0.3303	0.2463	1.12	0.3516		Y
20070927	0.2744	0.3897	-0.01	0.3606	Y	
20071030	0.3586	0.4611	0.90	0.4083	Y	
20071129	0.4519	0.3232	0.69	0.4743		
20071228	0.3436	0.5840	-1.10	0.4887	Y	
20080130	0.5876	0.3762	1.88	0.5827		Y
20080228	0.3569	0.4390	-1.44	0.6006		
20080328	0.4147	0.2602	0.25	0.6278		
20080429	0.2474	0.2107	-1.33	0.6276		
20080529	0.2732	0.2512	1.62	0.6260		Y
20080627	0.2818	0.3059	0.62	0.6265		
20080730	0.2769	0.2711	-0.77	0.6306		
20080828	0.3043	0.5264	0.79	0.6309		
20080929	0.4686	1.0981	0.34	0.6705	Y	
20081030	0.8472	0.5503	0.19	0.9371		

Table 7

Signaling Test of Extreme Event using Black's Implied Volatility (Put)

The table presents the performance of implied volatility derived by Merton model in signaling the extreme event. The implied volatility is derived as a simple average of the eight implied volatilities nearest to the money Hang Seng index Call options. The extreme event is defined as the occurrence of annualized realized volatility (RV) exceeding the mean of realized volatility by three standard deviation. The regression is in the form of

$$IV_{t,B,P} = a_0 + a_1[RV_{t-1} - IV_{t-1,B,P}] + a_2 IV_{t-1,B,P} + \varepsilon_t$$

A signal occurs if the difference between the actual and modeled implied volatility is larger than one root mean squared error as expressed in the form of

$$Signal_t = \frac{[Log(IV_{t,B,P}) - Log(I\hat{V}_{t,B,P})]}{\sqrt{MSE}} > 1$$

$$\text{where } I\hat{V}_{t,B,P} = \hat{a}_0 + \hat{a}_1[RV_{t-1} - IV_{t-1,B,P}] + \hat{a}_2 IV_{t-1,B,P}$$

The last two columns of the table indicate the corresponding occurrences of the extreme event and the signal generated during the period from January 2007 to October 2008 are studied.

Date	IV_{BS}	RV	Signal	E(RV) + 3σ	Extreme Event	Signal>1
20070130	0.2030	0.1740	0.78	0.2413		
20070227	0.1925	0.2599	0.67	0.2444	Y	
20070329	0.2107	0.1447	-0.69	0.2708		
20070427	0.1976	0.1570	1.62	0.2708		Y
20070530	0.1872	0.1565	0.65	0.2709		
20070628	0.1908	0.1711	0.95	0.2702		
20070730	0.2361	0.4119	2.35	0.2618	Y	Y
20070830	0.3601	0.2463	0.68	0.3516		
20070927	0.3067	0.3897	0.29	0.3606	Y	
20071030	0.3783	0.4611	0.27	0.4083	Y	
20071129	0.4656	0.3232	0.37	0.4743		
20071228	0.3529	0.5840	-1.51	0.4887	Y	
20080130	0.6326	0.3762	2.13	0.5827		Y
20080228	0.3866	0.4390	-1.45	0.6006		
20080328	0.4401	0.2602	0.14	0.6278		
20080429	0.2758	0.2107	-1.07	0.6276		
20080529	0.3059	0.2512	2.07	0.6260		Y
20080627	0.3201	0.3059	1.07	0.6265		Y
20080730	0.3073	0.2711	-0.63	0.6306		
20080828	0.3194	0.5264	0.53	0.6309		
20080929	0.5011	1.0981	0.35	0.6705	Y	
20081030	0.9161	0.5503	0.27	0.9371		

Table 8

Signaling Test of Extreme Event using Model Implied Volatility with Jump (Call)

The table presents the performance of implied volatility with jump in signaling the extreme event. The extreme event is defined as the occurrence of annualized realized volatility (RV) exceeding the mean of realized volatility by three standard deviation. The regression is in the form of

$$IV_{t,JD,C} = a_0 + a_1[RV_{t-1} - IV_{t-1,JD,C}] + a_2 IV_{t-1,JD,C} + \varepsilon_t$$

A signal occurs if the difference between the actual and modeled implied volatility is larger than one root mean squared error as expressed in the form of

$$Signal_t = \frac{[Log(IV_{t,JD,C}) - Log(\hat{IV}_{t,JD,C})]}{\sqrt{MSE}} > 1$$

$$\text{where } \hat{IV}_{t,JD,C} = \hat{a}_0 + \hat{a}_1[RV_{t-1} - IV_{t-1,JD,C}] + \hat{a}_2 IV_{t-1,JD,C}$$

The last two columns of the table indicate the corresponding occurrences of the extreme event and the signal generated during the period from January 2007 to October 2008 are studied

Date	IV_{JD}	RV	Signal	E(RV) + 3σ	Extreme Event	Signal>1
20070130	0.2885	0.1740	2.13	0.2413		Y
20070227	0.2405	0.2599	-0.86	0.2444	Y	
20070329	0.2296	0.1447	-1.00	0.2708		
20070427	0.2193	0.1570	-0.14	0.2708		
20070530	0.2193	0.1565	-0.15	0.2709		
20070628	0.2140	0.1711	-0.34	0.2702		
20070730	0.2369	0.4119	0.43	0.2618	Y	
20070830	0.3629	0.2463	1.17	0.3516		Y
20070927	0.3433	0.3897	1.21	0.3606	Y	Y
20071030	0.3433	0.4611	-0.11	0.4083	Y	
20071129	0.3404	0.3232	-0.53	0.4743		
20071228	0.3944	0.5840	1.59	0.4887	Y	Y
20080130	0.3944	0.3762	-0.49	0.5827		
20080228	0.3887	0.4390	0.59	0.6006		
20080328	0.3887	0.2602	0.13	0.6278		
20080429	0.3553	0.2107	0.77	0.6276		
20080529	0.3553	0.2512	1.37	0.6260		Y
20080627	0.3553	0.3059	0.79	0.6265		
20080730	0.3135	0.2711	-0.77	0.6306		
20080828	0.6113	0.5264	3.52	0.6309		Y
20080929	0.5123	1.0981	-0.20	0.6705	Y	
20081030	0.4773	0.5503	-0.82	0.9371		

Table 9

Signaling Test of Extreme Event using Model Implied Volatility with Jump (Put)

The table presents the performance of implied volatility with jump in signaling the extreme event. The extreme event is defined as the occurrence of annualized realized volatility (RV) exceeding the mean of realized volatility by three standard deviation. The regression is in the form of

$$IV_{t,JD,P} = a_0 + a_1[RV_{t-1} - IV_{t-1,JD,P}] + a_2 IV_{t-1,JD,P} + \varepsilon_t$$

A signal occurs if the difference between the actual and modeled implied volatility is larger than one root mean squared error as expressed in the form of

$$Signal_t = \frac{[Log(IV_{t,JD,P}) - Log(I\hat{V}_{t,JD,P})]}{\sqrt{MSE}} > 1$$

$$\text{where } I\hat{V}_{t,JD,P} = \hat{a}_0 + \hat{a}_1[RV_{t-1} - IV_{t-1,JD,P}] + \hat{a}_2 IV_{t-1,JD,P}$$

The last two columns of the table indicate the corresponding occurrences of the extreme event and the signal generated during the period from January 2007 to October 2008 are studied

Date	IV_{JD}	RV	Signal	E(RV) + 3σ	Extreme Event	Signal>1
20070130	0.1909	0.1740	-0.18	0.2413		
20070227	0.1909	0.2599	-0.10	0.2444	Y	
20070329	0.1909	0.1447	-0.29	0.2708		
20070427	0.1909	0.1570	0.02	0.2708		
20070530	0.1909	0.1565	-0.02	0.2709		
20070628	0.1909	0.1711	-0.02	0.2702		
20070730	0.2404	0.4119	1.77	0.2618	Y	Y
20070830	0.3947	0.2463	1.57	0.3516		Y
20070927	0.2415	0.3897	-1.90	0.3606	Y	
20071030	0.3974	0.4611	1.47	0.4083	Y	Y
20071129	0.5217	0.3232	1.07	0.4743		Y
20071228	0.4540	0.5840	0.53	0.4887	Y	
20080130	0.5050	0.3762	-0.15	0.5827		
20080228	0.5051	0.4390	0.57	0.6006		
20080328	0.4815	0.2602	-0.16	0.6278		
20080429	0.4217	0.2107	0.58	0.6276		
20080529	0.4341	0.2512	1.52	0.6260		Y
20080627	0.4391	0.3059	0.87	0.6265		
20080730	0.4185	0.2711	-0.01	0.6306		
20080828	0.4185	0.5264	0.46	0.6309		
20080929	0.4280	1.0981	-0.96	0.6705	Y	
20081030	0.4198	0.5503	-1.70	0.9371		

Table 10

Signaling Test of Extreme Event using Implied Skewness (Call)

The table presents the performance of implied skewness (ISkew) in signaling the extreme event. The extreme event is defined as the occurrence of annualized realized volatility (RV) exceeding the mean of realized volatility by three standard deviation. The regression is in the form of

$$IV_{t,JD,C} = a_0 + a_1[RV_{t-1} - IV_{t-1,JD,C}] + a_2 IV_{t-1,JD,C} + \varepsilon_t$$

A signal occurs if there is a change of sign in skewness expressed in the form of

$$ISkew = \frac{\lambda\omega(\omega^2 + 3\delta^2)}{(\sigma_{JD,C})^3\sqrt{T}}$$

The last two columns of the table indicate the corresponding occurrences of the extreme event and the signal generated during the period from January 2007 to October 2008 are studied

Date	ISkew	RV	E(RV) + 3σ	Extreme Event	Change of Signal
20070130	-17.422	0.1740	0.2413		
20070227	1.059	0.2599	0.2444	Y	Y
20070329	-1.584	0.1447	0.2708		Y
20070427	0.593	0.1570	0.2708		Y
20070530	0.607	0.1565	0.2709		
20070628	0.574	0.1711	0.2702		
20070730	-0.666	0.4119	0.2618	Y	Y
20070830	-1.328	0.2463	0.3516		
20070927	-13.476	0.3897	0.3606	Y	
20071030	-13.166	0.4611	0.4083	Y	
20071129	-14.847	0.3232	0.4743		
20071228	-4.640	0.5840	0.4887	Y	
20080130	-5.060	0.3762	0.5827		
20080228	-5.241	0.4390	0.6006		
20080328	-4.985	0.2602	0.6278		
20080429	-24.314	0.2107	0.6276		
20080529	-24.645	0.2512	0.6260		
20080627	-23.202	0.3059	0.6265		
20080730	-16.722	0.2711	0.6306		
20080828	3.430	0.5264	0.6309		Y
20080929	3.984	1.0981	0.6705	Y	
20081030	6.214	0.5503	0.9371		

Table 11

Signaling Test of Extreme Event using Implied Skewness (Put)

The table presents the performance of implied skewness (ISkew) in signaling the extreme event. The extreme event is defined as the occurrence of annualized realized volatility (RV) exceeding the mean of realized volatility by three standard deviation. The regression is in the form of

$$IV_{t,JD,P} = a_0 + a_1[RV_{t-1} - IV_{t-1,JD,P}] + a_2 IV_{t-1,JD,P} + \varepsilon_t$$

A signal occurs if there is a change of sign in skewness expressed in the form of

$$ISkew = \frac{\lambda\omega(\omega^2 + 3\delta^2)}{(\sigma_{JD,P})^3\sqrt{T}}$$

The last two columns of the table indicate the corresponding occurrences of the extreme event and the signal generated during the period from January 2007 to October 2008 are studied

Date	ISkew	RV	E(RV) + 3σ	Extreme Event	Change of Signal
20070130	-0.068	0.1740	0.2413		
20070227	-0.062	0.2599	0.2444	Y	
20070329	-0.068	0.1447	0.2708		
20070427	-0.063	0.1570	0.2708		
20070530	-0.065	0.1565	0.2709		
20070628	-0.063	0.1711	0.2702		
20070730	0.055	0.4119	0.2618	Y	Y
20070830	0.575	0.2463	0.3516		
20070927	0.060	0.3897	0.3606	Y	
20071030	1.337	0.4611	0.4083	Y	
20071129	1.298	0.3232	0.4743		
20071228	1.216	0.5840	0.4887	Y	
20080130	0.960	0.3762	0.5827		
20080228	0.946	0.4390	0.6006		
20080328	0.606	0.2602	0.6278		
20080429	0.083	0.2107	0.6276		
20080529	0.753	0.2512	0.6260		
20080627	3.103	0.3059	0.6265		
20080730	5.446	0.2711	0.6306		
20080828	5.180	0.5264	0.6309		
20080929	4.640	1.0981	0.6705	Y	
20081030	4.648	0.5503	0.9371		

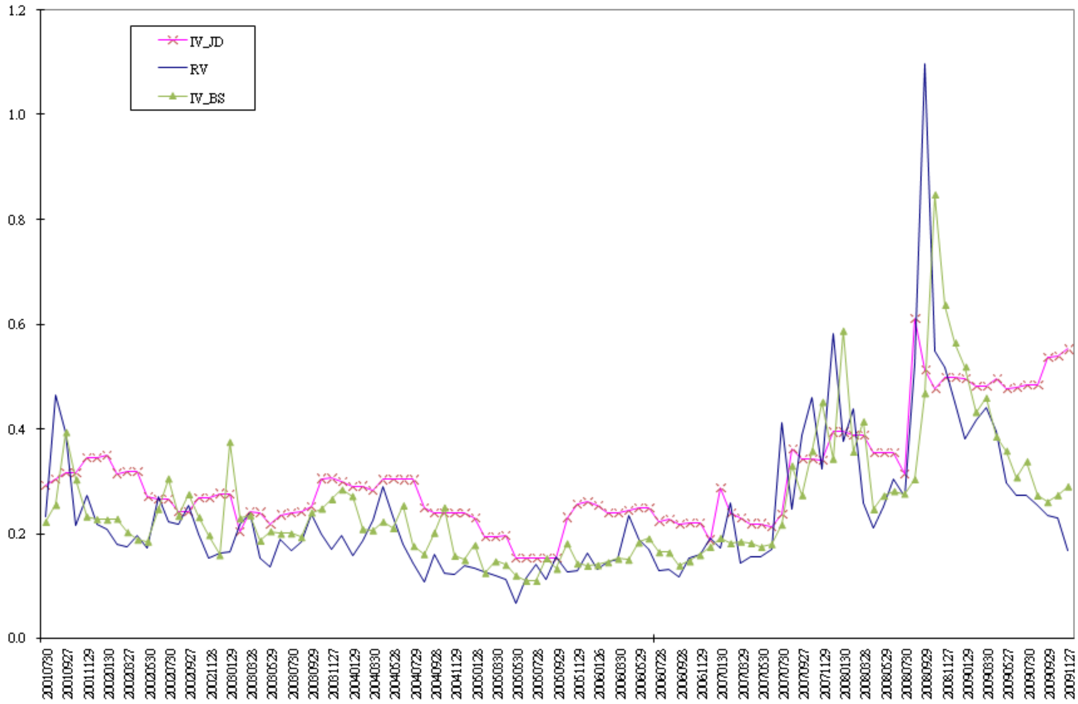

Figure 1. Comparison of Realized volatility, Implied Volatility ($IV_{t,BS}$) and Implied Volatility ($IV_{t,JD}$) for Hang Seng Index using Call Options

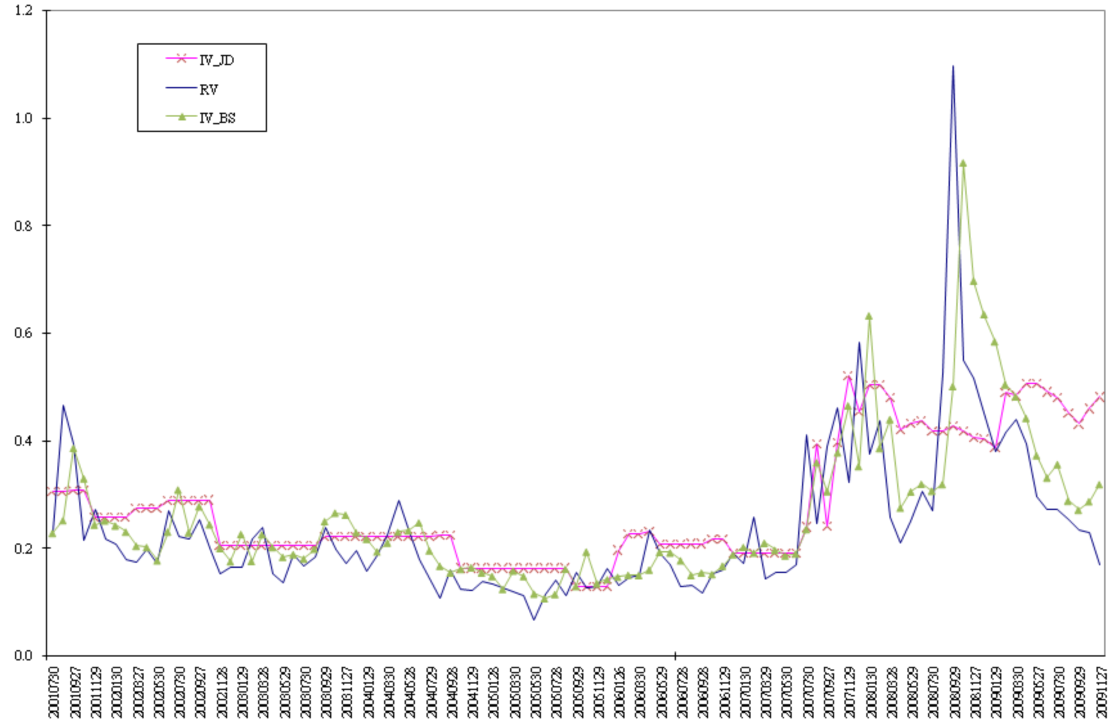

Figure 2. Comparison of Realized volatility, Implied Volatility ($IV_{t,BS}$) and Implied Volatility ($IV_{t,JD}$) for Hang Seng Index using Put Options

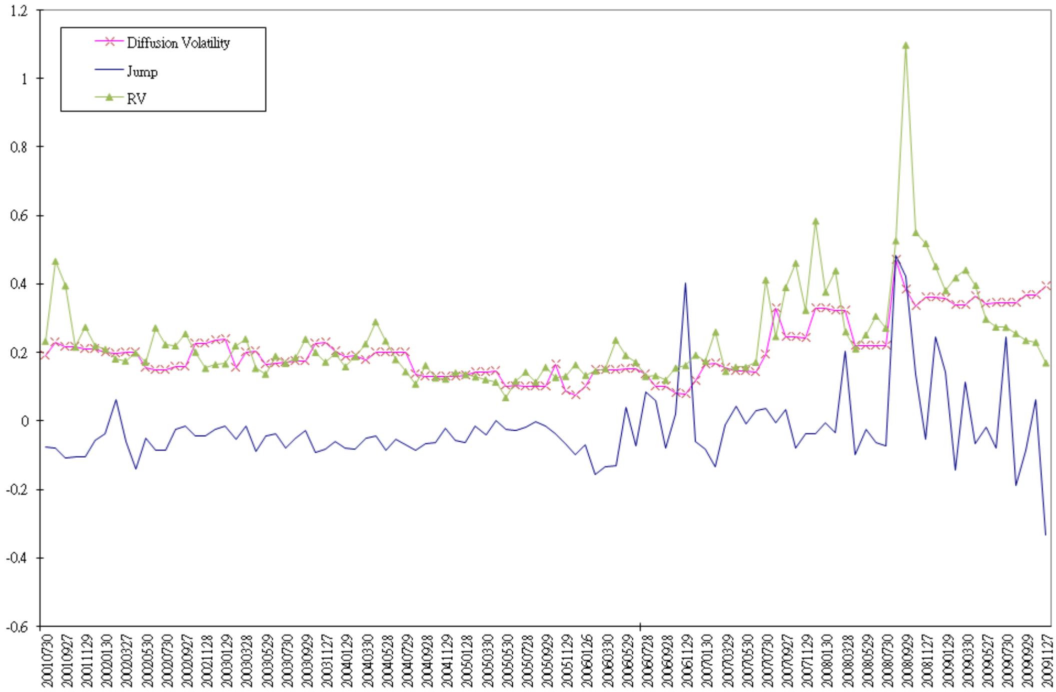

Figure 3. Comparison of realized volatility, Jump and diffusion volatility of Jump-Diffusion model for Hang Seng Index using Call Options

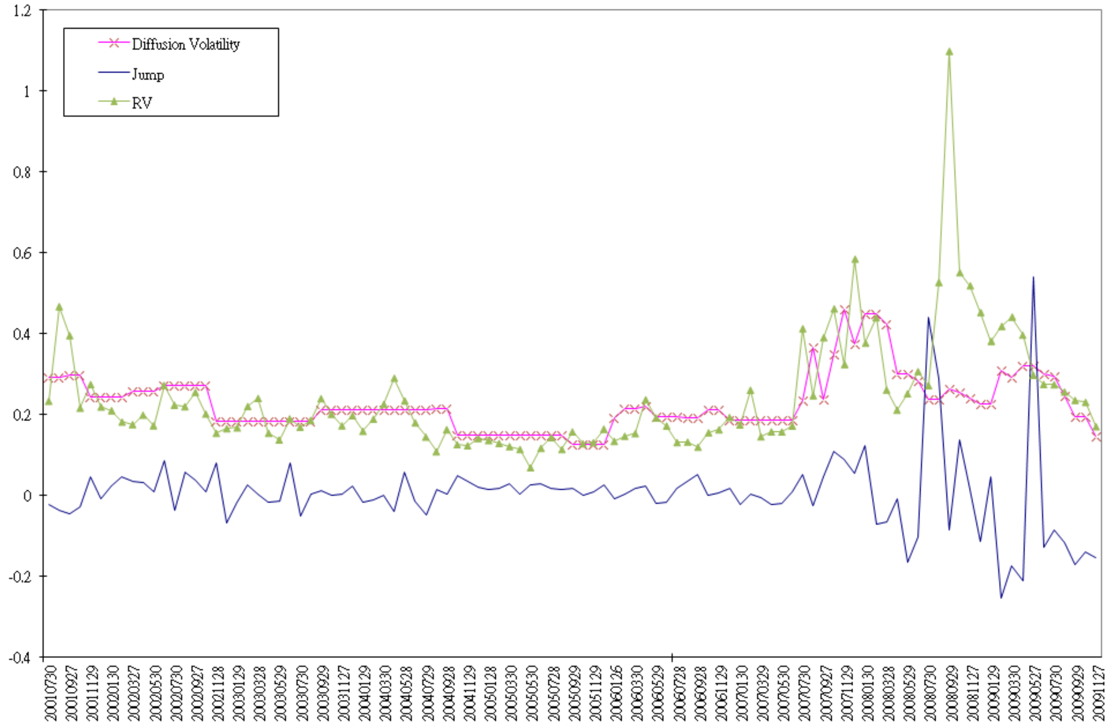

Figure 4. Comparison of realized volatility, Jump and diffusion volatility of Jump-Diffusion model for Hang Seng Index using Put Options