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The predictive power of the implied volatility of options traded OTC and on exchanges

Wayne W. Yu [a,*], Evans C.K. Lui [b], Jacqueline W. Wang [a]

[a] School of Accounting and Finance, The Hong Kong Polytechnic University, Hong Kong
[b] Department of Finance, The Chinese University of Hong Kong, Hong Kong

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ABSTRACT

This paper investigates the efficiency of stock index options traded over-the-counter (OTC) and on the exchanges in Hong Kong and Japan. Our findings suggest that implied volatility is superior to either historical volatility or a GARCH-type volatility forecast in predicting future volatility in both the OTC and exchange markets. This paper is also one of the first to compare the predictive power of the implied volatility of stock index options traded OTC to that of exchange-traded stock index options. Our evidence suggests that the OTC market is more efficient than the exchanges in Japan, but that the opposite is true in Hong Kong.

1. Introduction

The implied volatility of an option's price is widely believed to function as a forecast of the future volatility of the underlying asset over the remaining life of the option. Furthermore, if the option market is efficient, the implied volatility should subsume information contained in all other variables, including historical volatility, in explaining future volatility. Prior empirical studies provide mixed evidence on the information content of implied volatility relative to historically-based volatility. In general, early papers document that implied volatility is an inefficient predictor of future volatility. Day and Lewis (1992) examine S&P 100 index options with expiries from 1985 through 1989 and find that historical volatility contains predictive power about future volatility beyond that in implied volatility. Lamoureux and Lastrapes (1993) reach a similar conclusion using options on 10 stocks with expiries from 1982 through 1984. On the basis of a sample of S&P 100 index options from March 1983 through March 1987, Canina and Figlewski (1993) find that historical volatility, instead of implied volatility, is significantly correlated with future volatility, leading them to conclude that implied volatility has no information content.

But the findings in the papers above are subject to a few problems in their research designs. For example, implied volatility in Day and Lewis (1992) is computed from S&P 100 index options with remaining lives up to 36 trading days, which is related to one-week-ahead future volatility. Lamoureux and Lastrapes (1993) examine the one-day-ahead predictive power of implied volatility based on stock options with maturities up to 129 trading days. Both studies therefore suffer a maturity mismatch problem. In addition, both use overlapping samples, as do Canina and Figlewski (1993). These papers construct their data on a daily basis, resulting in an extreme degree of overlap in consecutive observations in the time series of historical and future volatility. Overcoming these problems, more recent papers find evidence that implied volatility embedded in option prices is informationally efficient in forecasting future volatility. Christensen and Prabhala (1998), using monthly non-overlapping data, re-examine the information content of implied volatility of S&P 100 index options. They find that implied volatility outperforms historical volatility in forecasting future volatility and even subsumes the information content of historical volatility in some of their models. They also document that the predictive power of implied volatility improved after the October 1987 stock market crash. Szakmary et al. (2003) find that for a large majority of the 35 futures options markets in the US, implied volatility outperforms historical volatility as a predictor of future volatility in the underlying futures prices over the remaining life of the option. Furthermore, historical volatility is subsumed

* Corresponding author. Tel.: +852 2766 7970; fax: +852 2330 9845.
E-mail address: afwyu@polyu.edu.hk (W.W. Yu).

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by implied volatility for most of the 35 markets examined. More recent studies on the implied volatility of S&P 500 index options show that it has the ability to predict the future return on the S&P 500 (Banerjee et al., 2007), and that it has the ability to anticipate the impact of non-continuous price changes (jumps) in the S&P 500 index (Becker et al., 2009).

In this paper, we investigate the efficiency of stock index options traded over-the-counter (OTC) and on the exchanges in Hong Kong and Japan. To our knowledge, our paper is among the first to examine the information content of the implied volatility of *stock index* options traded OTC.[1] Research using exchange-traded index options such as Day and Lewis (1992) and Christensen and Prabhala (1998) may suffer measurement errors that can affect the accuracy of the resultant implied volatility. These errors can arise from bid-ask spread, non-synchronous option and underlying asset prices, discrete strike prices, and time-varying maturity, as discussed in Canina and Figlewski (1993) and Christensen and Prabhala (1998).

There are four major differences between OTC and exchange-traded options. First, the quoted option price in the OTC market is actually implied volatility itself. Second, exchange-traded stock index options have a fixed number of expiration months at any given point in time, resulting in varying time-to-expiration. In contrast, the OTC stock index options have constant maturity. For example, on any given day, a 1-month OTC option will expire in exactly one month. Third, OTC options are always at-the-money, thereby reducing variations in implied volatility owing to the volatility "smile" in which implied volatility varies with the strike price. Discrete strike prices for exchange-traded options mean that even the nearest-the-money options are only approximately at-the-money, subjecting the computed implied volatility to the volatility smile effect. Finally, the OTC market is generally more liquid since most option exchanges, including those in Hong Kong and Japan, impose position limits for each investor. Consequently, professional (institutional) investors prefer to trade options in the OTC market because of its deeper liquidity and anonymity. Although official data on the OTC option markets do not exist, our discussion with many option traders reveals that the turnover of OTC index options is much higher than the corresponding exchange-traded index options in Hong Kong and Japan.

Another consideration, as we will discuss in more detail in Section 2, is that the implied volatility of exchange-traded options in our study is more carefully derived by our data provider, Bloomberg. First, Bloomberg makes an adjustment in ascertaining each option's settlement price on each day to minimize measurement problems resulting from the bid-ask spread and non-synchronous closing prices between the spot and options markets. In addition, our implied volatility is also less subject to the volatility smile effect owing to a weighting scheme employed by Bloomberg. In particular, at the end of each trading day, Bloomberg uses three options of the same class (three calls or three puts) closest to at-the-money to compute the implied volatility of the call or put options. For the three options of each class, Bloomberg's weighting scheme gives much more weight to at-the-money options than to either out-of-the-money or in-the-money options.

Perhaps the most noteworthy feature of our study is that it is one of the first to test the efficiency of the OTC market in relation to the exchanges. As mentioned earlier, professional (institutional) investors are more likely to execute their option trading strategies in the OTC market because of its deeper liquidity and anonymity, while retail (individual) investors are the major participants in the option exchanges. To the extent that professional investors are more sophisticated in obtaining and processing information, the OTC implied volatility is expected to be a more efficient forecast of future volatility than is the implied volatility of exchange-traded options. But as noted above, Bloomberg takes great care in deriving exchange-traded implied volatility, a practice that may mitigate problems stemming from liquidity and other measurement errors. We therefore believe it is an empirical issue as to which market is more efficient.

Our paper is also motivated by the consideration that the options markets in Hong Kong and Japan are not as liquid as that in the United States.[2] The various measurement errors discussed above are exacerbated in less liquid markets. For example, Chang et al. (2009) report that, to deal with the low liquidity problem, the Hong Kong Stock Exchange (HKEx) applies a piecewise linear volatility function to determine the daily settlement prices. But they show that the adjustment procedure still results in significant overpricing for about 90% of HKEx traded option contracts. Furthermore, prior studies using non-US samples provide mixed evidence regarding the informational efficiency of the implied volatility in option prices. Doidge and Wei (1998) examine the Toronto Stock Exchange 35 index options market from January 1991 through July 1995 and find that implied volatility is outperformed by historical volatility. In fact, they report that implied volatility has the lowest predictive power about future volatility, compared with that using all other volatility forecasts, such as historical, GARCH (1,1), and EGARCH (1,1). Using a sample of FTSE 100 index options in the UK from June 1993 through May 1995, Gwilym and Buckle (1999) find that although implied volatility is informative of future volatility, historical volatility contains incremental information beyond that in implied volatility. But Hansen (2001) finds some evidence that the implied volatility of the Danish KFX stock index options is an efficient forecast of future volatility, after correcting the errors-in-variables problem in the sample. Although Fung (2007) does not focus on the superiority of implied volatility relative to historical volatility in forecasting realized volatility, he reports that the implied volatility of exchange-traded Hang Seng Index options outperformed a number of volatility predictors, such as trading volume and the open interest of both index options and index futures, at the time of the 1997 crash in Hong Kong.[3] Given the equivocal results in the non-US options markets, it is clear that further research on the information content of implied volatility is warranted, as both Hong Kong and Japan have gained importance as financial centers over the last few years.[4]

We summarize our findings as follows: First, for stock index options traded OTC in both Hong Kong and Japan, implied volatility subsumes historical volatility or a GARCH-type volatility forecast in predicting future volatility. We find similar results for stock in-

[1] OTC *currency* options have been used in a couple of earlier studies. Covrig and Low (2003) find that future volatility can be forecast by implied volatility in the OTC currency options market. Campa and Chang (1998) also use OTC currency options to examine whether the correlation derived from implied volatilities in the currency options can outperform alternative forecasts such as historical correlation.

[2] Using the ratio of the notional value underlying the stock index options traded in a year over the total market capitalization in a country as a measure of its option market's liquidity, we find that the stock index options market is the most liquid in the US with an average ratio of 0.7121, followed by Japan with an average of 0.4664, and Hong Kong with an average of 0.2413, for the years 2002–2006.

[3] Our paper further differs from Fung (2007) in two significant respects. First, we use the OTC option data and Bloomberg's exchange-traded options data in our tests of the informational efficiency of implied volatility. Second, our base sample begins from May 1998, after the 1997 market crash in Hong Kong. During an extremely volatile period such as a market crash, historical volatility, by design, is inferior to implied volatility in forecasting future realized volatility. Therefore, the information content of implied volatility is best examined in a non-crash period such as ours.

[4] According to the World Federation of Exchanges, in terms of the domestic market capitalization at the end of 2006, the New York Stock Exchange was the largest with a market cap of US $15,421 billion, the Tokyo Stock Exchange was the second largest with a market cap of US $4,614 billion, and the Hong Kong Stock Exchange was the sixth largest with a market cap of US $1,715 billion. More detailed information for the rankings can be found on the World Federation of Exchanges' Website: http://www.world-exchanges.org/publications/EQUITY106.XLS.

dex options traded on the exchanges in Hong Kong and Japan. Taken together, these results are consistent with the hypothesis that the stock index options markets are efficient in that implied volatility can forecast future volatility, and that historically-based volatility measures provide no incremental information. When we compare the efficiency of the OTC market with that of the exchanges in each country, we report mixed results. In particular, we find evidence that the implied volatility of options traded OTC is more efficient than that of exchange-traded options in Japan, but that the opposite holds true in Hong Kong.

The rest of the paper is organized as follows. Section 2 describes the data and defines the variables. Section 3 explains the methodology for testing option market efficiency. In Section 4 we discuss the empirical results, and Section 5 concludes the paper.

2. Data and sampling procedure

2.1. Data for OTC stock index options

We first examine the efficiency of the implied volatility of stock index options traded OTC in Hong Kong and Japan. The implied volatility of the Hang Seng Index (HSI) and Nikkei-225 Index options traded OTC is provided by a major international investment bank, JP Morgan, for the period from May 1998 to February 2005. As mentioned earlier, the quoted option price in the OTC market is actually implied volatility, a single number applicable to *both* call and put options. Second, options traded OTC have constant maturity. On any given day, for example, a 1-month OTC index option will expire in exactly one month. This allows us to compute the future volatility over the exact remaining life of an option, thereby eliminating the maturity mismatch problem in many prior studies using exchange-traded options. Third, OTC options are *always* at-the-money, thereby reducing variations in implied volatility owing to the volatility "smile" effect.

2.2. Data for exchange-traded stock index options

The implied volatility of exchange-traded options on the HSI and Nikkei-225 is provided by Bloomberg for the same time period of May 1998 through February 2005. Bloomberg uses stock index options data at the end of each trading day provided by the Hong Kong Stock Exchange and Osaka Stock Exchange to calculate the implied volatility of the HSI and Nikkei-225 Index options, respectively.

To mitigate the non-synchronous closing prices problem, Bloomberg sets each index option's settlement price on each day to the last trade price if it falls between the bid and ask at the close, the ask price if the last trade falls above the ask, and the bid price if the last trade price falls below the bid. This practice promotes the use of a settlement price nearest the market close. Since each exchange-traded index option on the HSI and Nikkei-225 is a European option, Bloomberg then plugs the adjusted settlement price into the Black–Scholes model to back out its implied volatility with the dividend yield adjusted.

Furthermore, to reduce the volatility smile effect, Bloomberg takes a weighted average of implied volatilities for three options of the same *class* (i.e., either three calls or three puts) of the current expiry closest to at-the-money.[5] The weighting for each of the three options is inversely related to the absolute deviation of each strike price from the underlying index's closing price, with the biggest weight given to the at-the-money option. In particular, suppose index option i's strike price is X_i and the underlying index price is S, then option i's weight, W_i, is given by the following expression:

$$W_i = \frac{1}{2} - \frac{|X_i - S|}{2\sum_{j=1}^{3}|X_j - S|}. \tag{1}$$

To illustrate, suppose $S = 100$, as well as three index options of the current expiry with strike prices of $X_1 = 90$, $X_2 = 100$, and $X_3 = 110$, respectively. The weights for the corresponding index options are therefore 0.25, 0.5, and 0.25.

Finally, the implied volatility of index options of the same *class* is therefore the weighted average of the three options closest to the at-the-money option, as follows:

$$Ivol = \sum_{i=1}^{3} W_i IV_i, \tag{2}$$

where W_i is the weight of the index option as determined in Eq. (1) above and IV_i is the implied volatility of option i backed out using the Black–Scholes model. Therefore, Bloomberg's computation of implied volatility is less likely to suffer measurement problems as a result of the bid-ask spread and non-synchronous closing prices between the spot and options markets, and is also less subject to the volatility smile effect owing to the weighting scheme above where out-of-the-money and in-the-money options are given smaller weights than at-the-money options.

Because there may be differences in moneyness between call and put options, the implied volatilities of the calls and puts may differ. As a result, Bloomberg provides an implied volatility separately for index *call* options and index *put* options. When we perform our tests in Section 4 using exchange-traded options, we will use implied volatility based on call options, put options, and the average of the two.[6]

2.3. Sampling procedure

Earlier studies such as Day and Lewis (1992), Lamoureux and Lastrapes (1993), and Canina and Figlewski (1993) construct their data on a daily basis, resulting in an extreme degree of overlap in consecutive observations in the time series of historical and future volatility. The overlapping sampling procedure presents a serious problem of serial correlation, which leads to underestimating the standard error for the coefficient on historical volatility, thereby favoring historical volatility as an efficient forecast of future volatility. To overcome the problems associated with overlapping sampling, we follow more recent studies such as Christensen and Prabhala (1998) by taking a non-overlapping sample on a monthly basis as follows.

Exchange-traded options on the Hang Seng Index expire on the last business day of each month, while exchange-traded Nikkei-225 Index options expire on the second Friday of each month. Throughout our study, we will focus only on stock index options with an expiry of one month since they are the most actively traded.[7] Therefore, our series of implied volatility of exchange-traded stock index options for Hong Kong and Japan consists of the implied volatility on *the first business day of each month* and *the first business day following the second Friday of each month*, respectively. To match the expiry cycles of the exchange-traded options in the respective markets, our series of implied volatility

[5] The three options used in calculating implied volatility are of the most current expiry month, unless there are less than 20 days to expiry. Otherwise, the three options closest to at-the-money from the *next* expiry month will be used. This practice means that the remaining life of an option varies in our overlapping samples. Please see Section 2.3 for a detailed discussion in handling this complication.

[6] Szakmary et al. (2003), Covrig and Low (2003), Ederington and Guan (2002), and Hansen (2001) also use both call and put implied volatilities in their tests.

[7] We do this for another technical reason as well: the non-overlapping procedure would result in only 41 and 27 observations for index options with an expiry of 2 and 3 months, respectively. Results based on the rather small sample sizes may not be statistically reliable. In any case, although not tabulated here, results using either 41 or 27 observations are similar to the ones reported here.

of OTC stock index options consists of the implied volatility provided by JP Morgan on the same corresponding day. Because the implied volatility we use is of a constant maturity (one month) in our non-overlapping samples, we are able to compute the future volatility over the exact remaining life of the option, eliminating the maturity mismatch problem in earlier studies such as Day and Lewis (1992) and Lamoureux and Lastrapes (1993).

To determine whether our results are sensitive to the sampling procedure, we also repeat our tests using daily overlapping volatility data for the stock index options. As we explained above, since the OTC implied volatility is always of a constant maturity, we can easily compute the future volatility over the exact remaining life of an OTC option on any day. But the implied volatility of exchange-traded options computed by Bloomberg is based on the three options closest to at-the-money of the most current expiry month *if* there are 20 or more calendar days to expiry; otherwise, it is based on the three options closest to at-the-money of the *next* expiry month. Figs. 1 and 2 illustrate the time line for Bloomberg's computation of implied volatility of exchange-traded Hang Seng and Nikkei-225 Index options, respectively. As Figs. 1 and 2 show, the remaining life of an exchange-traded option varies from day to day as the expiration date is fixed. In particular, in our overlapping samples of implied volatility of exchange-traded options, the remaining life ranges from 20 to 50 days for a 1-month Hang Seng Index option, and 20 to 53 days for a 1-month Nikkei-225 Index option. The maturity of the corresponding future volatility will be carefully matched to that of implied volatility in our overlapping samples.

3. Methodology

In addition to the series of implied volatility, we need to construct several time series of realized volatility, both historical and future. For each observation of implied volatility, we calculate an annualized standard deviation of daily index returns over a time period that matches the remaining life for the option. In particular, historical (realized future) volatility is the annualized standard deviation of daily index log returns over 22 trading days before (after) the forecast day for each 1-month option contract.[8] But when we perform our tests for the overlapping samples of exchange-traded index options, historical and realized future volatility are calculated to match the changing remaining life of an option, as explained in detail in Section 2.3 above.

Following Claessen and Mittnik (2002), we use 250 trading days to annualize the standard deviation of daily log returns as follows:

$$\sqrt{250/(N_T-1)\sum_{t=1}^{N_T}(R_t-\overline{R}_t)^2}, \tag{3}$$

where $R_t = \ln(P_t/P_{t-1})$ and P_t is the closing spot index level on day t, and N_T is the number of trading days remaining in the life of the option.

Under the assumption of a stationary mean, the historical volatility as computed in Eq. (3) is the best forecast of future volatility. But volatility in stock market returns may be predictable and persistent, and the conditional variance from a GARCH-type model might provide better estimates of future volatility than the simple, historical volatility above (Engle, 1993). Following Akgiray (1989), Baillie and DeGennaro (1990), Schwert and Seguin (1990), Jorion (1995), Brailsford and Faff (1996), and Covrig and Low (2003), we adopt the GARCH (1,1) specification, which has been found the most appropriate. The GARCH (1,1) model is specified as follows:

$$\tilde{r}_t = \bar{r}_t + \tilde{\varepsilon}_t, \quad \varepsilon_t \sim N(0, h_t), \tag{4}$$

$$h_t = \beta_0 + \beta_1\tilde{\varepsilon}^2_{t-1} + \beta_2 h_{t-1}, \tag{5}$$

where $\tilde{r}_t$ is the continuously compounded return of the underlying index and $\bar{r}_t$ is the mean daily return, and h_t is the conditional variance. In the variance equation, β_0 represents the mean variance, β_1 is the coefficient on the squared forecast-error term, and β_2 is the coefficient on the lagged conditional-variance term. Following Engle and Bollerslev (1986), a daily s-step ahead volatility forecast can be formed as follows:

$$\hat{h}_{t+s} = \hat{\beta}_0\sum_{i=0}^{s-2}(\hat{\beta}_1+\hat{\beta}_2)^i + (\hat{\beta}_1+\hat{\beta}_2)^{s-1}\hat{h}_{t+1} \quad s = 1,2,\ldots,N_T, \tag{6}$$

where $\hat{h}_{t+1}$ is the one-day ahead volatility forecast for the first observation day of each month generated by the counterpart of expression (5). Monthly volatility forecasts are then formed by aggregating the s-step-ahead daily forecasts across trading days in each observation month as follows:

$$\hat{\sigma}^2_{t,T} = \sum_{s=1}^{N_T}\hat{h}_{t+s}, \tag{7}$$

where T is the number of days ahead to the forecast and $\hat{\sigma}^2_{t,T}$ is the forecast variance at time t over the next T days. The parameters in the GARCH model are estimated using daily log index returns over the last three years, following Day and Lewis (1992). This forecast variance is multiplied by 250/T; the square root is then taken to yield the annualized GARCH (1,1) volatility forecast for that month. The GARCH (1,1) model parameter estimation period is then rolled forward one month for the next observation. If the monthly GARCH volatility forecast is a better predictor of future volatility, including it in a regression model will render the implied volatility insignificant.

Following Szakmary et al. (2003) and Covrig and Low (2003), among others, we examine the following three hypotheses to test whether the implied volatility contains a significant amount of information over and beyond the historical volatility or the GARCH volatility forecast:

H1. Implied volatility is an unbiased estimator of future realized volatility.

H2. Implied volatility has more explanatory power than historical volatility (or the GARCH volatility forecast) in forecasting future realized volatility.

H3. Implied volatility incorporates all information regarding future volatility; historical volatility (or the GARCH volatility forecast) contains no information beyond what is already contained in implied volatility.

To test the above hypotheses, we employ the following regression models commonly used in the literature, such as Harvey and Whaley (1992), Christensen and Prabhala (1998), and Szakmary et al. (2003)[9]:

$$Rvol_t = \alpha + \beta Ivol_t + e_t, \tag{8}$$

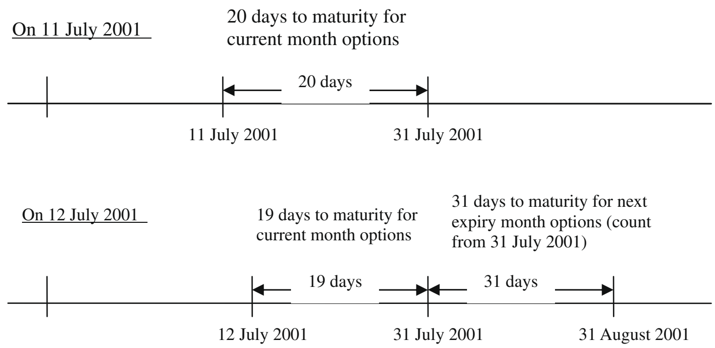
$$Rvol_t = \alpha' + \beta' Hvol_t + e_t, \tag{9}$$

$$Rvol_t = \alpha + \beta Ivol_t + \beta' Hvol_t + e_t, \tag{10}$$

where *Rvol* is future realized volatility and *Hvol* is historical volatility, both calculated according to Eq. (3) above, and *Ivol* is the implied volatility provided by JP Morgan for the OTC index options and by Bloomberg for the exchange-traded index options. As mentioned earlier, for exchange-traded options, Bloomberg provides two measures of implied volatility, one based on call options and the other on put options. We therefore include each separately in

[8] When we use 20 trading days in a month, the results are qualitatively the same as those reported here using 22 trading days.

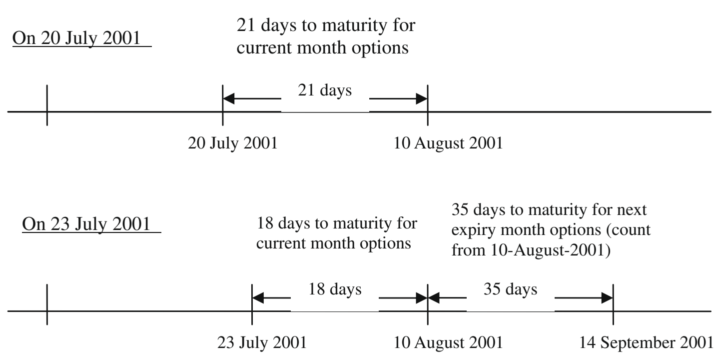
[9] The regression framework we use here is the most popular one according to a recent comprehensive survey on this topic by Poon and Granger (2003).



Notes:

1. The expiration date for exchange-traded Hang Seng Index options is the last business day of the month, which is 31 July 2001 for the example used here.
2. On 11 July 2001, since there are 20 days to the current expiry date, Bloomberg uses three options closest to at-the-money of the *current* expiry month to calculate the 1-month implied volatility.
3. On 12 July 2001, since the current month options have less than 20 days to maturity, Bloomberg uses three options closest to at-the-money of the *next* expiry month to calculate the exchange-traded 1-month implied volatility. Therefore, on 12 July, the 1-month implied volatility calculated has a maturity of 50 days.

Fig. 1. Time-line for Bloomberg's calculation of implied volatility for the 1-month exchange-traded Hang Seng Index options.



Notes:

1. The expiration date for exchange-traded Nikkei-225 Index options is the second Friday of the expiration month, which is 10 August 2001 for the example used here.
2. On 20 July 2001, since there are 21 days to the current expiry date, Bloomberg uses three options closest to at-the-money of the *current* expiry month to calculate the 1-month implied volatility.
3. On 23 July 2001, since the options of the current expiry have less than 20 days to maturity, Bloomberg uses three options closest to at-the-money of the *next* expiry (with maturity of 53 days) to calculate the 1-month implied volatility. Therefore, on 23 July, the 1-month implied volatility calculated has a maturity of 53 days.

Fig. 2. Time-line for Bloomberg's calculation of implied volatility for the 1-month exchange-traded Nikkei-225 Index options.

a regression, and we also use the average of the two to further alleviate measurement problems. We repeat the same regressions, replacing historical volatility (*Hvol*) by the GARCH volatility forecast from Eq. (7).

If H1 is true—that implied volatility is an unbiased estimator of realized volatility—we would expect $\alpha = 0$ and $\beta = 1$ in Eq. (8). If H2 is true—that implied volatility contains more information than historical volatility (or the GARCH forecast)—we would expect a higher adjusted R^2 from regression Eq. (8) than from regression (9). If H3 is correct, then when both implied volatility and historical volatility (or the GARCH volatility forecast) are included in the same regression as in Eq. (10), we would expect $\beta = 1$ and $\beta' = 0$.

In addition, since we have the implied volatility data on both the OTC and exchange-traded index options, our study is one of the first to test which market is more efficient in forecasting future realized volatility. If the OTC market is more efficient than the option exchanges, regressions with OTC implied volatility should result in higher adjusted R^2s. Furthermore, as a more formal test, we run the following encompassing regressions with both the OTC and the exchange implied volatility included as explanatory variables:

$$Rvol_t = \alpha + \beta OTCIvol_t + \beta' EXIvol_t + e_t, \tag{11}$$

where *OTCIvol* is the OTC implied volatility and *EXIvol* is the exchange-traded implied volatility. Intuitively, if OTC implied volatility subsumes exchange implied volatility, it is expected that β will be significant and β' be insignificant. Conversely, if exchange implied volatility subsumes OTC implied volatility, the opposite will be true.

Table 1
Descriptive statistics for implied and realized volatilities. This table reports the descriptive statistics, the differences and their corresponding *t*-statistics between the mean implied volatility and the mean realized volatility, and between the mean implied volatilities taken from exchange-traded and OTC options. The statistics are for the non-overlapping (once-monthly) samples of the Hang Seng Index and Nikkei-225 Index options for the period May 1998 to February 2005.

	OTC implied volatility	Exchange-traded implied volatility			Realized volatility
		Call	Put	Call-put average	
Panel A: Hang Seng Index options					
Mean	0.2826	0.2628	0.2816	0.2722	0.2246
Standard deviation	0.0945	0.0788	0.1071	0.0899	0.0953
Difference between mean implied volatility and mean realized volatility (*t*-statistic)	0.0580 (7.640)	0.0382 (5.028)	0.0570 (7.395)	0.0476 (6.809)	
Difference between mean exchange-traded implied volatility and mean OTC implied volatility (*t*-statistic)		−0.0198 (−4.472)	−0.0010 (−0.205)	−0.0104 (−3.136)	
Panel B: Nikkei-225 Index options					
Mean	0.2569	0.2570	0.2567	0.2569	0.2205
Standard deviation	0.0638	0.0713	0.0743	0.0713	0.0723
Difference between mean implied volatility and mean realized volatility (*t*-statistic)	0.0363 (6.044)	0.0365 (5.568)	0.0362 (5.323)	0.0363 (5.616)	
Difference between mean exchange-traded implied volatility and mean OTC implied volatility (*t*-statistic)		0.0002 (0.065)	−0.0001 (−0.052)	0.0000 (0.004)	

4. Empirical results

4.1. Descriptive statistics

Table 1 presents the summary statistics for the realized and implied volatilities for both the OTC and exchange-traded stock index options for the non-overlapping (once-monthly) samples.[10] Table 1 also reports the differences and their corresponding *t*-statistics between the mean implied volatility and the mean realized volatility, and between the mean implied volatilities taken from exchange-traded and OTC options. Two observations can be made from Table 1. First, regardless of the type of implied volatility, the mean implied volatility is always statistically significantly greater than the respective mean realized volatility. The difference in the means is also economically significant, ranging from 0.0362 for the exchange-traded Nikkei-225 Index put options to 0.0580 for the OTC Hang Seng Index options. These results suggest that implied volatility is unlikely to be an unbiased estimator of realized volatility, which will be formally tested in the next few sections. The significant differences in the mean volatilities for our sample are similar to the mean difference for the S&P 500 index options reported by Becker et al. (2007). Second, for the Nikkei-225 Index, the bias is similar regardless of whether the implied volatility is taken from OTC or exchange-traded options. However, for the Hang Seng Index, the bias is generally smaller for the implied volatility taken from exchange-traded options than that taken from OTC options. The contrasting results may have implications on our formal tests of the predictive power of OTC vs. exchange-traded implied volatilities, as will be discussed in Section 4.4 below.

4.2. OTC stock index options

The regression results for testing the relative predictive power of implied volatility over historical volatility for the OTC Hang Seng and Nikkei-225 Index options are shown in Panels A and B in Table 2, respectively. For each regression, we report the coefficients, their *t*-statistics, and the model adjusted R^2. From the first row in each panel in Table 2, we see that the coefficients for implied volatility (β) in Eq. (8) are all statistically significantly positive at the 1% level, while the intercept terms (α) are all statistically insignificant. But similar to many previous studies such as Covrig and Low (2003), the *F*-test rejects the unbiasedness hypothesis of $\alpha = 0$ and $\beta = 1$ for each OTC market. As noted in Section 4.1 above, the mean implied volatility is significantly greater than the mean realized volatility; thus the rejection of unbiasedness is not surprising. Overall, our finding that implied volatility contains substantial information about future realized volatility in each OTC market is consistent with H1, although it does not appear to be an unbiased estimator. These results are generally in line with prior studies such as Covrig and Low (2003) and Martens and Zein (2004).

To test our second hypothesis (H2), that implied volatility is a better predictor of future realized volatility than is historical volatility, we compare the adjusted-R^2 of regression model (8), displayed in the first row of each panel in Table 2, to those of regression model (9), displayed in the second and third rows of each panel. As is evident from Table 2, in each OTC market the adjusted-R^2 of Eq. (8) using implied volatility as the explanatory variable is substantially higher than those of Eq. (9) using either historical volatility or the GARCH(1,1) volatility forecast as the explanatory variable. It is clear that the predictive power of implied volatility is much superior to that of historical volatility or the GARCH(1,1) volatility forecast in explaining future realized volatility, evidence consistent with H2. It is worth noting that the superiority of implied volatility relative to historically-based volatility is much more pronounced in the OTC market in Japan.

Finally, we test H3 by fitting regression models that include both implied and historically-based volatility as specified in Eq. (10). The results are shown in the last two rows in each panel in Table 2. As can be seen, all coefficients for implied volatility (β) are statistically significant, while all those for either historical volatility or the GARCH(1,1) volatility forecast (β') are all statistically insignificant. Therefore, once the implied volatility is included, the partial effect of including historically-based volatility on future realized volatility is zero, on average. The outperformance of implied volatility over historically-based volatility in forecasting future volatility is also evident from the small incremental adjusted-R^2 resulting from adding historical volatility to implied volatility. In particular, when we move from Eq. (8)–(10), the increase in the adjusted-R^2 is very marginal and in some cases even negative. These results together suggest that including either historical volatility or the GARCH volatility forecast adds very little or no information to that already contained in implied volatility,

[10] We thank an anonymous referee for suggesting the additional analysis in this sub-section, which helps to explain why the unbiasedness hypothesis (H1) is so decisively rejected in our study as well as in many other recent studies such as Covrig and Low (2003) and Szakmary et al. (2003). The results are similar for the overlapping samples, which are not reported to conserve space.

Table 2
Information content of OTC implied volatility versus historical volatility and the GARCH (1,1) volatility forecast. This table reports regression coefficients and t-statistics (in parentheses) for Eqs. (8)–(10) based on the monthly non-overlapping samples of stock index options traded OTC for the period May 1998 to February 2005. $F1$ is the Wald statistic for the joint hypothesis of $\alpha = 0$ and $\beta = 1$, and $F2$ is for the joint hypothesis of $\alpha = 0$, $\beta = 1$, and $\beta' = 0$. DW is the Durbin–Watson statistic.

Intercept α/α'	OTC implied volatility β	Historical volatility β'	GARCH(1,1) volatility forecast	Adj-R^2	DW	$F1$	$F2$
Panel A: OTC Hang Seng Index options							
0.01	0.76			0.56	2.14	37.76***	
(0.479)	(9.898)						
0.08		0.66		0.42	2.18		
(3.534)		(7.490)					
0.02			0.75	0.46	2.06		
(0.920)			(8.092)				
0.01	0.71	0.05		0.55	2.18	1.37	24.92***
(0.504)	(4.889)	(0.334)					
0.01	0.72		0.05	0.55	2.16	2.32*	24.89***
(0.380)	(4.162)		(0.264)				
Panel B: OTC Nikkei-225 Index options							
0.02	0.78			0.47	2.02	22.24***	
(0.845)	(8.457)						
0.13		0.41		0.15	1.92		
(5.331)		(3.890)					
0.04			0.75	0.20	1.71		
(0.974)			(4.668)				
0.02	0.91	−0.17		0.47	1.85	0.50	15.77***
(0.998)	(7.092)	(−1.478)					
0.02	0.77		0.02	0.46	2.02	1.80	14.64***
(0.555)	(6.214)		(0.107)				

For F-statistics, $F1$ and $F2$:
* Significant at 0.1.
*** Significant at 0.01.

Table 3
Information content of OTC implied volatility versus historical volatility using overlapping samples. This table reports the regression coefficients and their t-statistics (in parentheses) for Eqs. (8)–(10) based on the daily overlapping samples of stock index options traded OTC for the period May 1998 to February 2005. Standard errors of the coefficients are adjusted by Newey and West's (1987) consistent covariance estimator for both heteroskedasticity and autocorrelation. The number of lags is set to 22, which is equal to the maximum number of days of overlap for the OTC options. DW is the Durbin–Watson statistic.

Intercept α/α'	OTC implied volatility β	Historical volatility β'	Adj-R^2	DW
Panel A: OTC Hang Seng Index options				
0.00	0.80		0.60	0.10
(0.10)	(12.17)			
0.07		0.70	0.48	0.07
(5.03)		(11.42)		
0.00	0.68	0.13	0.60	0.09
(0.26)	(4.78)	(1.11)		
Panel B: OTC Nikkei-225 Index options				
0.02	0.77		0.41	0.09
(0.79)	(7.81)			
0.13		0.40	0.16	0.07
(6.39)		(5.04)		
0.02	0.92	−0.17	0.42	0.09
(0.70)	(6.84)	(−2.00)		

consistent with H3. The F-test, however, rejects the joint hypothesis of the unbiasedness of $\alpha = 0$, $\beta' = 0$, and $\beta = 1$. Overall, our results indicate that the implied volatility of OTC stock index options in both Hong Kong and Japan seems to subsume information contained in historically-based volatility in forecasting future volatility.

As a robustness check, we use the daily, overlapped samples to determine whether our results are sensitive to the sampling methodology. As noted earlier, the daily overlapping sampling procedure presents a serious problem of serial correlation, a major drawback being an underestimated standard error of the coefficient for historical volatility. To reduce this bias, we compute our t-statistics using the Newey and West (1987) method, which corrects for both heteroskedasticity and autocorrelation in the residuals caused by the overlapping sampling procedure. Newey and West (1987) suggest that the number of lags should normally be $T^{0.25}$, where T is the number of observations. But in our context of overlapping data, it is appropriate to set the number of lags to equal the maximum number of days of overlap. Therefore, we set the number of lags to 22 days for the OTC options. Similarly, when we perform the regressions using overlapping exchange-traded options in Section 4.3 below, we set the number of lags to 53 days.[11]

The regression results using the overlapped data for the Hang Seng and Nikkei-225 Index options traded OTC are reported in Panels A and B in Table 3, respectively. As can be seen, using overlapped samples does not alter our earlier conclusions. In particular, the predictive power of implied volatility remains much superior to that of historical volatility, while it subsumes the information contained in historical volatility in predicting future volatility.[12] But we note here some slight changes in the adjusted-R^2 of Eq. (8)–(10). Specifically, for each corresponding regression, the overlapping procedure generally results in a higher adjusted-R^2 for the OTC market in Hong Kong, but a lower adjusted-R^2 for the Japanese market.

4.3. Exchange-traded stock index options

The regression estimates of Eqs. (8)–(10) for exchange-traded Hang Seng and Nikkei-225 Index options are shown in Panels A and B in Table 4, respectively. As explained earlier, Bloomberg provides an implied volatility of call options and put options separately. Therefore, we fit three alternative model specifications:

[11] We thank an anonymous referee for suggesting this approach.

[12] As explained in Section 2.3, the remaining life of an option under the overlapping sampling procedure varies from 20 to 53 days, which considerably complicates the computation of the GARCH(1,1) volatility forecast. Furthermore, as can be seen from the non-overlapped results in Table 2, the information content of the volatility forecast is similar to that of historical volatility. As a result, we do not repeat the same analysis using the GARCH(1,1) volatility forecast.

Table 4
Information content of exchange-traded implied volatility versus historical volatility and the GARCH (1,1) volatility forecast. This table reports the regression coefficients and t-statistics (in parentheses) for Eqs. (8)–(10) based on the non-overlapping samples of exchange-traded stock index options for the period May 1998 to February 2005. $F1$ is the Wald statistic for the joint hypothesis of $\alpha = 0$ and $\beta = 1$, and $F2$ is for the joint hypothesis of $\alpha = 0$, $\beta = 1$, and $\beta' = 0$. DW is the Durbin–Watson statistic.

Intercept	Implied volatility			Historical volatility	GARCH(1,1) volatility forecast	Adj-R^2	DW	$F1$	$F2$
	Put	Call	Call-put average						
α/α'	β			β'					
Panel A: Exchange-traded Hang Seng Index options									
0.03	0.69					0.60	2.22	46.71***	
(1.527)	(10.850)								
0.00		0.87				0.51	1.95	13.71***	
(−0.137)		(9.009)							
−0.000			0.83			0.60	2.23	27.1***	
(−0.0003)			(10.830)						
0.08				0.66		0.42	2.18		
(3.534)				(7.490)					
0.02					0.75	0.46	2.06		
(0.920)					(8.092)				
0.02	0.68			0.02		0.60	2.24	4.09**	30.76***
(1.477)	(5.915)			(0.183)					
0.00		0.68		0.19		0.52	2.14	3.08*	9.84***
(0.097)		(4.043)		(1.345)					
−0.001			0.87	−0.047		0.60	2.20	0.66	17.89***
(−0.037)			(5.908)	(−0.330)					
0.04	0.76				−0.09	0.60	2.17	2.95*	30.91***
(1.555)	(5.293)				(−0.486)				
−0.01		0.60			0.29	0.52	2.11	3.59**	10.52***
(−0.423)		(3.462)			(1.818)				
0.00			0.93		−0.12	0.60	2.19	0.10	18.06***
(0.166)			(5.298)		(−0.638)				
Panel B: Exchange-traded Nikkei-225 Index options									
0.06	0.63					0.41	1.99	27.38***	
(2.647)	(7.603)								
0.05		0.67				0.43	1.95	25.77***	
(2.145)		(7.837)							
0.05			0.68			0.44	2.00	25.72***	
(2.070)			(8.013)						
0.13				0.41		0.15	1.92		
(5.331)				(3.890)					
0.04					0.75	0.20	1.71		
(0.974)					(4.668)				
0.06	0.64			−0.02		0.41	1.97	6.00***	18.04***
(2.549)	(5.957)			(−0.181)					
0.05		0.73		−0.08		0.42	1.86	3.53**	17.25***
(2.252)		(6.263)		(−0.725)					
0.05			0.73	−0.09		0.44	1.91	3.37**	17.24***
(2.187)			(6.449)	(−0.750)					
0.02	0.55				0.23	0.42	2.07	9.94***	19.04***
(0.701)	(5.514)				(1.346)				
0.02		0.60			0.18	0.43	2.01	7.15***	17.59***
(0.659)		(5.687)			(1.066)				
0.02			0.62		0.17	0.44	2.06	6.78***	17.47***
(0.659)			(5.858)		(0.996)				

For F-statistics, $F1$ and $F2$:
* Significant at 0.1.
** Significant at 0.05.
*** Significant at 0.01.

the implied volatility of call options, the implied volatility of put options, and the average implied volatility of the call and the put. Regardless of the type of implied volatility, we draw the following conclusions for exchange-traded stock index options in both Hong Kong and Japan: (a) implied volatility contains useful information in predicting future realized volatility, as indicated by the highly significant coefficients and relatively high model adjusted-R^2s in Eq. (8); (b) implied volatility is more informative than either historical volatility or the GARCH(1,1) volatility forecast in predicting future realized volatility, since the adjusted-R^2s for Eq. (8) are all much higher than those for Eq. (9); and (c) implied volatility subsumes historical volatility or the GARCH volatility forecast in predicting future realized volatility, since all the coefficients on implied volatility in the encompassing regressions are close to unity and are statistically significant, whereas those for historically-based volatility measures are both close to zero and statistically insignificant.[13] Furthermore, as expected, implied volatility averaged over both put and call options is more efficient than either call or put implied volatility separately. This result is consistent with the view that measurement errors in the implied volatility calculation are reduced by taking the average of the call and put implied volatilities. Overall, our analysis of the ex-

[13] But similar to the OTC options, the exchange-traded implied volatilities also fail the unbiasedness test, as evident from the high $F1$ and $F2$ Wald test statistics. For example, in the encompassing regression context, with HSI-index put implied volatility and historical volatility as independent variables, the high $F2$ test statistics of 30.76 (with a critical value of around 4.5 for $p < 0.01$) strongly reject the unbiasedness hypothesis of $\alpha = 0$, $\beta = 1$, $\beta' = 0$. The rejection of the unbiasedness hypothesis is again consistent with the findings reported in Section 4.1 that the mean implied volatility is significantly greater than the mean realized volatility.

Table 5
Information content of exchange-traded implied volatility versus historical volatility using overlapping samples. This table reports the regression coefficients and their t-statistics (in parentheses) for Eqs. (8)–(10) based on the daily overlapping samples of exchange-traded index options for the period May 1998 to February 2005. Standard errors of the coefficients are adjusted by Newey and West's (1987) consistent covariance estimator for both heteroskedasticity and autocorrelation. The number of lags is set to 53, which is the maximum number of days of overlap for the exchange-traded options. DW is the Durbin–Watson statistic.

Intercept	Implied volatility			Historical volatility	Adj-R^2	DW
	Put	Call	Call-put average			
α/α'	β			β'		
Panel A: Exchange-traded Hang Seng Index options						
0.02	0.73				0.64	0.20
(1.44)	(13.04)					
−0.00		0.88			0.56	0.16
(−0.16)		(9.76)				
−0.01			0.88		0.66	0.12
(−0.90)			(14.69)			
0.07				0.70	0.48	0.07
(4.67)				(12.06)		
0.02	0.68			0.07	0.64	0.18
(1.55)	(6.62)			(0.63)		
0.00		0.62		0.27	0.58	0.12
(0.16)		(3.85)		(1.82)		
−0.01			0.93	−0.06	0.66	0.13
(−0.93)			(6.65)	(−0.61)		
Panel B: Exchange-traded Nikkei-225 Index options						
0.03	0.73				0.41	0.17
(1.22)	(7.47)					
0.02		0.77			0.41	0.17
(1.04)		(8.19)				
0.02			0.79		0.43	0.12
(0.67)			(7.75)			
0.13				0.40	0.17	0.07
(5.94)				(4.82)		
0.03	0.79			−0.08	0.41	0.18
(1.26)	(6.09)			(−1.03)		
0.03		0.86		−0.11	0.41	0.19
(1.03)		(6.77)		(−1.36)		
0.02			0.92	−0.15	0.44	0.14
(0.65)			(6.27)	(−1.88)		

Table 6
Information content of exchange-traded versus OTC implied volatility. This table reports the regression coefficients and t-statistics (in parentheses) for Eq. (11). DW is the Durbin–Watson statistic.

Intercept	OTC implied volatility	Exchange-traded implied volatility			Adj-R^2	DW
		Put	Call	Call-put average		
α	β	β'				
Panel A: Hang Seng Index options						
0.02	0.21	0.53			0.60	2.30
(0.852)	(1.090)	(3.134)				
−0.00	0.57		0.24		0.56	2.15
(−0.021)	(3.049)		(1.068)			
(−0.00)	0.10			0.72	0.60	2.26
(−0.049)	(0.430)			(2.926)		
Panel B: Nikkei-225 Index options						
0.02	0.87	−0.08			0.46	2.01
(0.713)	(2.822)	(−0.308)				
0.02	0.76		0.02		0.46	2.02
(0.832)	(2.375)		(0.053)			
0.02	0.86			−0.07	0.46	2.02
(0.727)	(2.011)			(−0.187)		

change-traded HSI and Nikkei-225 Index options suggests that implied volatility is an efficient forecast for future realized volatility.

Lastly, we employ the overlapping sampling procedure and re-run the regressions as a robustness test. The model estimates with their t-statistics adjusted by the Newey and West (1987) method are displayed in Panels A and B in Table 5, respectively, for options on the Hang Seng Index and Nikkei-225. Again, regardless of the type of implied volatility (call, put, or average), the adjusted-R^2s for Eq. (8), where the independent variable is implied volatility, are all much higher than those for Eq. (9), where the independent variable is historical volatility; in the encompassing regression Eq. (10), all coefficients for implied volatility are close to one and highly statistically significant, whereas those for historical volatility are much smaller in magnitude, with most being statistically insignificant. These results suggest that our findings regarding the efficiency of implied volatility versus historical volatility are invariant to the sampling procedure.

4.4. OTC versus exchanges

The analyses so far suggest that, in either the OTC market or option exchanges, implied volatility is an efficient forecast of future volatility, while historical volatility contains no information. As explained earlier, major differences exist in the liquidity and composition of market participants between the OTC market and the exchanges that suggest that the former may be more efficient in predicting future volatility. After all, the OTC market is almost exclusively accessible by professional, institutional, or sophisticated investors with comparative advantages in collecting and processing information relative to retail investors. In this subsection, we explore a couple of tests to determine which market is more efficient.

We first compare the goodness of fit in models where the implied volatility of OTC options is the explanatory variable with that in models where the implied volatility of exchange-traded options is the explanatory variable. It is quite intuitive that the implied volatility that yields a higher explanatory power will be more efficient in predicting future volatility. When we compare the model adjusted-R^2 using the OTC implied volatility in Table 2 to that using the implied volatility of exchange-traded options in Table 4, the OTC implied volatility generally yields a *poorer* fit for Hang Seng Index options, but a *better* fit for Nikkei-225 options. In particular, for Hang Seng Index options, the model adjusted-R^2 using OTC implied volatility is lower than that using either the implied volatility of exchange-traded put or the average implied volatility of exchange-traded call and put; however, it is higher than that using the implied volatility of exchange-traded call. But for Nikkei-225 Index options, the model adjusted-R^2 using OTC implied volatility is uniformly higher than that using exchange-traded call, put, or the call-put average. The same pattern is observed when we compare the overlapping sampling results in Tables 3 and 5. These seem to suggest that, compared with the respective options exchange, the OTC market is less efficient in Hong Kong but more efficient in Japan.

Furthermore, we develop a more formal test by running an encompassing regression in which future volatility is regressed on both the OTC and exchange-traded implied volatilities as specified by Eq. (11) in Section 3. Intuitively, the implied volatility that retains its statistical significance in this multivariate setting is more efficient. The encompassing regression results for Hong Kong and Japan are displayed in Panels A and B in Table 6, respectively.

We can see from Panel A that, in Hong Kong, the OTC implied volatility retains its significance only in the models where the implied volatility of exchange-traded call is included as a competitor. But the OTC implied volatility loses its significance when either the implied volatility of exchange-traded put or the average volatility of exchange-traded call and put is included. Therefore, on the whole, the implied volatility of exchange-traded options subsumes OTC implied volatility in predicting future volatility, suggesting that the OTC market is less efficient than the exchange in Hong Kong. On the other hand, the results in Panel B indicate that the implied volatility of OTC options is superior to that of exchange-traded options in Japan. In all the model specifications in Panel B, it is always the OTC implied volatility that retains its statistical significance in explaining the future volatility of Nikkei-225 Index options. Our findings based on the encompassing regressions are consistent with those using the goodness-of-fit analysis earlier.[14]

In theory, the OTC market may be expected to outperform not only because its participants are more sophisticated professional investors, but also because OTC implied volatility is much less subject to the various measurement errors as outlined in Covrig and Low (2003). Our rather limited evidence provides inconclusive support for this conjecture. Perhaps one reason is Bloomberg's extra care in deriving the implied volatility of exchange-traded options as explained in Section 2. The various adjustments to the settlement price and the use of a weighted average of the implied volatility of the three options may substantially reduce the measurement errors for exchange-traded options in our samples, enhancing their ability in explaining future volatility. More importantly, our inclusive evidence is consistent with the view that any significant mispricing would attract arbitraging activities until the prices in the competing markets were practically equal. Hence, the existence of arbitraging should eliminate any significant inefficiency in one market relative to another.

5. Conclusion

Using a proprietary database on stock index options trading in Hong Kong and Japan, we examine and compare the predictive power of the implied volatility of options traded OTC and on the option exchanges. For the OTC market, our analysis reveals that implied volatility is informative of future realized volatility, that it outperforms both historical volatility and GARCH (1,1) volatility forecasts, and that it subsumes both of the historically-based volatility measures. We also examine stock index options traded on the exchanges in Hong Kong and Japan and report similar results to those for the OTC market. It appears that the potential measurement problems associated with exchange-traded options as discussed in Christensen and Prabhala (1998) and Covrig and Low (2003) do not cause serious problems in our study, perhaps because of the careful computation procedure used by our data provider, Bloomberg. Furthermore, we employ an overlapping sampling procedure and repeat the analysis above for both the OTC and option exchanges in the two countries and reach the same conclusions as above.

Our findings therefore support a popular theoretical proposition that implied volatility is efficient since it is determined by market participants who are more informed and/or trained for predicting future volatility. After all, implied volatility is a forward-looking forecast, unlike any historically-based volatility, including the more sophisticated GARCH forecast. Consistent with prior studies such as Christensen and Prabhala (1998) and Hansen (2001), and despite its performance over the historically-based volatility measures, implied volatility is not an unbiased estimator for future volatility.

Our paper is one of the first to compare explicitly the predictive power of the implied volatility of options traded OTC to that of exchange-traded options. Our test results suggest that the implied volatility of the former is generally less efficient than that of the latter in Hong Kong. But the OTC market is more efficient than the exchange in Japan. Although the OTC market is expected to be more efficient since it is more liquid and is accessible only by professional and sophisticated investors, our initial, inclusive evidence is perhaps partly the result of the various adjustments by Bloomberg in deriving the implied volatility of exchange-traded options. Furthermore, our inconclusive results are also consistent with the view that any significant mispricing would be arbitraged away, making markets similarly efficient. Further research is needed to examine the extent of deviations from efficiency and to explore factors influencing the efficiency of option markets.

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[14] The results in this section are consistent with the findings in Section 4.1 that, for the Hang Seng Index options, the OTC implied volatility is generally more biased than the exchange-traded implied volatility; whereas for the Nikkei-225 index options, there is little difference in the bias between the OTC and exchange-traded implied volatilities.

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