**What Determines Price Discovery Between Index and Index Futures?**

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## Abstract

We examine the intraday price discovery process between the Hang Seng Index (HSI) futures contract and the underlying cash index during the 1998 Asian Financial Crisis and intervention by the Hong Kong government. The mid-quote index is used to eliminate potential effects of non-synchronous trading in the reported index. The results show that futures dominate the cash index in price discovery throughout the period. The information share for the futures declines gradually from before the financial crisis to the crisis period, and reverts to its original level after the crisis. We also find that short-selling activities in index stocks, relative liquidity, and the relative volatility of the futures and cash index returns significantly affect the information shares of the two markets.

## I. Introduction

In a perfect capital market, prices of index futures and the underlying cash index should move absolutely in unison, or there would be an opportunity for riskless arbitrage. In reality, however, various market frictions impede arbitrage. For instance, the arbitrage basis has to be higher than the transaction cost to trigger arbitrage. This means that the futures price may fluctuate randomly between no-arbitrage bounds for any given level of the cash index. Other frictions like constraints and risk associated with the short selling of index stocks, execution risk during extreme market conditions, time-to-maturity effect of the futures contracts and asymmetrical liquidity conditions in the cash stock market may also drive futures prices away from the cash index price. Microstructures that affect the transparency and execution efficiency of markets also affect market preference and arbitrage efficiency.

We examine the factors that may affect the price discovery process between the futures and cash markets for the Hang Seng Index (HSI) in Hong Kong. Our research tests how market conditions, like volatility, price direction and liquidity, affect the process by examining two adjacent and distinctive sample periods – the periods right before and after the Asian financial crisis. The sample includes 33 months of complete transaction data for the spot month Hang Seng Index Futures, the minute-by-minute reported index value and the mid-quote index based on concurrent bid and ask quotes of all the component stocks of the index. The Stock Exchange of Hong Kong (SEHK) adopts electronic trading for all listed stocks. Hence, the reported bid ask quotes represent firm commitment of traders and are potentially executable. The mid-quote index based on concurrent bid ask quotes of all index stocks eliminates the non-synchronous trading problem in the tests. A comparison between the results provided by the reported index (which is based on transaction price) and the mid-quote index reveals the impact of non-synchronous trading and bid-ask bounce on the information share of the cash index versus the futures. The sample period runs from June

1996 through February 1999, including both the most volatile period during the Asian financial crisis and the intervention by the Hong Kong government. The extent of the sample period permits a robustness test of the study result over different market conditions.

A comparison between the 1 and 5-minute results show that the information share of the mid-quote index is less affected by non-synchronous trading and bid-ask bounce. However, these effects are more pronounced in the results with the reported index.

Using the Hasbrouck (1995) information share model, we find that that the HSI futures is the dominant price contributor in the Hang Seng Index market. Its information share declines gradually from the pre-crisis period to the crisis period and reverts to its pre-crisis level following the financial crisis. Short-selling activities in cash index stocks, relative liquidity and market volatility are major factors affecting the price discovery process of the HSI futures market. The results from the study support the notion that information share of the cash index is expected to be larger in an electronic trading environment compared to a floor trading. Moreover, the result shows that quote based index perhaps would provide more accurate market information than the transaction price based index since the latter is affected by non-synchronous trading of index component stocks and bid ask price bounces.

## II. Literature Review and Hypotheses

### A. Hasbrouck (1995) information share model

Earlier studies on assets traded in multiple markets have focused on whether price series are driven by a single implicit factor. Garbade and Silber (1979) assume a common implicit efficient price is shared by securities traded in more than one market. Equilibrium in prices among securities traded in multiple markets is widely observed. Engle and Granger (1987) develop the idea of cointegration and vector error correction in time series. Hasbrouck's (1995) information share model is derived from the vector error correction model (VECM), which assumes that prices in different markets are cointegrated. A VECM of $n$ cointegrated

time series has the form:

$$\Delta Y_t = \alpha\beta' Y_{t-1} + \sum_{i=1}^{k} A_i \Delta Y_{t-i} + \varepsilon_t \qquad (1)$$

where $Y_t$ is an $n \times 1$ column vector consisting of n price series, $\alpha$ is the error correction vector, $\beta$ is the cointegrating vector, $A_i$ are the $n \times n$ matrices of the lead-lag parameters and $\varepsilon_t$ is a vector of serially uncorrelated residuals with covariance matrix $\Omega = \{\sigma_{ij}\}$. Assuming that the price changes are covariance-stationary, Hasbrouck (1995) describes the VECM in an integrated form of vector moving average form:

$$Y_t = \psi(1)\sum_{s=1}^{t} \varepsilon_t + \psi^*(L)\varepsilon_t \qquad (2)$$

where $\varepsilon_t$ is a zero-mean vector of serially uncorrelated disturbances with covariance matrix $\Omega$, and $\psi$ is a polynomial in the lag operator. The prices are cointegrated of order *n*-1. That means the *n*-1 variables defined by $\beta' Y_t$ are stationary. If $\beta' Y_t$ is stationary, then $\beta'\psi(1)$ will be equal to zero, where $\psi(1)$ denotes the sum of the moving average coefficients. $\psi(1)\varepsilon_t$ is the long-run impact of an innovation on each of the prices. If the series are cointegrated then every row of $\psi(1)$ should be the same. If $\psi$ denotes the common row vector in $\psi(1)$, equation (2) becomes:

$$Y_t = \varsigma\psi\left(\sum_{s=1}^{t} \varepsilon_t\right) + \psi^*(L)\varepsilon_t \qquad (3)$$

where $\varsigma$ is a column vector of ones. The first term in equation (3) is the common factor component, and the second term is the transitory component, which does not have a permanent effect on prices. The increment $\psi\varepsilon_t$ is the component of the price changes that has a permanent impact caused by new information. The variance of this term is $\psi\Omega\psi'$.

Hasbrouck (1995) defines the information share of market *j* relative to the whole market to be the proportion

$$S_j = \frac{\psi_j \Omega_{jj}}{\psi\Omega\psi'} \qquad (4)$$

where $\psi_j$ is the $j^{\text{th}}$ element of $\psi$, if the cross-equation residuals are uncorrelated. This is

the proportion of variation contributed by market $j$ to the variance of the implicit common factor. To eliminate the effect of correlation among the residuals, Hasbrouck uses a Cholesky factorization of $\Omega = CC'$, where $C$ is a lower triangular matrix. In this way, the information share of market $j$ is computed as:

$$S_j = \frac{([\psi C]_i)^2}{\psi \Omega \psi'} \qquad (5)$$

where $[\psi C]_i$ is the $i^{\text{th}}$ element of the row of matrix $\psi C$. If a particular market is ordered first in the computation, equation (5) gives the upper bound of the information share of that market. By the same token, the lower bound of the information share will be given if that market is ordered last.

## B. Factors affecting price discovery

If two synchronous markets impound information efficiently at the same speed, the price innovations in these markets should contribute equally to the price discovery process, and their information shares should be the same. Index futures and the underlying cash index are driven by the same information and should move in the same direction. Yet, index arbitrage involves substantial trading and financing cost to establish and maintain futures and stock positions (Kawaller, 1987; Kumar and Seppi, 1994). Therefore, arbitrage may occur only when the deviation between the futures and its fair value (as implied by the cash index) is great enough to offset the cost of arbitrage.[1] The dynamic relation between the futures and the cash market is widely known to be affected by a number of factors, that also determine the information share of the two markets. The factors we investigate include relative trading intensity, volatility of the two markets and short sale restrictions against the index stocks.

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[1] Since arbitrageurs may also speculate against a future change in the arbitrage basis, arbitrage portfolios can be established at any level of the arbitrage basis. See MacKinlay and Ramaswamy (1988) and Brennan and Schwartz (1990). The intensity of arbitrage should still be positively related to the magnitude of the arbitrage basis; see Dwyer, Locke, and Yu (1996).

### B.1 Level of index stock short selling

The level of short selling of index stocks may reduce the information share of the cash index in falling market conditions. There are constraints against short selling of stocks but none against the shorting of futures. Short sales restrictions keep futures prices from returning to the equilibrium price when the futures is underpriced. At the same time, the overpricing of futures should be lessened as well because early-unwinding strategies will occur more often when the futures is overpriced. Fung and Draper (1999) show that both the frequency and the level of futures underpricing are reduced following the lifting of restrictions against short-selling. Mispricings also become less persistent, indicating increased arbitrage efficiency. Fung and Li (1999) show that the lifting of short sales restrictions enhances the error correction process, especially in a down-market. Li, Fung, and Cheng (2001) show that the lifting of restrictions against short-selling reduces the lead of the futures over the cash index, especially when futures are underpriced. Draper and Fung (2003) find that the large negative basis in Hang Seng Index futures coexists with an unusually low level of short-selling in the index constituent stocks after the direct market intervention of the Hong Kong government.

Kempf's (1998) study of the German DAX contracts reveals similar results. Then Chan (1992) and Neal (1996) argue that short-selling may not matter because institutional investors can perform quasi-arbitrage within their cash stock portfolios when futures are underpriced. Hence, whether short-selling or the market environment that induces short-selling affects the information share of futures is an empirical issue. When the market is going down, as indicated by the level of index short sale activities, more traders have to reveal negative information in the market. As the futures contract is a more convenient trading alternative, with lower transaction cost, more information should be revealed in the futures market.

We set up our first hypothesis to test this issue:

Hypothesis 1 (H1): The information share of the futures contract increases in down-markets.

### B.2 Relative liquidity and transaction costs of the markets

Markets with more trading intensity should capture a higher information share and lead the other markets because more information is being transmitted. Schwarz and Laatsch (1991) show a positive relation between the lead from the futures market to the cash market and the trading volume of futures. Chan and Chung (1993) focus on mispricings of the MMI futures contracts, and find that an increase in cash trading volume leads to a reduced arbitrage spread.

The second hypothesis is thus:

Hypothesis 2 (H2): Traders prefer to trade in liquid markets. The information share of futures increases with futures volume.

The trading cost hypothesis is first proposed by Fleming, Ostdiek, and Whaley (1996). It states that informed traders will try to look for the greatest profit maximization opportunities and therefore concentrate their trading in the market with the lowest transaction cost. Ample evidence supporting the trading costs hypothesis is found in a number of studies (e.g., Frino and West, 2003, and Eun and Sabherwal, 2003).

Chakravarty, Gulen, and Mayhew (2004), Ates and Wang (2005) report the information share of a market is jointly determined by relative liquidity and transaction costs. Chakravarty et al. compute the information shares of 60 stocks and their corresponding stock options and examine the variation of information share under different market conditions. They find that the information share of an option is directly proportional to the options trading volume but inversely related to its effective bid-ask spread. Ates and Wang (2005) examine the price discovery roles of regular and E-mini index futures, and report a significant and positive

relation between information share and trading volume of the E-mini index futures.

### B.3 Market Volatility

A few studies have examined how relative price volatility affects the dynamic relation between spot and futures markets. Kawaller, Koch, and Koch (1993) show that when S&P 500 futures became more volatile, both the contemporaneous and the subsequent feedback relation between futures and index is strengthened. Chan and Chung (1993) also report that increased cash and futures volatility will subsequently lead to less mispricing in the futures contracts. These observations suggest the hypothesis that when both cash and futures markets become similarly volatile, there should be a more even distribution of information share for the two markets.

Hypothesis 3 (H3): The information share of the futures contract increases with relative volatility increases between the futures and the cash market.

On the other hand, volatility in a particular market can tell us how vigorous the trading activity in that market is. The information share of futures should also increase with the volatility level in the futures market and decline with the volatility in the cash index market.

Hypothesis 4 (H4): The information share of the futures contract declines with cash index volatility.

Apart from the exogenous factors that may influence information shares in the two markets, the sampling frequency of the data and the effects of non-synchronous trading of index stocks will also have an impact. If the reported index is computed on the basis of the last transaction price of each stock (as the Hang Seng Index is) and if some stocks have not

been traded very frequently, the reported index value cannot reflect the true value of the underlying stocks.

The issue of non-synchronous trading of reported index has been addressed in a number of studies. Miller, Muthuswamy, and Whaley (1994) investigate the S&P 500 index basis changes and find that the mean reversion behavior of the basis changes can be partly explained by the non-synchronous trading of index stocks. Harris (1989) and Kleidon (1992) report similar results. After eliminating the effects of non-synchronous trading and stale prices, the futures market is still found to lead the cash market.

Furbush (1989) examines the relation between the frequency of index arbitrage activities and changes in basis errors during the October 1987 market crash. His results indicate a large and persistent basis on October 19, 1987, and index arbitrage transactions were not enough to align futures and cash prices.

## III. Data and Methodology

### A. Data

We obtain time-stamped bid and ask quotes and the number of outstanding shares of HSI constituent stocks from Hang Seng Index Services Limited. Tick-by-tick transaction records of the spot and next-month Hang Seng Index futures come from the Hong Kong Exchange (HKEx).

Hang Seng Index futures expire the day before the last business day of each contract month. This study focuses on the price discovery of the most liquid futures contracts versus the cash index. To ensure liquidity, we replace the spot month contract by the next-month contract on the expiration day each month.

The sample runs from June 3, 1996 through February 26, 1999. We divide the sample according to different market scenarios. The crisis period is defined as from May 14, 1997

through August 13, 1998, and the period prior to that is the pre-crisis period. August 14 - 27, 1998 is the preliminary government intervention period. Direct intervention by the Hong Kong government occurred between August 14 and 28, 1998. On August 28, 1998, the government put a price floor under the prices of index stocks at an index level of 7850. As the up-tick rule was reinstituted on September 7, 1998, we subdivide the post-intervention period into August 31, 1998 through September 6, 1998 (post-intervention period before imposition of the up-tick rule) and September 7, 1998 through the end of the sample period, i.e., February 26, 1999 (post-intervention period after imposition of the up-tick rule). Eleven days in the sample period that provide only half-day data are discarded.

Table 1 shows the sample periods and their length. Period 1 is called the pre-crisis period, Period 2 is the crisis period and Period 3 is the preliminary intervention period. Period 4 is the post-intervention period, and finally Period 5 is the period after imposition of the up-tick rule.

The Hang Seng Index, like other stock indexes, is computed on the latest traded prices of the component stocks. To eliminate the non-synchronicity problem caused by infrequent trading and stale prices, a bid-ask index is constructed using the concurrent bid and ask quotes of the component stocks in the index. Following Fung and Draper (2003), we calculate the bid and ask index only when all the bid and ask quotes for all 33 constituent stocks are available in the period.

## B. Computation of Information share

We estimate information share using two systems of time series. The first system includes the reported Hang Seng Index at the spot month HSI futures transaction prices. In the second system, we replace the reported index by the constructed bid-ask index. Daily estimates of the upper and lower bounds of information share are obtained for the whole sample period. Baillie et al. (2002) show that the mean of the bounds of information share is an unbiased

estimate of the information shares of markets, so we also compute daily averages of the bounds for purposes of interpretation.

## C. Computation of market variables

We compute daily volatility figures for the three series, the index short sale level and a futures-to-stock volume ratio. For the realized volatilities of the three series, we use the formula (Poteshman, 2000):

$$RV_t = \sqrt{\frac{1}{\Delta}\left[\frac{1}{M}\sum_{i=1}^{M}(\mu_{t+i\Delta})^2\right]} \qquad (6)$$

where $\Delta=(T-t)/M$ is the trading time interval (in fraction of a year) for calculating the corresponding price changes (futures, mid-quote and reported index) $\mu_{t+i\Delta} \equiv \ln\left(F_{t+i\Delta}/F_{t+(i-1)\Delta}\right)$, $T-t$ is the futures trading period and $M$ is the number of intraday futures returns within the period.

The ratio of index short selling turnover to total index turnover (excluding index short sale turnover) is calculated to see whether there is any change in short selling activity following reimposition of the up-tick rule.

Finally, the futures-to-stock volume ratio is computed as follows.

$$\frac{Number\ of\ spot\ month\ \ contracts\ \ traded\ (replaced\ by\ next\ month\ contracts\ on\ \exp iration\ day)}{index\ \ turnover\left(in\ index\ baskets\right)} \qquad (7)$$

where index turnover (in index baskets) equals $\frac{index\ turnover\ on\ day\ t}{50s^*}$, and s* is the average of the highest and lowest mid-quote index levels.

## D. Regression analysis

To examine the factors affecting information shares, we run regressions for each period and for the overall period:

$$IS_{fut} = \beta_0 + \beta_1 \ln(\frac{\sigma_{fut}}{\sigma_{mq}}) + \beta_2 \ln(SR) + \beta_3 \ln(VR) + \varepsilon_t \quad (8)$$

where $IS_{fut}$ stands for the mid-point of the upper and lower bounds of the information share for futures computed using minute-by-minute data, $\ln\left(\frac{\sigma_{fut}}{\sigma_{mq}}\right)$ is the logarithm of the ratio of futures volatility to midquote volatility, $\ln(SR)$ is the logarithmic ratio of index short sale turnover to index turnover (excluding short sale turnover), and $\ln(VR)$ is the logarithmic futures-to-stock volume ratio.

Greater index short sale turnover implies that the market tends to be bearish, and more traders will likely choose to reveal their negative information via the futures market. Hence, the coefficient of $\ln(ST)$ is expected to be positive. The coefficient for $\ln(VR)$ should also be positive, because the more trading intensity in futures, the more information should be reflected in the futures market. Finally, the coefficient for $\ln(\frac{\sigma_{fut}}{\sigma_{mq}})$ is also expected to be positive.

To further examine the individual impact of the market variables on the information share of futures, we use a regression that includes index short sale turnover, index turnover, futures volatility and mid-quote volatility as independent variables.

$$IS_{fut} = \beta_0 + \beta_1 \ln(IST) + \beta_2 \ln(IT) + \beta_3 \ln(\sigma_{mq}) + \varepsilon_t \quad (9)$$

where $\ln(IST)$ is the logarithm of index short sale turnover, $\ln(IT)$ is the logarithm of index turnover (excluding short sale turnover) and $\ln(\sigma_{mq})$ is the logarithm of mid-quote volatility.

## IV. Empirical Results and Interpretation

### A. Descriptive Statistics of market variables

Table 2 shows summary statistics for daily index turnover and trading volume in the spot month futures contracts. Daily averages of spot month contracts traded increase from 15,641 contracts per day in the pre-crisis to 35,467 contracts per day before August 28, 1998 when the government intervention took place. After government intervention, trading activity in the spot month contracts declined slightly, back to the level before the financial crisis.

Summary statistics for the futures-to-stock volume ratio are shown in Table 3. The volume ratio is computed using the most actively traded contract, replaced by the next-month contracts on the expiration day of each month. The ratio indicates gradual decline in the trading volume of futures before the intervention period and another decline after the intervention period. On August 28, 1998, Hong Kong government bought in a great number of index stocks in order to maintain the HSI at 7800, as indicated by the futures-to-stock volume ratio of 0.602 (before rollover to the next-month contracts on the expiration day). A similar pattern in index turnover is seen in panel A of Table 2.

Table 4a shows short sale activities in index stocks (in millions of shares). Both index turnover (in panel A of Table 2) and short selling turnover in the post-crisis period drop back to the level of the pre-crisis period. Table 4b expresses the short selling of index stocks as a percentage of total index turnover (excluding index short sale turnover).

A constant increase in the ratio of short selling of index stocks to total index turnover is seen during the initial periods before the government intervention, and then the ratio drops slightly in the week following August 28, 1998. In Period 5, the period after imposition of up-tick rule on the short selling of index stocks, the average daily short selling turnover of index stocks shows a slight increase to 224.6 million a day (Table 4a). This unexpected increase in short selling turnover, despite the tightening of short sale restrictions, we attribute to regained short seller confidence in the market after the financial crisis.

Table 5 presents summary statistics for the daily realized volatility of index futures, the cash index and the mid-quote index based on one-minute returns. As we focus on intraday price discovery of the cash index and the futures market, we do not show overnight and over-lunch returns. Futures are more volatile than the reported index and the mid-quote index. The reported index is in turn more volatile than the mid-quote index because of noise in the reported index caused by non-synchronous trading of index stocks. All three series exhibit similar patterns across periods, with gradual increases in volatility before the government intervention. Exceptionally high volatilities are observed in Period 3, followed by a slight decline in Periods 4 and 5.

## B. Factors affecting information share of futures in different periods

We first obtain daily figures for the upper bounds, lower bounds, and an average of the two bounds of the information shares of the two markets for the whole sample. Means of each measure in each period are reported in Tables 6a and 6b. The tables also show the correlation of the VECM residuals for the two sampling frequencies.

The one-minute results show that over 70% of price discovery in the Hang Seng Index market occurs in the futures market before the financial crisis. In Period 3, the government intervention period, the information share of the futures dropped to 50%. On August 28, 1998, 90% of price discovery took place in the futures market. After the government intervention, the information shares for futures and cash index markets revert to levels similar to those of the pre-crisis period.

The one minute results for information share in our sample periods show that around 60% to 70% of price discovery happens in the futures market. Despite the difference in sample periods, this result is consistent with evidence in So and Tse (2004) who also use one minute for the sampling frequency.

Certain market variables can provide some clues to explain the trend in the information

share of the futures market across periods. As we compare Tables 3 and 6a, we notice a simultaneous decline in both the futures-to-stock volume ratio and the information share of futures from Period 1 to Period 2. In Period 3, the futures-to-stock volume ratio dropped to its lowest level of the five sample periods, 2.171. This caused the information share of futures to plunge to around 50%. In periods after the financial crisis, both the futures-to-stock volume ratio and the information share of futures returned to a level like that in the pre-crisis period. A comparison of the two tables suggests a highly correlated relation between the volume ratio and the information share of futures. The two measures appear to move together in the same direction.

Index short sale activities have an effect on the price discovery process in the two markets. In Table 4b, the ratio of index stock short selling turnover-to-total index turnover increased from Period 1 until August 18, 1998 and then dropped sharply in Period 4, followed by an increase in the last period. The relation between the information share of futures and index short sale activities does not appear to be clear-cut, however.

Finally, we examine the effects of volatility in the futures and the cash markets. In Table 5, we see that both futures and cash index markets became more volatile in the crisis period but less volatile during the pre- and post-crisis periods. Information shares of the futures are lower in the crisis period and higher in the other periods. Hence, judging from Tables 5 and 6a, the information share of futures is negatively related to the volatility in the two markets.

### C. Effects of changes in sampling frequency

A closer look at Panel A of Tables 6a and 6b tells us something about the impact of sampling frequency on information share. Information shares are more similar in the five-minute results, but the information share of the futures market drops from about 70% in one-minute results (Panel A) to about 50% in five-minute results in (Panel B). As we have shown before, futures trade is about three times more than the index stocks over the whole

sample period.

Our results are consistent with the explanation in Tse et al. (2006) that the less frequent the sampling, the more observations are discarded from the more active market (the futures market), thus imposing a downward bias to the information share of futures. The five-minute results across periods are consistent with the one-minute results, with the information share of futures in the last period returning to its level in the pre-crisis period. The five-minute results reveal that slightly more than 50% of price discovery took place in the futures market and that the reported index has a greater information share than the mid-quote.

### D. Effects of non-synchronous trading in index stocks

Both the one-minute and five-minute results show that the mid-quote information share is lower than the reported index share. This is due to the non-synchronous trading of index stocks, which induces noise in the reported index and thus biases the return variance upward, as indicated by the more volatile reported index. Because the Hasbrouck information share model is defined as the contribution to the variance of the innovations of the common factor, the more volatile market should capture a higher proportion of the information share.

We do find that the differences between the mid-quote and reported index are more significant at higher sampling frequencies (e.g., one minute) (results available on request) when the sampling interval is increased from one minute to five minutes, more stocks are traded, lessening the effect of non-synchronous trading of index stocks. There is thus a less significant difference between the information shares of the mid-quote and the reported index results in the case of five-minute sampling.

The significant difference between the information shares of mid-quote and reported index indicate that the noise embedded in the reported index imposes a significant upward bias on the information share. In this case, we can claim that the mid-quote index should be better at reflecting the actual price discovery proportion of the cash index market.

## E. Regression Analysis

We can use regression analysis to assess the impact of various market variables on the information share of the futures market. Table 7a shows the result of Regression 1, Equation (8). The dependent variable is the mid-point of the upper and lower bounds of information share of futures. As the sample sizes for Periods 3 and 4 are too small for meaningful statistical inference, our regressions are for Periods 1, 2, and 5. The coefficients for index short sale turnover ratio are positive in all periods except Period 1. The increased level of index short sale activities implies that the market is becoming more bearish. Our results support Hypothesis 1 in that futures have a higher information share in down-markets, as indicated by the increased level of index short sale activity. The pre-crisis period, Period 1, is relatively calm, so the level of index short sale activities is not enough to have an impact on the information share of futures. Thus, the variation in the information share of futures is not significantly explained by the variation in the index short sale level, causing the sign of the coefficient in Period 1 to be inconsistent with the other periods.

The coefficients of the ratio of index short selling tend to increase from the pre-crisis period to the post-crisis period, showing that, for each one percent increase in the index short sale level, the information share of futures reacts more vigorously to the increase. The coefficients for the futures-to-stock volume ratio are again positive in all three periods, showing that more information is reflected via futures when futures trading volume relative to stocks increases. This proves Hypothesis 2.

The coefficients for the volatility ratio are significantly negative in all three periods, showing that the relative volatility in the two markets is a critical factor in the price discovery process in the two markets. The information share of futures declines with the increase in relative volatility, which is contrary to Hypothesis 3. The coefficients of the volatility ratio and the index short sale ratio increase across periods, while the futures-to-stock volume ratio

drops in Period 5. This means relative volatility and the index short sale level become increasingly important in determining the information share of futures in the post-crisis period.

To further investigate the impact of the index short sale level, index volume, and the volatilities of the cash index market, we run another regression using the logarithms of the three variables above as independent variables. Table 7b reports the results of this regression. The coefficients of the index short sale turnover are all positive, consistent with the results in Table 7a. When the market becomes more bearish, more traders choose to express their negative information via futures. Signs of the coefficients of index trading volume are negative in all periods, indicating that the information shares of futures are negatively related to the trading volume in the cash market.

Finally, the coefficients of mid-quote volatility are significantly negative in all three periods. This is consistent with the idea that when the cash index market is highly volatile, more information is reflected in the cash index market. And hence less information is processed in the futures market.

## V. Conclusions

We examine the minute-by-minute price discovery process between the Hang Seng Index futures contract and the underlying cash index during the period of the 1998 Asian Financial Crisis. Two systems of bivariate time series are used: (1) the intraday transaction prices of futures together with the reported values of the Hang Seng Index, and (2) the mid-quote index. Summary statistics for futures trading volume, level of index short sale activities and relative volatility are computed in different periods.

The results show that both the index short sale activities and volatility in the two markets reach in the highest levels in the most volatile period. The futures-to-stock volume ratio

plunges to its lowest level at the same time. The Hasbrouck (1995) information share model indicates that futures play a dominant role in the price discovery process of the HSI market. The information share of futures accounts for about 70% to 80% of price discovery in the HSI market in the pre-crisis period, drops gradually during the most volatile period to be followed by a rise in the post-crisis period. We also find that non-synchronous trading in index stocks has a more significant effect at higher sampling frequencies and that the reconstructed bid-ask index is a better tool than the reported index for assessing the amount of information reflected in the cash index market.

We also show that the index short sale turnover, the futures-to-stock volume ratio, and the relative volatilities of the cash and futures markets are three major determinants of the information shares of futures. The futures market tends to be more informative when there is a higher futures-to-stock volume ratio and a higher level of index short sale activities. The information share of futures is negatively related to the relative volatility in the two markets and the volatility of the cash index market, however. The signs of the coefficients are largely consistent across the three periods in this study, although the coefficients in the crisis period are more significant than in the other relatively calm periods. The results also show that the information share of futures reacts more strongly to changes in market variables in the crisis and post-crisis periods than in the pre-crisis period.

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**Table 1: Sample periods**

| Period | | Date | Number of days |
|---|---|---|---|
| Period 1 | Pre-crisis period | June 3, 1996 - May 13, 1997 | 227 |
| Period 2 | Crisis period | May 14, 1997 - August 13, 1998 | 299 |
| Period 3 | Preliminary intervention period | August 14, 1998 - August 27, 1998 | 9 |
| Aug 28, 1998 | All-out intervention | August 28, 1998 | 1 |
| Period 4 | Post-intervention period | August 31, 1998 – September 6, 1998 | 5 |
| Period 5 | Period after imposition of up-tick rule | September 7, 1998 – February 26, 1999 | 109 |

Notes: Eleven days that consist of only half-day data are deleted in our sample.

**Table 2: Summary statistics on daily index turnover and trading volume of spot month futures contracts**

| Panel A: Summary statistics of index stocks turnover (in millions) in different periods. | | | | | | |
|---|---|---|---|---|---|---|
| Period | N | Mean | Std | Maximum | Median | Minimum |
| Period 1 | 227 | 2821 | 1129 | 6863 | 2708 | 1030 |
| Period 2 | 299 | 4705 | 2411 | 19071 | 4109 | 1398 |
| Period 3 | 9 | 7700 | 5177 | 20542 | 6398 | 3408 |
| Aug 18, 1998 | 1 | 72971 | / | / | / | / |
| Period 4 | 5 | 4623 | 378 | 5161 | 4603 | 4096 |
| Period 5 | 109 | 3162 | 1538 | 9758 | 2933 | 500 |
| Panel B: Summary statistics of trading volume of spot month futures contracts | | | | | | |
| Period | N | Mean | Std Deviation | Maximum | Median | Minimum |
| Period 1 | 227 | 15641 | 4379 | 35501 | 15113 | 2654 |
| Period 2 | 299 | 24845 | 7579 | 69719 | 23478 | 4775 |
| Period 3 | 9 | 35467 | 7500 | 43364 | 38038 | 23414 |
| Aug 18, 1998 | 1 | 36907 | / | / | / | / |
| Period 4 | 5 | 29342 | 5110 | 37793 | 28478 | 23964 |
| Period 5 | 109 | 20814 | 5827 | 36729 | 19910 | 3263 |

Notes: Summary statistics in Panel A are obtained after excluding index short sale turnover.

Summary statistics in Panel B are obtained after rolling over to the next month contracts on expiration day. Since August 28, 1998 is the expiration day of the month August 1998, we replace the spot month contracts by the next month contracts on that day. The trading volume of spot month futures contracts on August 28, 1998 is 7444.

**Table 3: Summary statistics on daily futures-to-stock volume ratio (with rollover to the next month contracts on expiration day)**

| Summary statistics of futures-to-stock volume ratio | | | | | | |
|---|---|---|---|---|---|---|
| Period | N | Mean | Std | Max | Min | Median |
| Period 1 | 227 | 3.664 | 0.967 | 6.212 | 0.463 | 3.637 |
| Period 2 | 299 | 3.328 | 1.090 | 6.992 | 0.439 | 3.206 |
| Period 3 | 9 | 2.171 | 0.806 | 3.115 | 0.549 | 1.976 |
| Aug 28, 1998 | 1 | 2.986 | / | / | / | / |
| Period 4 | 5 | 2.324 | 0.354 | 2.935 | 2.024 | 2.232 |
| Period 5 | 109 | 3.535 | 1.298 | 8.818 | 1.430 | 3.286 |

Notes: Futures-to-stock volume ratios are computed using the formula:

$$\frac{Number\ of\ spot\ month\ \ contracts\ \ traded\ (replaced\ by\ next\ month\ contracts\ on\ \exp iration\ day)}{index\ \ turnover\ (in\ index\ baskets)}$$

where index turnover (in index baskets) equals $\frac{index\ turnover\ on\ day\ t}{50s^*}$, s* is the average of the highest and lowest mid-quote index levels.

Since August 28, 1998 is the expiration day of the month August 1998, we replace the spot month contracts by the next month contracts on that day. The futures-to-stock volume ratio computed using the number of spot month contracts traded on August 28, 1998 is 0.6022.

**Table 4a: Summary statistics on daily index short selling turnover**

| Summary statistics of index stocks short selling turnover (in millions) of different periods. | | | | | | |
|---|---|---|---|---|---|---|
| Period | N | Mean | Std | Max | Median | Min |
| Period 1 | 227 | 94 | 133.1 | 963 | 52 | 0.12 |
| Period 2 | 299 | 225 | 203.1 | 1257 | 147 | 12.57 |
| Period 3 | 9 | 554 | 663.1 | 2138 | 257 | 67.32 |
| Aug 28, 1998 | 1 | 9059 | / | / | / | / |
| Period 4 | 5 | 190 | 183.7 | 454 | 110 | 34.89 |
| Period 5 | 109 | 224 | 126.5 | 588 | 201 | 17.44 |

Notes: All figures are rounded off to 4 decimal places and figures are expressed in terms of number of millions.

Index stocks short selling turnover in index baskets at day t is computed as follows: $\frac{Index\ turnover\ at\ day\ t}{s^* x\ 50}$, where $s^*$ is the average of the highest and lowest mid-quote index level.

**Table 4b: Summary statistics of daily ratio of index stocks short selling turnover to total index turnover of different periods**

| Period | N | Mean | Std | Max | Median | Min |
|---|---|---|---|---|---|---|
| Period 1 | 227 | 0.0343 | 0.0510 | 0.4838 | 0.0194 | 0.0001 |
| Period 2 | 299 | 0.0627 | 0.0674 | 0.4876 | 0.0393 | 0.0024 |
| Period 3 | 9 | 0.0624 | 0.0422 | 0.1290 | 0.0408 | 0.0202 |
| Aug 28, 1998 | 1 | 0.1417 | / | / | / | / |
| Period 4 | 5 | 0.0431 | 0.0432 | 0.1096 | 0.0242 | 0.0077 |
| Period 5 | 109 | 0.0861 | 0.0530 | 0.2793 | 0.0697 | 0.0090 |

Notes: All figures are rounded to 4 decimal places.

The ratio is computed using the formula: $\frac{Index\ short\ sale\ turnover}{Total\ index\ turnover(excluding\ short\ sale\ turnover)}$

**Table 5: Summary statistics of daily realized volatility of HSI based on 1-minute intervals**

| Panel A: Summary Statistics of Futures daily realized volatility | | | | | | |
|---|---|---|---|---|---|---|
| Period | N | Mean | Std | Max | Min | Median |
| Period 1 | 227 | 0.0966 | 0.0327 | 0.2386 | 0.0428 | 0.0888 |
| Period 2 | 299 | 0.2625 | 0.1338 | 1.1130 | 0.0714 | 0.2343 |
| Period 3 | 9 | 0.3253 | 0.0937 | 0.4768 | 0.2126 | 0.3007 |
| 2808/1998 | 1 | 0.6143 | / | / | / | / |
| Period 4 | 5 | 0.4055 | 0.0448 | 0.4811 | 0.3685 | 0.4000 |
| Period 5 | 109 | 0.2378 | 0.0598 | 0.4510 | 0.1130 | 0.2277 |
| Panel B: Summary Statistics of Mid-quote daily realized volatility | | | | | | |
| Period 1 | 227 | 0.0714 | 0.0201 | 0.1593 | 0.0365 | 0.0662 |
| Period 2 | 299 | 0.1708 | 0.0730 | 0.7057 | 0.0676 | 0.1604 |
| Period 3 | 9 | 0.2051 | 0.0922 | 0.3376 | 0.0578 | 0.1996 |
| Aug 28, 1998 | 1 | 0.0237 | / | / | / | / |
| Period 4 | 5 | 0.2516 | 0.0316 | 0.2794 | 0.2124 | 0.2710 |
| Period 5 | 109 | 0.1547 | 0.0389 | 0.2703 | 0.0794 | 0.1492 |
| Panel C: Summary Statistics of HSI index daily volatility | | | | | | |
| Period 1 | 227 | 0.0881 | 0.0214 | 0.1867 | 0.0542 | 0.0839 |
| Period 2 | 299 | 0.1840 | 0.0683 | 0.7100 | 0.0962 | 0.1718 |
| Period 3 | 9 | 0.2277 | 0.0706 | 0.3306 | 0.1137 | 0.2180 |
| Aug 28, 1998 | 1 | 0.1058 | / | / | / | / |
| Period 4 | 5 | 0.2466 | 0.0337 | 0.2764 | 0.2070 | 0.2680 |
| Period 5 | 109 | 0.1630 | 0.0398 | 0.2610 | 0.0855 | 0.1575 |

Notes: Daily realized volatility of HSI futures based on one-minute intervals is computed as follows:

$RV = \sqrt{\frac{1}{\Delta}\left[\frac{1}{M}\sum_{i=1}^{M}\left(\mu_{t+i\Delta}\right)^2\right]}$ where T-t is the futures trading period in fractions of year (250 is used as an approximation of the number of trading days in a year), $\Delta = \frac{T-t}{M}$, M is the number of intraday returns, $\mu_{t+i\Delta} = \ln\left(F_{t+i\Delta} / F_{t+(i-1)\Delta}\right)$ is the logarithmic futures return at time t.

**Table 6a: Information share and correlation of VECM residuals of futures versus mid-quote and futures versus reported index for one minute interval**

| | Futures | | | Mid-quote | | | Correlation of residuals |
|---|---|---|---|---|---|---|---|
| | Min | Max | Mean | Min | Max | Mean | |
| Period 1 | 0.7354 | 0.8580 | 0.7967 | 0.1426 | 0.2645 | 0.2037 | 0.1837 |
| Period 2 | 0.5707 | 0.8601 | 0.7154 | 0.1399 | 0.4272 | 0.2835 | 0.3821 |
| Period 3 | 0.3709 | 0.6939 | 0.5324 | 0.3061 | 0.6291 | 0.4676 | 0.3808 |
| Aug 28, 1998 | 0.8545 | 0.9410 | 0.8978 | 0.059 | 0.1455 | 0.1023 | 0.1455 |
| Period 4 | 0.4990 | 0.7738 | 0.6364 | 0.2262 | 0.5010 | 0.3636 | 0.3020 |
| Period 5 | 0.5933 | 0.8628 | 0.7280 | 0.1372 | 0.4067 | 0.2719 | 0.3571 |
| | Futures | | | Reported Index | | | Correlation of residuals |
| | Min | Max | Mean | Min | Max | Mean | |
| Period 1 | 0.7094 | 0.8180 | 0.7637 | 0.1816 | 0.2921 | 0.2369 | 0.1441 |
| Period 2 | 0.4926 | 0.8051 | 0.6489 | 0.1951 | 0.5062 | 0.3507 | 0.3846 |
| Period 3 | 0.2623 | 0.6086 | 0.4355 | 0.3914 | 0.7343 | 0.5628 | 0.4159 |
| Aug 28, 1998 | 0.9321 | 0.9684 | 0.9503 | 0.0316 | 0.0679 | 0.0498 | -0.0849 |
| Period 4 | 0.2946 | 0.6268 | 0.4607 | 0.3732 | 0.7054 | 0.5393 | 0.3576 |
| Period 5 | 0.4881 | 0.7996 | 0.6438 | 0.2004 | 0.5119 | 0.3562 | 0.3663 |

Notes: All figures are rounded to 4 decimal places.

The figures reported in the above table are obtained by taking averages of the daily estimates across each period.

**Table 6b: Information share and correlation of VECM residuals of futures versus mid-quote and futures versus reported index for five minutes interval**

| | Futures | | | Mid-quote | | | Correlation of residuals |
|---|---|---|---|---|---|---|---|
| | Min | Max | Mean | Min | Max | Mean | |
| Period 1 | 0.3792 | 0.7562 | 0.5677 | 0.2472 | 0.6173 | 0.4323 | 0.5785 |
| Period 2 | 0.2929 | 0.8177 | 0.5553 | 0.1827 | 0.7065 | 0.4446 | 0.7550 |
| Period 3 | 0.2457 | 0.7873 | 0.5165 | 0.2127 | 0.7543 | 0.4835 | 0.6893 |
| Aug 28, 1998 | 0.6382 | 0.9999 | 0.8191 | 0.0001 | 0.3618 | 0.1810 | 0.5944 |
| Period 4 | 0.3341 | 0.8882 | 0.6112 | 0.1118 | 0.6659 | 0.3888 | 0.6822 |
| Period 5 | 0.3360 | 0.7788 | 0.5574 | 0.2208 | 0.6639 | 0.4424 | 0.7559 |
| | Futures | | | Reported index | | | Correlation of residuals |
| | Min | Max | Mean | Min | Max | Mean | |
| Period 1 | 0.4100 | 0.7385 | 0.5742 | 0.2574 | 0.5942 | 0.4258 | 0.5185 |
| Period 2 | 0.3047 | 0.7893 | 0.5470 | 0.2124 | 0.6936 | 0.4530 | 0.7649 |
| Period 3 | 0.2363 | 0.6856 | 0.4609 | 0.3144 | 0.7637 | 0.5391 | 0.7370 |
| Aug 28, 1998 | 0.6782 | 0.9087 | 0.7935 | 0.0913 | 0.3218 | 0.2066 | 0.2920 |
| Period 4 | 0.3363 | 0.8864 | 0.6113 | 0.1136 | 0.6637 | 0.3887 | 0.6976 |
| Period 5 | 0.3129 | 0.7897 | 0.5513 | 0.2103 | 0.6870 | 0.4486 | 0.7411 |

Notes: All figures are rounded to 4 decimal places.

The figures reported in the above table are obtained by taking averages of the daily estimates across each period.

**Table 7a: Regression Analysis of Determinants of futures contribution to Price Discovery**

| Dependent variable: information share of HSI Futures obtained when futures and mid-quote are fitted into the model(1 min) | | | | |
|---|---|---|---|---|
| Independent variables | Period 1 | Period 2 | Period 5 | Overall period |
| N | 227 | 299 | 109 | 635 |
| Intercept | 0.7645*** (<0.0001) | 0.8229*** (<0.0001) | 0.8603*** (<0.0001) | 0.7516*** (<0.0001) |
| $\ln\left(\frac{\sigma_{fut}}{\sigma_{mq}}\right)$ | -0.1103 (0.1010) | -0.1718** (0.0109) | -0.1929** (0.0144) | -0.2008*** (<0.0001) |
| $\ln(SR)$ | -0.0023 (0.8074) | 0.0280*** (0.0075) | 0.0311 (0.2451) | 0.0028 (0.6442) |
| $\ln(VR)$ | 0.0437 (0.2738) | 0.0462 (0.1239) | 0.0272 (0.5459) | 0.0656*** (0.0016) |
| R-square | 0.0138 | 0.0594 | 0.0646 | 0.0528 |
| F value | 1.04 (0.3740) | 6.21*** (0.0004) | 2.42* (0.0706) | 11.73*** (<0.0001) |

Note: The dependent variable is the mid-point between the upper and lower bound of the 1 min information shares of HSI futures against the midquote index. $\ln\left(\frac{\sigma_{fut}}{\sigma_{mq}}\right)$ is the logarithm of the ratio of futures volatility to midquote volatility, $\ln(SR)$ is the logarithmic ratio of index short sale turnover to index turnover (excluding short sale turnover), $\ln(VR)$ is the logarithmic futures-to-stock volume ratio. Futures-to-stock volume ratios are computed using the following formula,

$$\frac{Number\ of\ spot\ month\ \ contracts\ \ traded\ on\ day\ t}{index\ \ turnover\ (in\ index\ baskets)}$$

where index turnover (in index baskets) equals to $\frac{index\ turnover\ on\ day\ t}{50s^*}$, s* is the average of the highest and lowest mid-quote index levels. Spot month contracts are replaced by next month contracts on the expiration day of each month. *, ** and *** denote significance at 10%, 5% and 1% level respectively. All figures are rounded off to four decimal places.

**Table 7b: Regression Analysis of Determinants of futures contribution to Price Discovery**

| Dependent variable: information share of HSI Futures obtained when futures and mid-quote are fitted into the model(1 min) | | | | |
|---|---|---|---|---|
| Independent variables | Period 1 | Period 2 | Period 5 | Overall period |
| N | 227 | 299 | 109 | 635 |
| Intercept | 1.1065** | 1.1811*** | 0.8461 | 0.9520*** |
| | (0.0145) | (<0.0001) | (0.1152) | (<0.0001) |
| $\ln(IST)$ | 0.0049 | 0.0233* | 0.0225 | 0.0414* |
| | (0.6134) | (0.0636) | (0.4502) | (0.0485) |
| $\ln(IT)$ | -0.0587 | -0.0900*** | -0.0287 | -0.0564*** |
| | (0.1563) | (0.0006) | (0.5367) | (0.0010) |
| $\ln(\sigma_{mq})$ | -0.0493 | -0.0892*** | 0.0051 | -0.0856*** |
| | (0.4303) | (0.0082) | (0.9587) | (<0.0001) |
| R-square | 0.0319 | 0.1075 | 0.0081 | 0.0928 |
| F value | 2.45* | 11.85*** | 0.29 | 21.51*** |
| | (0.0643) | (<0.0001) | (0.8345) | (<0.0001) |

Note: The dependent variable is the mid-point between the upper and lower bound of the 1 min information shares of HSI futures against the midquote index. $\ln(IST)$ stands for the logarithm of index short sale turnover, $\ln(IT)$ denotes the logarithm of index turnover(excluding short sale turnover), and $\ln(\sigma_{mq})$ is the logarithm of midquote volatility. *, ** and *** denote significance at 10%, 5% and 1% level respectively. All figures are rounded off to four decimal places.