THE IMPACT OF SAMPLING FREQUENCY ON INTRADAY CORRELATION AND LEAD–LAG RELATIONSHIPS BETWEEN INDEX FUTURES AND INDIVIDUAL STOCKS

JOSEPH K.W. FUNG*, FRANCIS LAU and YIUMAN TSE

Transaction costs, liquidity effects, capital limits, and regulatory restrictions reduce arbitrage efficiency and weaken the link between futures prices and their underlying stocks. This study examines how the sampling frequency for return calculation affects the intraday correlation and the lead–lag relationship between the Hong Kong Hang Seng Index futures, the underlying cash index, an exchange-traded fund (ETF) that mimics the index, and each component stock. The paper uses firm bid and offer quotes to eliminate the negative bias in measuring the correlation between the futures and the less liquid stocks. The sampling frequency significantly affects the futures-stock dynamic relationship, particularly for small-cap stocks. The overall results indicate that market participants trade ETF and the largest index's constituent stocks to capitalize on index arbitrage opportunities. The lag of the cash index is greatest against futures price movement, a reflection of the adverse impact of stale prices on the informational role of stock indexes. © 2015 Wiley Periodicals, Inc. Jrl Fut Mark 35:939–952, 2015

1. INTRODUCTION

The theoretical or no-arbitrage price of an index futures contract is a linear function of the cash index. In a perfect market, the intraday returns of the futures and of the cash index must be perfectly positively correlated because any discrepancies (or pricing errors) will be instantaneously erased if any such arbitrage opportunities occur. By the same reasoning, the futures must also be perfectly correlated with an exchange-traded fund (ETF) that is designed to mimic the index as well as with each individual component stock in the index.

Joseph K.W. Fung is a Professor of Finance at Hong Kong Baptist University, Hong Kong, and a Member of Council of Advisors, Hong Kong Institute for Monetary Research, Hong Kong. Francis Lau is a Ph.D. Candidate in Finance at, Hong Kong Baptist University, Hong Kong. Yiuman Tse is the Peter G. Schick Endowed Professor of Finance, University of Missouri—St. Louis, St. Louis, Missouri. We acknowledge with gratitude help received from the Hong Kong Exchanges and Clearing Ltd. in providing the data. This study is based in part on Lau's Ph.D. dissertation at Hong Kong Baptist University. Part of the research was completed while Tse was visiting the university. We thank George Wang (the discussant), Michael Chng, Alex Frino, Yue-Kuen Kwok, and participants at the Third International Conference on Futures and Derivative Markets, particularly Bob Webb (the editor) and Wing Chan, for constructive comments and suggestions. The views expressed in this study are those of the authors and do not necessarily reflect those of the Hong Kong Institute for Monetary Research, its Council of Advisors, or the Board of Directors.

*Correspondence author, Department of Finance and Decision Sciences, Hong Kong Baptist University, Hong Kong, China. Tel: +1 852 3411 7559, Fax: +852-3411-7559, e-mail: jfung@hkbu.edu.hk

Received January 2015; Accepted January 2015

The Journal of Futures Markets, Vol. 35, No. 10, 939–952 (2015)

Published online 16 March 2015 in Wiley Online Library (wileyonlinelibrary.com).
DOI: 10.1002/fut.21715

In practice, transaction costs and regulatory restrictions disrupt the continuity and efficiency of index arbitrage activities, and thus the futures and index returns are not perfectly positively correlated. Arbitrageurs' risk-bearing capacity is further constrained by their position limits and capital supply. As market and regulatory friction has a greater impact on the price movements of stocks than on futures, the futures prices are generally found to lead the underlying cash index prices. However, competition among arbitrageurs increases the speed of arbitrage and reduces the frequency and magnitude of mispricing in index arbitrage.

All these practical considerations introduce an element of discretion in the conduct of index arbitrage. Discretionary arbitrage trading allows stock-specific and market factors to affect the dynamic relationship between index futures and different underlying cash stocks. In particular, traders may initiate an arbitrage by first trading the highly liquid and heavily weighted stocks to lock in an index-futures spread before establishing the complete index portfolio. Using the heaviest-weighted stocks in the most liquid index subset allows arbitrageurs to hide large trades, to reduce the market impact cost, and to preserve opportunities. However, stock prices of the illiquid segment of the cash index will subsequently align with the new index or index futures level, suggesting that arbitrage is slower in more illiquid markets, as shown by the Oehmke (2009) model.

The above "pecking order" for index arbitrageurs can be detected by the differential speeds at which each index stock reacts to futures price changes. Stocks at the top of arbitrageurs' choice list are expected to have a higher correlation with the futures and less lagging relationship than those at the bottom of the list. Moreover, lengthening of the time intervals for measuring returns should have a greater impact on the dynamic relationship for the illiquid stocks than for the liquid stocks. This paper investigates how the different time intervals influence the relationship between futures and individual index stocks.

Miller, Muthuswamy, and Whaley (1994) show in their seminal paper that the lead–lag relationship between a futures contract and cash index prices can be caused by the way in which stock indices are often computed. Most stock market indices are calculated with the last traded prices of the index's constituent stocks, and the futures lead over the cash index can be explained by the slow and gradual price updating of the less liquid stocks in the index. The phenomenon has been widely described as the effect of nonsynchronous trading or stale prices. Specifically, because the index's constituent stocks are not traded continuously throughout the trading session, the reported index price reflects only lagged market values of the index portfolio.

Bid–ask bounces in the traded prices introduce noise to the measurement of the cash basket value, which reduces the correlation between the index and the futures. This study uses midquotes to remove noise in the return series of individual cash assets due to bid–ask bounces, and the built-in nonsynchronous trading, especially of the index's constituent stocks, is dealt with by increasing the measurement intervals of cash asset returns. However, many studies, for example, Chan (1992) and Tse (1999, 2001), still find evidence that futures returns lead cash index returns even after adjusting for nonsynchronous trading of the index's constituent stocks.

This study is motivated by the widespread practice of index arbitrageurs—that is, instead of trading the full index basket, they use a proxy portfolio, which contains only a subset of the index's constituent stocks to reduce the cost and to improve execution efficiency in conducting index arbitrage. This approach allows them to focus on a small number of highly liquid and heavily weighted stocks in establishing the cash leg of the arbitrage portfolio. The portfolio of a small subset of the heavily weighted stock has little tracking error risk, and the high liquidity of these stocks allows arbitrageurs to hide their trades and, at the same time, to reduce the market impact cost to preserve the arbitrage spread upon execution. Then the prices of less liquid stocks in the index follow and reflect the futures and index movements due to quasi- and ETF arbitrages. Therefore, the study hypothesizes that the futures' correlations with heavily weighted and liquid stocks are higher than those with the lower-weighted and illiquid stocks. Moreover, as the correlation depends on the speed at which trading revises the price of a stock, the impact of the return measurement interval is expected to be higher for less liquid stocks. Overall, the correlations between the futures and the cash assets should be increasing with respect to the length of the return measurement intervals.

By the same token, the leads of futures over heavily weighted (and probably more liquid) stocks should be weaker than those over the lower-weighted (and probably less liquid) component stocks. The weaker lead of futures over heavily weighted stocks may be due to the fact that a heavily weighted stock can lead the futures if there is a revelation of firm-specific (or idiosyncratic) and price-sensitive information from the company with large capitalization (cap). Moreover, traders use the largest index's constituent stocks in establishing the cash leg of an arbitrage trade if the use of a proxy portfolio is warranted. In contrast, the impact of the price movement of small-cap stocks on the index is small due to their low market weights, hence it is less likely that small index stocks will lead the futures. These expectations regarding the correlation and lead–lag relationships between futures and cash prices are further strengthened by the lower cost and greater convenience in shorting the more liquid segment of the index.

The study also examines the dynamic relationship between the Tracker Fund (HKEx, ticker symbol TRK), an ETF designed to track the Hang Seng Index. The high arbitrage efficiency between the ETF and the futures is expected to make their relationship an appropriate benchmark for comparison. This expectation is based on the fact that using ETF should reduce the tracking error risk associated with using a proxy portfolio and also improve execution efficiency compared with trading the full cash index basket. However, whether the correlation is stronger or the lead–lag is weaker between the futures and ETF compared to the index depends on the arbitrage efficiency between the ETF and the cash index basket.

This study contributes to the literature by examining how the length of the time intervals for measuring price movements or returns affects the intraday dynamic relationships between the futures and each constituent stock of the underlying cash index. Moreover, using firm bid and ask quote data, the study sheds light on the extent to which stale prices affect the information value of stock indexes that are calculated with the last traded prices. Last but not least, the comparative results of contemporaneous and lead–lag relationships provide evidence on the trading behaviors of arbitrageurs.

This study uses the lead–lag ratio of Huth and Abergel (2014) to examine the dynamic relationship between futures and cash assets. The paper finds that (1) the lead–lag ratios are all greater than 1, indicating that futures lead all individual cash assets; (2) the lead–lag ratios for small-cap stocks are larger than those for large-cap ones; (3) an increase in the length of measurement intervals increases the correlation between futures and cash assets; and (4) the lag in the cash index is the greatest against the futures price. These findings indicate that arbitrageurs trade ETF and the most liquid component stocks to capitalize on index arbitrage opportunities.

The rest of this study is structured as follows. Section 2 reviews the literature of index arbitrage, and Section 3 describes the data. Section 4 discusses the methodology of realized correlations and lead–lag ratios and lists the research hypotheses tested in this study. Section 5 presents the empirical results, and Section 6 concludes the paper.

2. LITERATURE REVIEW

In a frictionless (i.e., "perfect") market, with zero trading costs and perfect information, continuous actions of pure- and quasi-arbitrageurs eliminate any discrepancies between the actual and theoretical futures (or, conversely, spot) prices and cause perfect correlation between the two returns over any measurement intervals.

In an imperfect market, transaction costs, arbitrage capital constraints, and regulatory restrictions hinder price adjustments of individual cash assets. Relative pricing efficiency of individual cash assets is determined by the likelihood of their being included in proxy portfolios, the trading frequency, market impact costs, the amount of idiosyncratic information available, and short-selling capability. This paper investigates how these market and single-asset characteristics affect intraday dynamics between index futures and individual cash assets. Sampling frequency for return calculation is used as a proxy for the impact of the market and asset characteristics on the realized correlation and lead–lag coefficients. The methodology is based on the theoretical foundation that increasing the length of measurement intervals reduces microstructure noise caused by the market and single-asset characteristics and results in higher realized correlation.

Brennan and Schwartz (1990) show that position limits and transaction costs can force traders to adopt risky arbitrage strategies. For instance, arbitrageurs may engage in risky arbitrage even when the arbitrage spread is insufficient to guarantee a profit with the expectation of a potential reversal in pricing errors. Using Financial Times Stock Exchange (FTSE) 100 index futures contracts traded on the London International Financial Futures Exchange (LIFFE), Yadav and Pope (1990) show that deregulation decreases the frequency of mispricing and increases the tendency for mispricing to be reversed. Early unwinding and rollover of arbitrage positions are valuable options even after transaction costs are accounted for. Klemkosky and Lee (1991) test the efficiency of the Standard & Poor's (S&P) 500 index futures. The authors find that exchange members have more profitable arbitrage opportunities than institutional investors.

Sofianos (1993) analyzes 2,659 index arbitrage trades on the S&P 500 in 1990 and finds that profitable opportunities are few and short-lived, on average for only 3 minutes. Moreover, cash and futures positions for 37% of the trades are not established simultaneously, exposing the arbitrage portfolio to market risk. He also finds that the cash leg contains only 280 stocks on average, and in 8% of trades fewer than 70 stocks are included in the proxy portfolios. The study therefore provides evidence of sequential execution in establishing the proxy portfolio and the popular use of index subsets for the cash leg. Neal (1996) compares actual results of S&P 500 arbitrage trades and predictions from index arbitrage models. He finds that arbitrage trading is not affected by the short-selling constraint.

The Tracker Fund ETF has been designed to perfectly mimic the Hang Seng Index. The ETF is an open-ended fund that is also allowed to be sold short. ETF can be a preferred vehicle for a proxy portfolio, which is an imperfect substitute for the complete index basket. Moreover, using ETF improves execution efficiency since it requires only a single trade to establish the cash leg in conducting index arbitrage. Whether the ETF is a preferred arbitrage vehicle depends on the efficiency of arbitrage between the futures and the ETF.

Arbitrageurs' choice depends on the relative efficiency of arbitrage trading of proxy portfolios or ETF against index futures compared to arbitrage trading of ETF against the underlying cash index. The choice between these two alternative strategies in establishing the cash leg affects the dynamic relationship between futures and the ETF.

Richie, Daigler, and Gleason (2008) emphasize that the SPDR S&P 500 ETF is a favorable cash instrument for executing index arbitrage trades, given its lower trading costs and price continuity compared to the stale prices of the index's constituent stocks. However, its relatively low trading volume creates a limit on index arbitrage trading opportunities. Marshall, Nguyen, and Visaltanachoti (2013) examine the mispricing between two S&P 500 ETFs—SPDR Trust (SPY) and iShare (IVV)—between February 2001 and August 2010. The authors find that the daily return correlation between the two ETFs is 0.99, and price deviations from fair values are corrected within 2 minutes. They also find that more buyers (sellers) initiated arbitrage trades in response to underpricing (overpricing). Deville, Gresse, and Séverac (2014) study the impact of the Lyxor CAC 40 ETF on the pricing and arbitrage efficiency between the index futures and the underlying index. The authors find that the no-arbitrage pricing relation for index futures significantly improved after the introduction of the ETF. They also find that mispricing between index futures and index price decreases in the post-ETF period after controlling for the impact of bid–ask spreads of the index's constituent stocks, turnover of the ETF, index-futures mispricing, and time-of-the day effects.

None of the above papers examine the lead–lag relation between futures and component stocks. Chan (1992) finds that MMI (Major Market Index) futures lead all component stocks using 5-minute returns. However, the MMI consists of only 20 Blue Chip industrial stocks of major U.S. corporations. His results, therefore, cannot show the difference between large and small firms as the current study does.

Andersen, Bollerslev, Diebold, and Labys (1999, 2001) show that conditional mean of asset returns has no impact on the realized measures and argue that realized volatility and correlation are unbiased estimators of the conditional variance and covariance. Most importantly, the realized correlation measure is a model-free measure that is independent of the return-generating process of the asset. Nevertheless, using the Dow Jones Industrial Average (DJIA), they show that the realized volatility and correlation are proportional to the length of the measurement interval. Extending the methodology of Andersen et al. (1999, 2001), this study tests the impacts of sampling frequency on the realized volatility of individual assets and contemporaneous correlation and the lead–lag relationship in the Hang Seng Index markets.

3. DATA

The Hang Seng Index (HS Index) is a market-capitalization weighted index computed from the last transaction prices of the index's constituent stocks. It is representative of the Hong Kong stock market, as it has a 45-year history (it was launched November 24, 1969) and market capitalization of the index's 50 constituent stocks accounted for 60% of the total market capitalization of HKEx's Main Board (MB). As of December 30, 2011, the total market capitalization of the MB was HKD17,453 billion (USD 2,238 billion). Not only market capitalization but also turnover is concentrated on the HS Index constituent stocks. In 2011, turnover of the HS Index's constituent stocks comprised 55% of the MB's HKD17,091 billion (USD 2,191 billion) annual turnover.

As all the HS Index's constituent stocks are allowed to be sold short and have relatively low bid–ask spreads, this increases the tradability of these stocks and reduces market impact costs of arbitraging for these stocks.[1] These are contributing factors to the trading concentration in the HS Index's constituent stocks.

The HS Index futures contract that started trading in 1986 is the most popular and actively traded derivative instrument in Hong Kong, with an annual volume of 23 million contracts in 2011. The Tracker Fund (TraHK) is the first ETF that closely mimics the Hang Seng Index in terms of its composition. The ETF was launched on HKEx November 12, 1999, with an initial public offering (IPO) of HKD33.3 billion (USD 4.3 billion), the largest IPO in ex-Japan Asia at that time.

[1]HKEx only permits investors to short-sell selected cash assets. HKEx updates the list of securities eligible for short-sale regularly and publishes the list at http://www.hkex.com.hk/eng/market/sec_tradinfo/stkcdorder.htm.

HS Index futures, HS Index constituent stocks, and TraHK (hereafter, the ETF) are all traded electronically, and the bid and ask quotes displayed on the limit order book of the trading screen represent a firm commitment by traders and are potentially executable. The study uses time-stamped and continuously updated bid–ask quotes for HS Index futures, all HS Index constituent stocks, and TraHK provided by the HKEx. The use of midquote prices eliminates the problems of nonsynchronous trading and bid–ask price bounces from the traded instruments but not from the cash index. This study also uses the official 15-second HS Index quotes provided by the Hang Seng Index Services (HSIS). The sample period of January 2006–December 2011 covers a wide range of market conditions, from the boom of 2007 through the subprime financial crisis to the post-crisis recovery period.

4. METHODOLOGY AND RESEARCH HYPOTHESES

Intraday returns based on the midquote prices for the futures and individual cash assets (i.e., single stocks and the ETF) are computed at measurement intervals of 15, 30 seconds, 1, 3, 5, 15, and 30 minutes. The 15-second interval matches the reporting time frame of the HS Index values. Overnight and lunch-break returns are discarded. Standard data-filtering procedures are adopted, including the exclusion of erroneous bid and ask quotes, where the offer price is above the bid price. The results derived from different measurement intervals allow an examination of the potential impact of (il)liquidity or nontrading on the intraday correlation and lead–lag relationship between HS Index futures and individual cash assets.

To clarify cross-sectional differences between the correlations and lead–lag relationships of futures with single cash assets, the results are stratified into three distinct groups based on index weights of the constituent stocks: large-cap, midcap, and small-cap stocks. Large-cap stocks (3 stocks) are defined as constituent stocks with weights greater than or equal to 10% in the index, small-cap stocks (24 stocks) with weights less than 1%, and midcap (29 stocks) stocks with weights between 1% and 10%. [Correction added on 30 April 2015, after first online publication: the numbers of midcap and small-cap stocks were changed.]

The return at time t for asset i is defined as:

$$r_{it} = \ln\left(\frac{P_{it}}{P_{it-1}}\right), \tag{1}$$

where P_{it} is the midquote of the bid and ask prices. In particular, r_{it}, with $i = 1, 2, \ldots, 57$, represents the returns for HS Index constituent stocks and TraHK.[2]

HS Index returns are computed from intraday 15-second quotes provided by the HSIS. Returns of the HS Index (r_{ht}) at time t is defined as:(2)

$$r_{ht} = \ln\left(\frac{I_t}{I_{t-1}}\right), \tag{2}$$

where I_t is the reported HS Index value. Similarly, r_{ft} represents the returns for HS Index futures.

[2]The index's constituent stocks changed during the sample period. The constituent stocks throughout the period were from 27 companies. The ticker numbers of these companies are 0001, 0002, 0003, 0004, 0005, 0006, 0011, 0012, 0013, 0016, 0017, 0019, 0023, 0066, 0083, 0101, 0144, 0267, 00291, 0293, 0330, 0494, 0762, 0883, 0941, 1199, and 2388.

Following Andersen et al. (1999), the realized correlation (ρ_{it}) between returns of asset i and HS Index futures on day t is computed as follows.

$$\rho_{it} = \frac{\sum_{t=1}^{n} r_{ft} r_{it}}{\sigma_{ft} \sigma_{it}}, \tag{3}$$

where $\sigma_{it} = \sqrt{\frac{\sum_{t=1}^{n} f_{it}^2}{n-1}}$ is the realized volatility of asset i, r_{it}^2 is asset i's squared returns and n is the number of time intervals.

The study adopts Huth and Abergel's (2014) Lead–Lag Ratio (LLR) to quantify the extent of the dynamic relationship between futures and cash assets. This measure allows a direct comparison between different assets. LLR is defined as the ratio of the squared cross-correlations between contemporaneous returns of individual cash assets and lead and lag returns of the index futures. If futures returns on average lead returns of a particular underlying stock on a given day, then the ratio is expected to be greater than 1. The LLR quantifies on a daily basis the extent of the lead–lag relationship between HS Index futures and individual cash assets. The higher the LLR, the more futures lead cash and vice versa.

The lead–lag ratio between returns of asset i and HS Index futures on day t is estimated as follows:

$$\mathrm{LLR}_{it} = \frac{\sum_{i=-1}^{-p} \rho_j^2 \left(r_{ft+j} r_{it} \right)}{\sum_{\mathrm{j}=1}^{\mathrm{p}} \rho_{\mathrm{j}}^2 \left(r_{ft+j} r_{it} \right)} \tag{4}$$

where $\rho_j^2 \left(r_{ft+j} r_{it} \right)$ is the squared partial cross-correlation between returns of asset i and HS Index futures at lag j on day t and p is the number of lead and lag periods. The study uses partial cross-correlation instead of cross-correlation as in the original model to control for the impact of cross-correlations between cash assets on the measure. Partial cross-correlation measures the marginal change in the correlation coefficients with respect to changes in the measurement intervals. Although Huth and Abergel's (2014) model permits the use of random measurement time intervals, the study uses a fixed-interval length window for lead and lag index futures returns at 15 minutes before and after the contemporaneous cash asset returns. Barndorff-Nielsen and Shephard (2004) justify the use of a fixed measurement interval in estimating realized correlations, as it generates robust estimates with stable asymptotic distribution. In this paper, the number of lead and lag terms used to compute the LLRs is dependent upon the sampling frequency of the returns, for example, 60 lead and lag index futures returns, if the LLRs are computed from the 15-second returns.The research hypotheses are as follows.

H1: The intraday correlation between HS Index futures and individual cash assets increases monotonically with the length of the return measurement interval.
H2: The impact of the measurement interval length is greater for small (illiquid) stocks than for large (liquid) stocks in terms of realized correlation.
H3: The lead of HS Index futures over highly weighted stocks is weaker than those over low-weight stocks.
H4: The lag of the cash index is the greatest against index futures.

H1 and H3 are constructed to test the impacts of nontrading on the intraday dynamic relationship between index futures and individual cash assets. H2 tests the differential impacts of the measurement interval between small- and large-cap stocks on the intraday correlation between futures and single cash assets. H4 tests the impact of stale prices on the role of information discovery of the cash index. All four hypotheses are supported by the results.

5. EMPIRICAL RESULTS

Table I shows the distribution of the daily readings of portfolio weights, turnover relative to the total dollar volume of all index component stocks, and bid–ask spread for the three stock groups. During the period of January 2006 through December 2011, the weights of the large-, mid-, and small-cap stocks in the index are 42.3%, 47.9%, and 9.8%, and the turnovers are 27.5%, 60.9%, and 11.5%, respectively. There are only three large-cap stocks on average, despite the group's large weight in the index.

The average bid–ask spread of all the constituent stocks is 0.187%, while the spreads of the large-, mid-, and small-cap stocks are 0.113%, 0.166%, and 0.229%. The spread of the ETF, 0.220%, is higher than the average spread of the constituent stocks but close to that of the small-cap stocks. These results are consistent with the notion that arbitrageurs can reduce the trading and market impact cost with limited impact on tracking errors by overweighting large index stocks in their proxy portfolios.

Table II summarizes the return distributions for all the futures, cash index, ETF, and categories of individual cash assets at 15-, 30-second, 1-, 3-, 5-, 15-, and 30-minute intervals. The intraday returns are not significantly different from zero, a result that provides additional support for the use of realized correlation in measuring comovements between HS Index futures and individual cash assets. Not surprisingly, individual stocks are more volatile than the index, futures, and ETF.

Table III reports the results for realized correlations between the HS Index and the HS Index instruments. The results are consistent with H1. The coefficients for individual assets increase five to seven times when sampling frequency decreases from 15 seconds to 30 minutes. As expected, the realized correlation between the HS Index and HS Index futures is strong, with a coefficient ranging from 0.18 measured at the 15-second intervals to 0.79 at 30-minute intervals. The ETF closely tracks the movements of the HS Index, and its correlation coefficients with the futures, 0.21 at 15-second intervals and 0.66 at 30-minute intervals, resemble those between the HS Index and HS Index futures. [Correction added on 30 April 2015, after first online publication: the results of Table III were changed and the references to specific values in Table III in the text were also updated to reflect the correction.]

The realized correlations between the futures and individual constituent stocks vary widely across company sizes. The realized correlations for large-cap stocks with weights

TABLE I

Index Weights, Turnover, and Bid–Ask Spreads (January 2006–December 2011)

Statistics	*Large-Cap* $w_{it} \geq 10\%$	*Mid-Cap* $10\% > w_{it} \geq 1\%$	*Small-Cap* $1\% > w_{it}$
Number of stocks	3	29	24
Index weights (std. dev.)	42.3% (3.70%)	47.9% (4.00%)	9.8% (1.70%)
Turnover (std. dev.)	27.5% (7.70%)	60.9% (7.40%)	11.5% (3.40%)
Bid–ask spreads (std. dev.)	0.113% (0.05%)	0.166% (0.09%)	0.229% (0.12%)

Note. The index weights and turnovers are in percentages of all index stocks.All the averages are taken with respect to daily data.

TABLE II
Summary Statistics of Intraday Returns of Hang Seng Index markets (January 2006–December 2011)

Frequency	*Assets*	*Mean (%)*	*Std. Dev.*
15-second	Futures	0.0000	0.0007
	ETF	−0.0000	0.0008
	Index	−0.0001	0.0003
Index stocks	$w_{it} \geq 10\%$	0.0000	0.0008
	$10\% > w_{it} \geq 1\%$	0.0000	0.0009
	$1\% > w_{it}$	−0.0001	0.0010
	All index stocks	−0.0000	0.0009
30-second	Futures	−0.0000	0.0006
	ETF	0.0000	0.0011
	Index	−0.0001	0.0005
Index stocks	$w_{it} \geq 10\%$	−0.0000	0.0023
	$10\% > w_{it} \geq 1\%$	0.0001	0.0027
	$1\% > w_{it}$	−0.0003	0.0020
	All index stocks	−0.0001	0.0024
1-minute	Futures	−0.0001	0.0008
	ETF	0.0000	0.0016
	Index	0.0000	0.0011
Index stocks	$w_{it} \geq 10\%$	−0.0000	0.0033
	$10\% > w_{it} \geq 1\%$	0.0002	0.0038
	$1\% > w_{it}$	−0.0006	0.0028
	All index stocks	−0.0001	0.0034
3-minute	Futures	−0.0002	0.0013
	ETF	0.0000	0.0021
	Index	0.0002	0.0020
Index stocks	$w_{it} \geq 10\%$	−0.0000	0.0056
	$10\% > w_{it} \geq 1\%$	0.0006	0.0065
	$1\% > w_{it}$	−0.0015	0.0049
	All index stocks	−0.0002	0.0058
5-minute	Futures	−0.0003	0.0017
	ETF	0.0000	0.0033
	Index	0.0004	0.0025
Index stocks	$w_{it} \geq 10\%$	0.0000	0.0072
	$10\% > w_{it} \geq 1\%$	0.0012	0.0083
	$1\% > w_{it}$	−0.0022	0.0062
	All index stocks	−0.0002	0.0075
15-minute	Futures	−0.0011	0.0029
	ETF	0.0000	0.0043
	Index	0.0008	0.0044
Index stocks	$w_{it} \geq 10\%$	0.0007	0.0124
	$10\% > w_{it} \geq 1\%$	0.0039	0.0142
	$1\% > w_{it}$	−0.0055	0.0105
	All index stocks	0.0003	0.0128
30-minute	Futures	−0.0047	0.0041

continued

TABLE II
(Continued)

Frequency	*Assets*	*Mean (%)*	*Std. Dev.*
	ETF	−0.0001	0.0060
	Index	0.0015	0.0059
Index stocks	$w_{it} \geq 10\%$	0.0002	0.0175
	$10\% > w_{it} \geq 1\%$	0.0065	0.0201
	$1\% > w_{it}$	−0.0110	0.0147
	All index stocks	−0.0003	0.0180

greater than 10% are larger than those for midcap and small-cap stocks. At 15-second (30-minute) intervals, the correlations are 0.07 (0.52), 0.04 (0.40), and 0.03 (0.31) for the large-cap, midcap, and small-cap stocks, respectively. The coefficients are even greater than those between the HS Index and HS Index futures at the 3-minute and 5-minute intervals. The realized correlation between the HS Index and the largest index constituent stocks—not reported in the table—ranges from 0.14 at 15-second intervals to 0.65 at 30-minute intervals. The results are obvious, as price changes of the largest HS Index constituent stocks have the greatest impacts on the reported HS Index values, and their returns should move more closely with that of the HS Index.

The results are consistent with H3, as all the realized correlations increase with the length of the measurement intervals. The realized correlation between TraHK and HS Index futures is the strongest, supporting arbitrage trading between them. Arbitrageurs also employ the largest HS Index constituent stocks to construct proxy portfolios for index arbitrage trading. The results reveal that market participants trade TraHK and the largest HS Index constituent stocks to capitalize gains ahead of general market movements and arbitrage against mispricing of HS Index futures.

Table IV shows the impact of sampling frequency on the lead–lag ratio between HS index futures and individual cash assets computed for 15-, 30-second, 1-, 3-, and 5-minute measurement intervals. The results are in line with H3, as all the lead–lag ratios are significantly greater than 1, and the lead of futures over large-cap stocks is weaker than that over small-cap stocks.

In other words, returns of index futures lead returns of individual cash returns over all measurement intervals. Given liquidity and execution efficiency of the HS index futures, market participants trade futures to capitalize their views on potential market movements and make price changes on HS Index futures significantly ahead of cash asset prices.

The lead of HS Index futures over the HS Index is the greatest up to the 1-minute intervals. The returns are computed from the last traded prices of the index's constituent stocks, while futures returns are obtained from continuously updated bid and ask quotes. This magnifies the lead of futures over the cash index. The results support H4 and show the impact of nontrading and bid–ask bounce on the futures-cash index relationship. The nonsynchronous trading problem of the constituent stocks is indicated by the significantly positive autocorrelations of index returns. The average first-order auto-correlation (AR1) coefficient of the minute-by-minute cash index returns is 17% and is statistically significant, while the autocorrelations of the ETF and individual stocks are insignificant (results available upon request). [Correction added on 30 April 2015, after first online publication: the results of Table IV and the first order correlation coefficient were changed.]

TABLE III
Realized Correlations Between Hang Seng Index Futures and Individual Cash Assets (January 2006–December 2011)

Frequency	*Assets*	*Mean*	*t-Value*	*Std. Dev.*	*% Change (Mean)*
15-second	ETF	0.213	44.56	0.184	
	Index	0.180	62.09	0.112	
Index stocks	$w_{it} \geq 10\%$	0.070	64.91	0.071	
	$10\% > w_{it} \geq 1\%$	0.042	124.0	0.063	
	$1\% > w_{it}$	0.029	77.31	0.055	
	All index stocks	0.039	156.3	0.062	
30-second	ETF	0.288	49.21	0.226	35.2%
	Index	0.333	87.79	0.146	85.0%
Index stocks	$w_{it} \geq 10\%$	0.145	81.81	0.116	107.3%
	$10\% > w_{it} \geq 1\%$	0.084	156.1	0.098	98.6%
	$1\% > w_{it}$	0.054	100.9	0.080	88.8%
	All index stocks	0.077	196.2	0.097	97.4%
1-minute	ETF	0.369	56.27	0.252	73.2%
	Index	0.510	121.99	0.161	183.3%
Index stocks	$w_{it} \geq 10\%$	0.239	95.96	0.163	241.5%
	$10\% > w_{it} \geq 1\%$	0.140	182.3	0.141	231.0%
	$1\% > w_{it}$	0.088	118.9	0.111	209.5%
	All index stocks	0.128	227.2	0.138	228.2%
3-minute	ETF	0.509	73.99	0.265	139.0%
	Index	0.721	193.67	0.143	300.6%
Index stocks	$w_{it} \geq 10\%$	0.388	125.3	0.202	453.1%
	$10\% > w_{it} \geq 1\%$	0.249	231.9	0.197	487.9%
	$1\% > w_{it}$	0.166	150.0	0.166	481.4%
	All index stocks	0.228	286.4	0.195	484.6%
5-minute	ETF	0.561	79.41	0.272	163.4%
	Index	0.776	214.74	0.139	331.1%
Index stocks	$w_{it} \geq 10\%$	0.436	130.5	0.218	521.3%
	$10\% > w_{it} \geq 1\%$	0.293	243.2	0.221	593.6%
	$1\% > w_{it}$	0.204	153.5	0.200	617.2%
	All index stocks	0.270	299.0	0.222	592.3%
15-minute	ETF	0.646	82.15	0.303	203.3%
	Index	0.819	222.18	0.142	355.0%
Index stocks	$w_{it} \geq 10\%$	0.483	117.2	0.269	588.9%
	$10\% > w_{it} \geq 1\%$	0.357	232.6	0.281	742.8%
	$1\% > w_{it}$	0.273	148.5	0.277	859.0%
	All index stocks	0.334	289.2	0.284	756.4%
30-minute	ETF	0.663	72.22	0.354	211.3%
	Index	0.794	168.71	0.181	341.1%
Index stocks	$w_{it} \geq 10\%$	0.520	94.58	0.359	642.2%
	$10\% > w_{it} \geq 1\%$	0.395	192.0	0.377	833.3%
	$1\% > w_{it}$	0.314	123.7	0.382	1,003.0%
	All index stocks	0.374	240.7	0.382	859.0%

Note. The last column reports the changes of the means from those of 15-second interval. [Correction added on 30 April 2015, after first online publication: the results of Table III were changed and the references to specific values in Table III in the text were also updated to reflect the correction.]

The lead of HS Index futures over HS Index constituent stocks is greater than its lead over TraHK. The result is consistent with the conjecture that market participants employ TraHK to execute arbitrage trades. As in the findings for realized correlations, the lead of HS Index futures over the largest HS Index constituent stocks is smaller than that of other index constituent stocks. This finding is in line with the conjecture that arbitrageurs give excessive

TABLE IV
Lead-Lag Ratio Between Hang Seng Index Futures and Individual Cash Assets (January 2006–December 2011)

Frequency	*Assets*	*Mean*	*t-Value*	*Std. Dev.*	*% Change (Mean)*
15-second	ETF	1.184	8.76	0.81	
	Index	1.695	78.10	0.84	
Index stocks	$w_{it} \geq 10\%$	1.053	5.27	0.66	
	$10\% > w_{it} \geq 1\%$	1.237	58.08	0.75	
	$1\% > w_{it}$	1.320	58.68	0.82	
	All index stocks	1.255	81.15	0.77	
30-second	ETF	1.220	9.35	0.91	3.0%
	Index	1.877	61.45	1.18	10.7%
Index stocks	$w_{it} \geq 10\%$	1.092	8.09	0.74	3.7%
	$10\% > w_{it} \geq 1\%$	1.266	57.97	0.84	2.4%
	$1\% > w_{it}$	1.347	56.24	0.92	1.9%
	All index stocks	1.284	80.21	0.87	2.3%
1-minute	ETF	1.319	11.18	1.10	11.4%
	Index	2.058	52.18	1.52	21.4%
Index stocks	$w_{it} \geq 10\%$	1.235	15.08	1.02	17.3%
	$10\% > w_{it} \geq 1\%$	1.404	66.14	1.12	13.5%
	$1\% > w_{it}$	1.470	58.30	1.21	11.4%
	All index stocks	1.417	89.12	1.15	12.9%
3-minute	ETF	1.741	10.25	2.79	47.0%
	Index	1.782	27.89	2.46	5.1%
Index stocks	$w_{it} \geq 10\%$	1.758	19.96	2.48	66.9%
	$10\% > w_{it} \geq 1\%$	2.001	53.36	3.44	61.8%
	$1\% > w_{it}$	2.114	46.67	3.59	60.1%
	All index stocks	2.026	73.37	3.44	61.4%
5-minute	ETF	2.290	8.57	5.79	93.3%
	Index	2.036	12.42	6.31	20.1%
Index stocks	$w_{it} \geq 10\%$	2.630	13.34	7.98	149.7%
	$10\% > w_{it} \geq 1\%$	2.868	38.40	8.92	131.9%
	$1\% > w_{it}$	2.974	31.42	9.45	125.3%
	All index stocks	2.891	51.34	9.06	130.4%

Note. The last column reports the changes of the means from those of 15-second intervals. [Correction added on 30 April 2015, after first online publication: the results of Table IV were changed.]

weight to the largest and most liquid index constituent stocks in establishing the cash leg or an index proxy in conducting arbitrage.

The two-sample *t*-tests for differences in realized correlations between the large and small index stocks subsets show the differences are statistically significant. The realized correlations of the largest constituent stocks are significantly larger than those of the smallest constituent stocks. Similarly, the lead–lag ratios of the smallest constituent stocks are significantly larger than those of the largest constituent stocks, showing that futures have a greater lead over the smallest stocks. However, the differences of both the realized correlations and lead–lag ratios decline with the length of the measurement intervals. These results, consistent with H2 and H3, show that sampling frequency has a greater impact on the smallest stocks.

The Jonckheere–Terpstra test is also used to examine differences in average realized correlations and lead–lag ratios between futures and ETF, cash index, and index constituent stocks over different sampling frequencies. The Jonckheere–Terpstra test is a nonparametric test for ordered differences among classes. In the current study, it tests the null hypothesis that the distribution of the realized correlation with index futures does not differ among ETF and index constituent stocks. The results of two-sample t-tests and Jonckheere–Terpstra test are not reported here but are available upon request from the authors.

The results of the Jonckheere–Terpstra test indicate that the average realized correlations of futures with ETF are the strongest, followed by the correlations with large-cap, midcap, and small-cap stocks for all sampling frequencies. Similarly, the average lead–lag ratios between futures and ETF are the smallest, followed by large-cap, midcap, and small-cap stocks. Both of the average realized correlations and lead–lag ratios increase with the length of the measurement intervals. The impact of sampling frequencies is insignificant for ETF and most significant for the smallest constituent stocks. These results based on the nonparametric test are consistent with the results of the two-sample t-tests. In particular, the lead of HS Index futures over small constituent stocks is more significant than that for the large constituent stocks, while the lead over the ETF is the smallest.

6. CONCLUSIONS

This paper examines the impacts of sampling frequency on the intraday dynamic relationship between Hang Seng Index futures and individual cash assets. The results show that intraday realized correlation and lead–lag relationships are both strengthened by increasing the length of the intervals in the return measures.

Market participants employ the largest HS Index constituent stocks to construct proxy portfolios for index arbitrage trading. As a result, the lead of HS Index futures over the largest HS Index constituent stocks is smaller than that of other index constituent stocks. The overall results reveal that market participants trade TraHK and the largest HS Index constituent stocks to capitalize gains ahead of general market movements and arbitrage against mispricing of the HS Index futures. Moreover, the impacts of measurement interval length for returns are higher for small (illiquid) stocks than for large (liquid) stocks. Finally, the cash index has the greatest lag against the futures, indicating the adverse impact of stale prices on the informational role of stock indexes that are based on the last traded prices.

REFERENCES

Andersen, T., Bollerslev, T., Diebold, F. X., & Labys, P. (1999). Realized volatility and correlation. Working paper FIN-99-061, Stern School of Business, New York University.

Andersen, T. G., Bollerslev, T., Diebold, F. X., & Labys, P. (2001). The distribution of realized exchange rate volatility. Journal of American Statistical Association, 96, 42–55.

Barndorff-Nielsen, O. E., & Shephard, N. (2004). Econometric analysis of realized covariation: High frequency based covariance, regression and correlation in financial economics. Econometrica, 72, 885–925.

Brennan, M. J., & Schwartz, E. (1990). Arbitrage in stock index futures. Journal of Business, 63, 7–31.

Chan, K. (1992). A further analysis of the lead–lag relationship between the cash market and stock index futures market. Review of Financial Studies, 5, 123–152.

Deville, L., Gresse, C., & Séverac, B. (2014). Direct and indirect effects of index ETFs on spot-futures pricing and liquidity: Evidence from the CAC 40 index. European Financial Management, 20, 352–373.

Huth, N., & Abergel, F. (2014). High frequency lead/lag relationships—Empirical facts. Journal of Empirical Finance, 26, 41–58.

Klemkosky, R. C., & Lee, J. H. (1991). The intraday ex post and ex ante profitability of index arbitrage. Journal of Futures Markets, 11, 291–311.

Marshall, B. R., Nguyen, N. H., & Visaltanachoti, N. (2013). ETF arbitrage: Intraday evidence. Journal of Banking and Finance, 37, 3486–3498.

Miller, M. H., Muthuswamy, J., & Whaley, R. E. (1994). Mean reversion of Standard & Poor's 500 index basis changes: Arbitrage-induced or statistical illusion? Journal of Finance, 49, 479–513.

Neal, R. (1996). Direct tests of index arbitrage models. Journal of Financial Quantitative Analysis, 31, 541–562.
Oehmke, M. (2009). Gradual arbitrage. Working paper, Columbia University.
Richie, N., Daigler, R. T., & Gleason, K. C. (2008). The limits to stock index arbitrage: Examining S&P 500 futures & SPDRs. Journal of Futures Markets, 28, 1182–1205.
Sofianos, G. (1993). Index arbitrage profitability. Journal of Derivatives, 1, 6–20.
Tse, Y. (1999). Price discovery and volatility spillovers in the DJIA Index and futures markets. Journal of Futures Markets, 19, 911–930.
Tse, Y. (2001). Index arbitrage with heterogeneous investors: A smooth transition error correction analysis. Journal of Banking and Finance, 25, 1829–1855.
Yadav, P., & Pope, P. (1990). Stock index futures arbitrage: International evidence. Journal of Futures Markets, 10, 573–603.