Index arbitrage and the pricing relationship between Australian stock index futures and their underlying shares

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Abstract

This paper conducts an empirical analysis of the mispricing of Australian stock index futures. Exogenous and endogenous price volatility is confirmed to have a positive impact on the mispricing spread, after filtering out predictable time series components. More accurate pricing associated with surprise trading volume in the underlying stocks is consistent with arbitrageurs acting to narrow price disparities relative to the futures market. Ex-ante interest rate volatility is the primary source of risk faced by arbitrageurs and fluctuations in the market impact cost of opening index arbitrage positions influence the extent to which they drive prices towards theoretical fair values.

JEL classification: G13, G14

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1. Introduction

The price linkage between Australian stock index futures and the replicating portfolio of underlying shares is examined. It is generally accepted that this linkage is maintained by arbitrageurs. The purpose of this paper is to update and extend Brailsford and Hodgson's (1997) analysis of stock index futures pricing based on the former Australian All Ordinaries Share Price Index contract. The updated analysis for SFE SPI 200™ Index futures that are currently the most actively traded equity derivative in Australia provides further evidence about the efficiency of information transmission between the spot and futures markets. The analysis is extended to incorporate the impact of unexpected volume in the underlying stocks, in addition to price volatility and unexpected volume in the futures market. Expanding upon previous research, this study takes account of specific risks and transaction costs faced by arbitrageurs acting to narrow price disparities between the spot and futures markets. In particular, the relative importance of dividend yield uncertainty and ex-ante interest rate volatility in obstructing the extent to which arbitrageurs can drive prices towards theoretical levels further out from maturity are assessed. The influence of intraday variations in the transaction costs represented by bid-ask spreads in the spot and futures markets and securities borrowing are also estimated whereas previous mispricing studies have relied upon constant total transaction costs of index arbitrage trades. These extensions enable a more comprehensive examination of stock index futures pricing incorporating unexpected information arrival in conjunction with the relative effectiveness of the arbitrage mechanism.

1.1 Information transfer

This paper further explores the impact on the mispricing series of the possibility that the stock and futures markets react to different information sets (the 'differential information hypothesis'). In this context, the strength of the arbitrage pricing relationship for index futures reflects the efficiency with which the information sets are transferred between the stock and futures markets following their arrival in the most receptive market on each occasion. Hodgson, Masih and Masih (2006) provide evidence that substantial macroeconomic information flows in from Australian stock index futures price changes and predicts subsequent movements in stock prices. It is likely that market-wide information is incorporated with greater speed in the futures market relative to the underlying stock market, if transactions costs are substantially lower and execution delays are shorter in the futures market. Consistent with the relative dominance of the futures market compared to the cash market in the price discovery process, Brailsford and Hodgson (1997) find that unexpected trading volume and the volatility of futures prices have a positive impact on the mispricing spread of Australian stock index futures[1]. Conversely, individual stocks trading in the

[1] Garbade and Silber (1993) demonstrate that the price discovery function of futures markets hinges on whether price changes in futures markets lead price changes in cash markets more often than the reverse. In particular, if the futures market dominates the cash market, any deviations from the carrying cost relationship between cash and futures prices will be narrowed by cash prices moving further towards futures prices than futures prices move towards cash prices. Using daily data for cash and stock index futures markets in the United States, Merrick (1987) finds evidence of a strong causal flow from volatility to the cash/futures mispricing spread and Hill, Jain and Wood (1988) describe a positive, contemporaneous relationship between mispricing changes and larger absolute index returns. Using executable prices for the index basket every thirty seconds in Hong Kong, Draper and Fung

cash market are more likely to react to firm specific information. This study tests whether the arrival of unique information in the cash market represented by surprise turnover in the underlying basket of stocks dominates the presence of arbitrageurs acting to narrow price discrepancies relative to the futures market[2]. By estimating its impact on the mispricing spread, evidence is provided about the source of information arrival in the cash market.

The trading hours of the Australian stock market do not overlap with the United States stock market, which allows the effect of overnight 'public information' arrival to be observed. Brailsford and Hodgson (1997) find that volatility of the overnight United States stock market has a consistent significant impact on the absolute pricing errors of Australian stock index futures at the opening of the local stock market. Higher mispricing at the opening is likely to be compounded by a microstructural feature; the opening price setting mechanism in the stock market entails staggered opening times for groups of stocks over the first nine minutes.

1.2 Risks faced by index arbitrageurs

Greater absolute magnitudes of mispricing for longer times to maturity which have been observed in stock index futures markets are consistent with arbitrage being more risky further out from maturity (MacKinlay and Ramaswamy, 1988 in the United States; Yadav and Pope, 1990; 1994 in the United Kingdom). Arbitrageurs require greater compensation to act upon deviations from theoretical pricing levels when the risks they face are higher, permitting larger deviations to be sustained early in the futures expiry cycle. MacKinlay and Ramaswamy (1988) identify three of the risks that are greater with longer times until expiration: (i) the risk of unanticipated increases or decreases in dividends; (ii) unanticipated interest earnings or costs from financing the marking-to-market flows from futures positions; and (iii) attempts at arbitrage motivated trading that employ less than the full basket of stocks in the index must allow for a greater margin of error with longer times to expiration. Focusing on the parameters of the cost-of-carry valuation model that provides 'fair' values, the dividend yield and interest rate to maturity, this paper endeavours to disentangle which of the risks associated with index arbitrage activities have the most significant impact on absolute mispricing.

Existing research does not explicitly quantify the risk premium required by arbitrageurs on account of dividend yield uncertainty, except by considering worst case scenarios (Yadav and Pope, 1994). This study measures the uncertainty about the magnitude of dividends based on the dispersion of analysts' forecasts for index constituent stocks[3]. The likelihood of incorrectly predicting ex-dividend dates is also

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(2003) show greater mispricing of index futures occurs with increased market volatility (caused by the arrival of significant information).

[2] Kumar and Seppi (1994) develop an information-based model of arbitrage, where the order flow itself is informative about intermarket price discrepancies. An empirical implication of their model is that index arbitrage is associated with 'permanent' price revisions. Providing support for the model, Neal (1996) finds arbitrage trades narrow the deviation from fair value and most trades involve a simultaneous submission of the stock and futures portions of the trade.

[3] Typically, market participants estimate future dividends by applying a percentage growth factor to past dividends and use corresponding ex-dividend dates from previous years. Analyst forecasts for the sizes of dividends spanning the period to futures expiry are less reliable further out, dependent upon

higher for longer times until maturity. The risk pertaining to the unknown timing of ex-dividend dates is especially relevant to the pricing of the futures contract, in cases when either dividends are delayed that were expected to have ex-dividend dates before the expiration of the contract or dividends are brought forward that were expected to be deferred until after the expiration of the contract. Despite the presence of these forms of dividend uncertainty, Yadav and Pope (1994) are unable to attribute the magnitude of mispricing they observe in FTSE 100 futures to dividend forecast errors. Their measure of the uncertainty surrounding the timing of future dividends focuses on the difference between the ex-dividend date and the actual dividend payment date, which does not capture the pricing consequences of firms rescheduling ex-dividend dates relative to previous years. This issue is addressed in our study by constructing an alternative measure of the time to expiration based on gross dividends that remain undisclosed in relation to their magnitude and timing.

Interest rate risk arises from futures positions because the marking to market feature necessitates the daily reinvestment or borrowing of cash[4]. With the cost of financing the set of shares of the underlying index determined at the time of entering into a futures contract, index arbitrageurs are further exposed to interest rate risk if the borrowing or lending they undertake to support the cash leg of their transactions does not match the maturity of the futures[5]. The cost of continually rebalancing the maturities of cash and futures positions to neutralise this interest rate exposure may be prohibitive. Unanticipated changes in interest rates spanning the period to futures expiry are more likely to occur when starting further out. This paper investigates the dependence of absolute mispricing on the ex-ante estimate of interest rate volatility implied in interest rate option prices. Further, another alternative measure of the time to expiration is constructed based on the frequency of economic releases that influence interest rate expectations over the period to futures expiry.

MacKinlay and Ramaswamy (1988) provide evidence of countervailing forces that serve to establish a narrower trading band for index futures prices. Arbitrageurs' option to unwind their positions prematurely introduces path dependence into the mispricing series (refer also to Kempf, 1998). In particular, MacKinlay and Ramaswamy show that conditional on the mispricing of S&P 500 futures contracts having crossed one arbitrage bound, it is less likely to cross the opposite bound. This phenomenon is consistent with arbitrageurs unwinding positions established when the

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early guidance from a greater number of firms. Additionally, special dividends can constitute a substantial fraction of total dividends and are difficult to predict.

[4] The application of the cost-of-carry model for forward prices to the pricing of futures contracts relies upon the assumption of non-stochastic interest rates (Cox, Ingersoll and Ross, 1981). As an alternative, Ramaswamy and Sundaresan (1985) develop a continuous time model in which the stock index follows a lognormal diffusion process and the interest rate follows a mean-reverting process. Cakici and Chatterjee (1991) compare the pricing models with stochastic and non-stochastic interest rates for S&P 500 futures and conclude that the stochastic model gives significantly better results when the spot interest rate is far away from the long-term mean or when the parameter accounting for the speed of adjustment toward this long-term mean is very high. However, simulation analysis used by Modest (1984) suggests that stochastic interest rates and marking to market are likely to have a minimal effect on equilibrium prices. Bailey (1989) and Brailsford and Hodgson (1997) examine the empirical performance of the Ramaswamy-Sundaresan model in the Japanese and Australian markets respectively and find that the pricing errors are not substantially different from those for the simpler cost-of-carry model. These findings do not preclude interest rate volatility resulting in a widening of the arbitrage band for index futures prices.

[5] In practice arbitrage firms typically finance their activity on an overnight basis.

mispricing was outside one bound before it reaches the other bound. It is optimal to close out these positions before putting on new arbitrage trades in the reverse direction[6]. The early unwind option potentially mitigates the greater risks involved in arbitrage strategies further out from maturity[7]. Arbitrageurs also obtain the option to roll their futures positions forward into the next available maturity[8]. Brailsford and Hodgson (1997) argue that the risk faced by arbitrageurs in a small volatile market like Australia may be lower than in larger and more liquid markets because the implicit option component of an arbitrage position increases in value with the volatility of the mispricing.

1.3 Transaction costs

Even before the risks faced by arbitrageurs are taken into account, the existence of transaction costs implies that the price of the index futures can fluctuate within a band around its theoretical value without representing a profit opportunity for even the most favourably situated arbitrageurs (Modest and Sundaresan, 1983; Modest, 1984; Gould, 1988; Kawaller, 1987; 1991). Using minute-by-minute data, Dwyer, Locke and Yu (1996) estimate an error correction mechanism for the S&P 500 futures and cash indexes that allows for the non-linearity suggested by arbitrage with transaction costs. In response to shocks from the futures market, their results indicate the basis converges to the cost of carry as much in five to seven minutes when arbitrage is profitable as it converges in fifteen minutes when arbitrage is unprofitable[9]. The width of the band is determined by explicit costs such as fees paid to brokers, exchange levies and short selling costs and from implicit costs including the bid-ask spreads and price impact costs of opening up positions in both the stock and futures markets. This study further extends the mispricing analysis performed by Brailsford and Hodgson (1997) by determining the influence on the mispricing series of the minimum implicit round-trip transaction costs associated with bid-ask spreads in the stock and futures markets. In this way, the pricing relationship between the spot and futures markets is examined while controlling for fluctuations in the width of the arbitrage bounds due to

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[6] The option to close out early may also make it optimal to open a new arbitrage position even when the simple arbitrage profit is less than the cost incurred in opening and closing the position at maturity (Brennan and Schwartz, 1990). Empirical evidence provided by Finnerty and Park (1988) indicates that most program traders are better off not to hold their positions and unwind them at the expiration of the futures contract but instead to keep trading their positions until expiration. Neal (1996) finds arbitrage positions are typically liquidated early and very few are held to expiration.

[7] In this regard, greater dividend yield uncertainty and interest rate volatility may increase the value of the early unwind option by increasing the volatility of the mispricing series.

[8] Merrick (1989) and Yadav and Pope (1990; 1994) reveal early unwinding and rollovers are important determinants of arbitrage profits and explain why the arbitrage market can be active even though prices are within conventionally-measured transaction cost bounds.

[9] Also in the United States, Chung (1991) shows the frequency of ex ante pricing violations declines significantly with the assumed level of transaction costs and length of execution lags and the size of ex ante arbitrage profit is substantially smaller than the triggering ex post mispricing signal. In the United States and Korea respectively, Klemkosky and Lee (1991) and Gay and Jung (1999) find that member firms have more opportunity to engage in profitable index arbitrage than institutional investors who incur higher transaction costs. In Japan, Lim (1992) finds that arbitrage opportunities are very limited; accounting for transaction costs no arbitrage profit could be made by those outside of the brokerage business. In the United Kingdom, Butterworth and Holmes (2000) find that although mispricings tend to be larger and more persistent for the mid 250 contract than for the FTSE 100 contract, this is consistent with the larger transaction costs and difficulties associated with trading the illiquid constituents of the mid 250 index.

medium-term, seasonal and intraday variations in transaction costs incurred when laying on index arbitrage trades.

This study investigates whether there is any maturity effect on the magnitude of mispricing of the futures contract related to the cost of borrowing stock. Borrowing costs are incurred by arbitrageurs who do not have capital in the form of treasury bills (for buy programs when the futures contract is overvalued relative to the underlying stocks) and index stocks (for sell programs when the futures contract is undervalued relative to the underlying stocks)[10]. Short-sellers have to locate a willing stock lender and pay a stock borrowing fee[11]. The cost ranges from zero for those already owning the stock to a potentially high level. A dynamic equilibrium model developed by Kempf (1998) predicts that the absolute level of negative mispricing increases with time to maturity, since the holding costs associated with short arbitrage positions increase with time to maturity. If arbitrageurs have to borrow stocks to exploit negative index futures mispricing, the pricing of the near contract could deviate from its theoretical level more frequently when stock borrowing is relatively expensive. To test this expectation, it is determined whether borrowing costs in the Australian market have any incremental impact on the volatility of the mispricing series.

The remainder of this paper is structured as follows. Section 2 describes the institutional setting and data used in the empirical tests. The empirical results are reported in section 3 and the paper is concluded in section 4.

2. Institutional setting and data

Introduced in April 2000, the S&P/ASX 200 index measures the performance of the 200 largest stocks listed on the Australian Stock Exchange (ASX). The index is float-adjusted and represents approximately 80 percent of the Australian equities market capitalisation[12]. The stocks comprising the index are traded on the ASX's computerised trading system, known as the Stock Exchange Automated Trading System (SEATS) until October 2006. The level of the S&P/ASX 200 is calculated by Standard & Poor's and is reported to the market every 30 seconds as constituent prices change.

SFE SPI 200™ Index Futures are written over the S&P/ASX 200 index with a contract unit of 25 Australian dollars per index point. The contracts follow a March-June-September-December quarterly maturity cycle and are cash settled at a price

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[10] In Australia, the borrower pays the lender a fee for the use of the borrowed securities ranging anywhere between 25 and 400 basis points per annum for ASX 200 equities and between 5 and 50 basis points per annum for Commonwealth Government securities (refer to King, 2005a). Pricing typically takes into account factors such as demand and supply for particular securities, the size of any manufactured dividend and the likelihood of the lender recalling the securities early (King, 2005a; b). There is no automated electronic platform for negotiating securities lending transactions in use in Australia and all transactions are entered into between the counterparties. Thus, whereas bid-ask spreads in both the stock and futures markets are able to be gauged, transaction costs associated with securities lending and repo transactions are not reported in Australia.

[11] Modest and Sundaresan (1983) demonstrate that if part of the proceeds from short sales in the spot market is unavailable to traders for earning interest, the trading band dictated by transaction costs can be asymmetric around the theoretical fair value and the futures price can be below the spot index especially when the cost of shorting the spot index is large.

[12] The index was converted from a market capitalisation weighted index to a free float based index on 1 October 2002.

calculated using the first traded price of each component stock in the index on the last trading day (denoted day 0 in this article). From the June 2003 expiry onwards, the last trading day is the third Thursday of the settlement month. Earlier contracts expired on the last business day of the settlement month[13].

Trading of SFE SPI 200™ futures in the daytime session commences at 9:50 a.m. and finishes at 4:30 p.m. on the Sydney Futures Exchange (SFE). In contrast, the stocks from which the index is constructed are traded on the ASX from 10:00 a.m. to 4:00 p.m.. Stocks on the ASX do not open simultaneously. Rather, they are grouped according to the starting letter of their ASX code and each group is opened randomly up to fifteen seconds on either side of different times between 10.00 a.m. and 10.09 a.m..

2.1 Data description

Reuters trade and quote data for SFE SPI 200™ futures were provided by the Securities Industry Research Centre of Asia-Pacific (SIRCA). The data covers the period 1 January 2002 to 15 December 2005, which provides a structural break free data set of sixteen contract maturities for analysis[14]. Though up to six maturities are listed at any particular time, our analysis is confined to the nearest-to-maturity contract which has by far the most significant trading volume. Hence, each contract is followed from the expiry date of the previous contract until its expiration. Expiration day observations are not included[15]. The data describes the time (to the nearest second), price and volume of each trade and the prices of the best available bids and offers. End-of-day open interest figures were obtained from Bloomberg.

S&P/ASX 200 stock index values, time-stamped approximately 30 seconds apart, and Reuters trade and quote data for the index constituents were also provided by SIRCA. The index constituents were identified using a daily list from Bloomberg. The list contains the float-adjusted index weights, numbers of shares outstanding that are included in the index calculation and closing prices for stocks in the index. The Reuters transaction file records all trades and quotes on the ASX. It contains the time to the nearest second, the price and volume for each trade and the time and bid/ask prices for each quotation.

Daily series for the overnight cash, 30, 90 and 180 day bank accepted bills rates were obtained from the Reserve Bank of Australia. The interest rate for loans maturing at the expiration date of the futures was estimated using linear interpolation between these four reference interest rates. A daily dividend series was obtained from Bloomberg. The dividend series contains the total actual cash dividends and gross dividends (cash dividends plus imputation credits) paid each ex-dividend day by

[13] An exception is the December 2002 contract which expired on 9 December 2002.
[14] Observations for 11 January 2002 and 2 May 2003 with average intraday mispricing given by equation 3 of +0.29 percent indicating the futures contract was unusually expensive and -0.67 percent indicating the contract was unusually cheap respectively are excluded from the sample.
[15] Stoll and Whaley (1987) provide evidence of price effects associated with S&P 500 futures contract expirations. The cash settlement feature of index futures contracts requires arbitrageurs to unwind positions in the stock market. Abnormal stock price movements may arise if many arbitrage programs are being unwound in the same direction at the opening call auction on the expiration day.

stocks in the S&P/ASX 200[16]. Our mispricing estimates are based on the assumption that the dividend amounts and franking percentages are known from the expiry date of the previous contract. The discrete and seasonal dividend payments of the S&P/ASX 200 index portfolio are taken into account by using the actual ex-post daily dividend inflows for the basket stocks, which Harvey and Whaley (1992) show reduces pricing errors that occur when constant dividend yields are assumed.

In calculating the differences between actual and theoretical index futures prices, futures price quotes and index values that are approximately five minutes apart and that are the latest available before the end of each five minute mark are used. The bid-ask midpoint price prevailing at the end of each five minute interval is taken to represent the actual futures price[17]. In the same way, the most recent index value reported to the market before the end of the five minute interval is taken to represent the actual spot market price[18]. While traders have access to the updated index level throughout the course of the day, the index calculation utilises non-synchronous or stale prices especially for thinly traded stocks, so that the truly tradeable price of the replicating portfolio can diverge temporarily from the instantaneously reported value[19]. These price series are constructed for every five minute interval from 10:00 a.m. to 4:00 p.m. Sydney time, which is the segment of the trading day when both the futures and cash markets are open simultaneously in continuous auction mode. Observations for which there were zero futures trading volume are excluded to provide results comparable with those reported by Brailsford and Hodgson (1997)[20]. The final sample consists of 66,040 observations.

The levels of autocorrelation in the price changes for both SFE SPI 200™ futures and the S&P/ASX 200 spot price series are shown in table 1. The autocorrelations of the futures price changes are close to zero at all ten lags, although are slightly negative at the first and second lags consistent with traders picking off liquidity using market orders when it becomes available at improved quote prices. More noticeably, the index series is positively auto-correlated at the first lag with a first order autocorrelation coefficient of 0.19 similar to that reported by Brailsford and Hodgson (1997) for the Australian All Ordinaries index (0.20). This behaviour is consistent with the presence of stale prices in the available index values (described by Fisher, 1966).

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[16] Daily dividend payments of basket stocks are unavailable for other studies. For example, Brailsford and Hodgson (1997) rely upon published Australian All Ordinaries index dividend yields that were only available on a monthly basis in order to form ex-ante expectations about dividend yields.

[17] Quote midpoint prices are used to minimise the effect on the mispricing series of bid-ask bounce in the futures market. Similarly, Bühler and Kempf (1995) use the mean of the current bid-ask quotes for futures contracts and interest rates to calculate the relative mispricing of German stock index futures.

[18] As the stock index values are clocked approximately thirty seconds apart, they will be updated on average fifteen seconds before the five minute mark. The deviations from theoretical pricing levels computed from these values may be slightly upward biased due to the momentary delay until the end of the each interval.

[19] The index is updated using transaction prices and does not use the bid and offer quotes for the component stocks. This problem may be exacerbated in the relatively thinly traded Australian stock market because not all stocks in the index trade every five minutes. The problem of non-synchronous trading in the futures market is overcome by using the bid-ask midpoint price prevailing at the end of each interval.

[20] As a result, 730 observations were removed representing 1.1 percent of the original sample.

Table 1
Autocorrelations for changes of the logarithm of price in SFE SPI 200™ futures and the S&P/ASX 200 index

	Log of price ratios	
	SFE SPI 200™ futures	S&P/ASX 200 index
Autocorrelation coefficients		
ρ_1	-0.012 *	0.193 *
ρ_2	-0.011 *	-0.012 *
ρ_3	0.002	-0.001
ρ_4	0.002	0.001
ρ_5	0.000	0.005
ρ_6	-0.001	-0.001
ρ_7	0.004	-0.003
ρ_8	-0.006	-0.006
ρ_9	-0.001	-0.003
ρ_{10}	-0.003	-0.003

Autocorrelations are based on five minute observation intervals. *Denotes significance at the 1% level.

2.2 Variable measurement

Published empirical work on stock index futures pricing has implicitly assumed that investors face the same marginal tax rate on all forms of income and employ only the cash value of dividends. These assumptions can lead to significantly biased estimates of futures mispricing in a market like Australia, where interest and dividend income are taxed more harshly than capital gains on stocks and an imputation system provides investors with a tax credit on franked dividends (see Cummings and Frino, 2008). Assuming the following—investors do not default on any contract; no money changes hands through marking to market during the lifetime of the contract, only on the maturity date; all investors can borrow and lend at the same non-stochastic interest rate; the cash dividend yield and imputation credit yield of the index over the remaining life of the near futures contract are known in advance; no transaction costs; and no restrictions on short sales—the theoretical price of a futures contract under the tax-adjusted cost-of-carry model developed by Cummings and Frino (2008) is:

$$f_{t,T}(p) = S_t + (1-\tau_1)S_t(\mathrm{e}^{r(T-t)} - 1) - \gamma_1 \sum_{s=t+1}^{T} D_s \mathrm{e}^{r(T-s)} - \gamma_2 \sum_{s=t+1}^{T} IC_s \qquad (1)$$

where

$f_{t,T}(p)$ = the fair value at time t of an index futures contract with partially valued carry components maturing at time T;
S_t = the spot index value at time t;
r = the annualised risk-free interest rate at time t for repayment at time T;
D_s = the aggregate dividend cash flows on the index associated with an ex-dividend date s;
IC_s = the aggregate imputation credits for the basket stocks in the index associated with an ex-dividend date s;
τ_1 = the reduction in the financing cost achieved through the tax deductibility of one dollar of interest on loans;
γ_1 = the value of one dollar of accumulated cash dividends allowing for the harsher tax treatment of dividend income relative to capital gains on stocks; and
γ_2 = the value of one dollar of imputation credits.

The accumulated value of cash dividends on the underlying stocks over the remaining life of the contract are calculated on the assumption that the forward interest rate at time t for loans made at time s to be repaid at time T is identical to the spot interest rate at time s for loans maturing at time T. Substituting the values of the parameters $\tau_1 = 0.066$, $\gamma_1 = 0.804$ and $\gamma_2 = 0.521$ estimated by Cummings and Frino (2008) for SFE SPI 200™ futures over the same sample period, the theoretical fair price of a futures contract at time t with maturity date T is given by:

$$f_{t,T}(p) = S_t + 0.934 \times S_t(\mathrm{e}^{r(T-t)} - 1) - 0.804 \times \sum_{s=t+1}^{T} D_s \mathrm{e}^{r(T-s)} - 0.521 \times \sum_{s=t+1}^{T} IC_s \tag{2}$$

The tax-adjusted mispricing series is defined as:

$$M_t^n(p) = \log F_t^n - \log f_{t,T}(p) \tag{3}$$

where F^n_t is the actual futures bid-ask midpoint price and $f_{t,T}(p)$ is the theoretical futures price at time t for a contract expiring at time T using the tax-adjusted cost-of-carry model.

3. Empirical results

Section 3.1 reports on the behaviour of the mispricing series. In section 3.2 a time series and regression based approach is taken to explain the mispricing series.

3.1 Behaviour of the mispricing series

Table 2 provides descriptive statistics for the mispricing series. The overall mean pricing error is close to zero (-0.010 percent) with a standard deviation of 0.108 percent[21]. The average mispricing is lowest for the June 2002 contract (-0.093 percent) and highest for the September 2003 contract (0.060 percent). These estimates are closer to zero than the estimate of -0.131 percent provided by Brailsford and Hodgson (1997) for average mispricing of the former Australian All Ordinaries Share Price Index futures contract employing only the cash value of the dividend. The results are consistent with the hypothesis that the adjusted cost-of-carry pricing model allowing for the different tax treatment of interest and dividends versus capital gains on stocks and the market value of imputation tax credits produces an unbiased estimate for the futures price[22].

Slightly more than half of the observations (51.8 percent) are negatively mispriced. This result could be due to the relatively higher costs of short selling when the arbitrage strategy calls for shorting rather than buying stocks (also noted by Modest and Sundaresan, 1983 in the United States; Fung and Draper, 1999; 2003 in Hong Kong; Brenner, Subrahmanyam and Uno, 1989a in Japan; Gay and Jung, 1999 in Korea; Vipul, 2005 in India; Kempf, 1998 in Germany; Puttonen and Martikainen, 1991; and Puttonen, 1993 in Finland; and Brailsford and Hodgson, 1997 in Australia). Mispricing is predominantly positive in some periods and negative in other periods, as shown in previous empirical work (for example, Figlewski, 1984b; Klemkosky and Lee, 1991 in the United States; Brenner, Subrahmanyam and Uno, 1989a; 1989b; 1990 in Japan; Yadav and Pope, 1994; Butterworth and Holmes, 2000 in the United Kingdom; and Bowers and Twite, 1985 in Australia).

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[21] When measured as the simple difference between the actual and theoretical index futures contract price, the average mispricing over the entire sample is -0.45 points and the standard deviation is 3.85 points, where each index point is valued at AUD 25.

[22] Similarly for the S&P 500 futures contract, Klemkosky and Lee (1991) find that the frequency of pricing violations notably decreases when taxes are considered in the analysis.

Table 2

Summary statistics on the levels of mispricing in SFE SPI 200[TM] Index Futures contracts employing the tax-adjusted cost-of-carry model, by expiration (5-minute quote snapshot data, mispricing in percent of theoretical futures price)

	$M^n{}_t(p)$				
	Mean %	Std. dev. %	Number positive	Number negative	*N*
Contract					
Mar-02	0.000	0.127	1,903	1,981	3,884
Jun-02	-0.093	0.118	1,048	3,072	4,120
Sep-02	-0.020	0.107	1,747	2,580	4,327
Dec-02	0.044	0.094	2,726	1,098	3,824
Mar-03	0.024	0.110	2,538	1,821	4,359
Jun-03	0.026	0.089	2,138	1,245	3,383
Sep-03	0.060	0.084	3,393	983	4,376
Dec-03	-0.043	0.089	1,413	2,863	4,276
Mar-04	-0.025	0.089	1,539	2,336	3,875
Jun-04	0.006	0.110	2,352	1,744	4,096
Sep-04	0.027	0.101	2,710	1,572	4,282
Dec-04	0.014	0.078	2,419	1,775	4,194
Mar-05	-0.012	0.113	1,780	2,327	4,107
Jun-05	-0.017	0.073	1,786	2,325	4,111
Sep-05	-0.079	0.096	1,056	3,329	4,385
Dec-05	-0.058	0.097	1,295	3,146	4,441
Overall	**-0.010**	**0.108**	**31,843**	**34,197**	**66,040**

Note: $M^n{}_t(p) = \log F^n{}_t - \log f_{t,T}(p)$ where $F^n{}_t$ is the futures bid-ask midpoint price and $f_{t,T}(p)$ is the theoretical futures price employing the tax-adjusted cost-of-carry model.

3.2 Modelling mispricing

In this section, the time series and regression based approach to explaining the mispricing series adopted by Brailsford and Hodgson (1997) is extended to incorporate the impact of unexpected information arrival in both the cash and futures markets and risks and transaction costs faced by arbitrageurs. The modelling process is undertaken in two stages. First, the dynamic and static time series components are filtered out by applying the following model to raw mispricing.

$$M_t^n = \sum_{j=1}^{25} \beta_j M_{t-j}^n + \beta_{26} M_{t-d}^n + \beta_{27} M_{t-2d}^n + \beta_{28} D_{1t} + \beta_{29} D_{2t} + \beta_{30} D_{3t} + \beta_{31} D_{4t} + \beta_{32} D_{5t} + \varepsilon_t \quad (4)$$

The dependent variable $M^n{}_t$ is defined as the difference in logarithms between the market futures price and its theoretical price, that is $M^n{}_t = \log F^n{}_t - \log f_{t,T}$, β_1 to β_{27} are dynamic autoregressive parameters where t is the five-minute sample interval and d is one trading day, $D_1, D_2, \ldots, D_5$ are zero-one dummy variables to test whether there are systematic and fixed mispricing patterns related to each day of the week where D_1 = Monday, …, D_5 = Friday[23]. This model allows a comparison to previous

[23] Garbade and Silber (1983) specify a model which describes the interrelationship between cash market prices and futures prices of storable commodities as a first-order autoregressive process. The

domestic and overseas studies which have identified strong first order autocorrelation and day of the week effects in the mispricing series.

Select results for the time series analysis using equation 4 on the tax-adjusted mispricing series are shown in table 3. For the autoregressive parameters, only the significant estimates are reported.

Table 3
Dynamic and fixed time series components of the tax-adjusted mispricing series

	Estimate	|*t*|	Variable
Coefficient			
β_1	38.939	100.08*	Mispricing lag 1 interval
β_2	14.453	34.64*	Mispricing lag 2 intervals
β_3	9.109	21.64*	Mispricing lag 3 intervals
β_4	6.672	15.80*	Mispricing lag 4 intervals
β_5	4.528	10.70*	Mispricing lag 5 intervals
β_6	2.759	6.52*	Mispricing lag 6 intervals
β_7	2.447	5.78*	Mispricing lag 7 intervals
β_8	1.689	3.99*	Mispricing lag 8 intervals
β_9	2.403	5.67*	Mispricing lag 9 intervals
β_{10}	1.587	3.75*	Mispricing lag 10 intervals
β_{11}	1.561	3.68*	Mispricing lag 11 intervals
β_{12}	1.367	3.23*	Mispricing lag 12 intervals
β_{15}	1.130	2.67*	Mispricing lag 15 intervals
β_{25}	1.139	2.93*	Mispricing lag 25 intervals
β_{27}	1.906	8.29*	Mispricing lag 2 days
β_{28}	0.002	3.61*	Monday dummy
β_{29}	0.001	1.42	Tuesday dummy
β_{30}	-0.002	3.57*	Wednesday dummy
β_{31}	-0.001	1.50	Thursday dummy
β_{32}	-0.001	1.80	Friday dummy
adj R^2	0.76		
F	6,427.55*		
N	66,040		

*Denotes significance at the 1% level. Coefficients are multiplied by 10^2.

The results in table 3 confirm that the mispricing of SFE SPI 200™ futures is highly predictable; consecutive autoregressive coefficients are uniformly positive and significant out to twelve intervals as well as 144 intervals, equivalent to two trading days. The significance of the consecutive autoregressive coefficients indicates a high degree of persistence in the mispricing series, consistent with infrequent trading in the underlying stocks (Miller, Muthuswamy and Whaley, 1994)[24]. In combination with the autoregressive effects, mispricing is significantly higher on Monday and significantly lower on Wednesday than on other days of the week.

After pre-filtering using the model specified in equation 4, the absolute values of the residuals are obtained. The mean absolute residual is 0.031 percent with a standard

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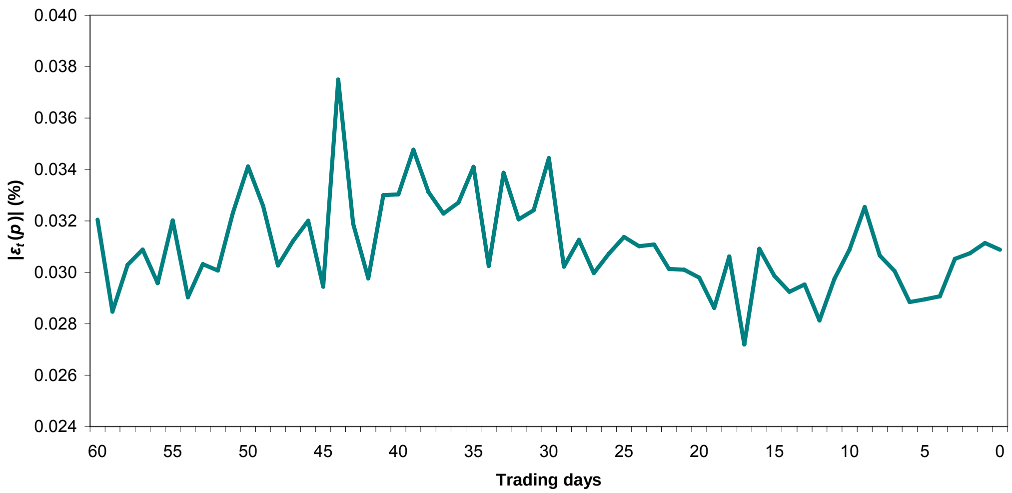
autoregressive parameter δ in their model measures the (inverse of) the elasticity of supply of arbitrage services. Furthermore, Wang and Yau (1994) show that the estimated first-order autoregressive coefficient of the mispricing series can measure the degree of market linkage if it is statistically different from one.

[24] The persistence in the mispricing series is consistent with Klemkosky and Lee (1991), who find that an arbitrage position is still profitable ten minutes after it is initially identified as profitable.

deviation of 0.044 percent as shown in table 4 panel A. The relationship between time to maturity and the absolute residuals is illustrated in figure 1. The absolute residuals are greater in the first half of the expiry cycle. Since the residuals represent the unpredictable innovations in futures contract mispricing, this is consistent with index arbitrage being more risky further out from maturity.

Figure 1
Time-to-expiry pattern in the absolute value of the pre-filtered mispricing series employing the tax-adjusted cost-of-carry model



The impact of explanatory variables is estimated using the following model.

$$\begin{aligned}|\varepsilon_t| = \alpha &+ \beta_1 Opening1_t |US_t| + \beta_2 Opening2_t |US_t| + \beta_3 Volatility_t^n \\ &+ \beta_4 UVolume_t^n + \beta_5 UVolume_t^c + \beta_6 Close_t + \beta_7 TExpiry_t^n \\ &+ \beta_8 UDividend_t + \beta_9 IVInterest_t + \beta_{10} MICost_t + \beta_{11} BCost_t + \varepsilon_t\end{aligned} \quad (5)$$

A number of possible explanatory variables are considered before constructing the above model. Descriptive statistics (panel A) and correlations between the variables representing the risks and transaction costs faced by arbitrageurs (panel B) are presented in table 4. The explanatory variables are defined as follows.

$Opening1_t$ and $Opening2_t$ are zero-one dummy variables for the first two intervals at the opening of stock trading ending at 10.05 a.m. and 10.10 a.m. respectively, included to assess the possible impact of opening procedures in the stock market.

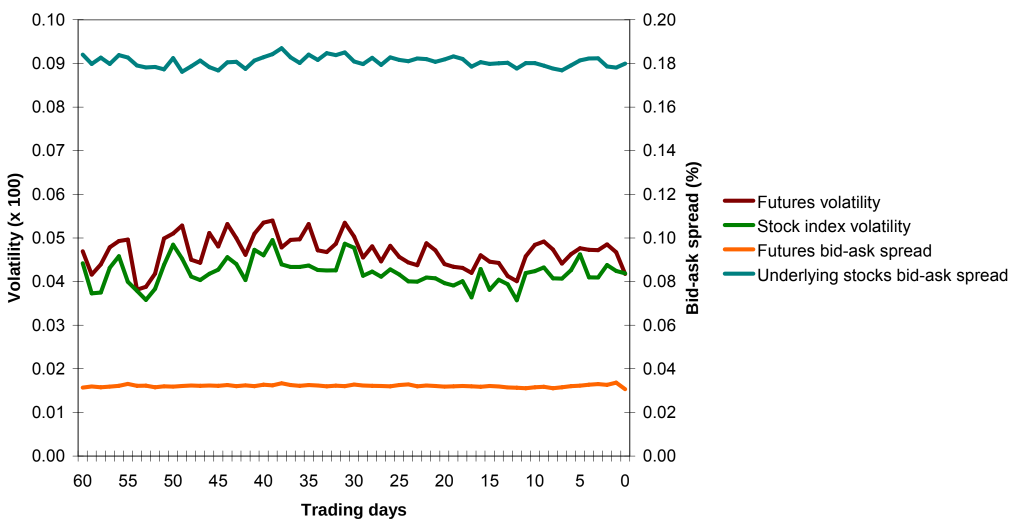
$|US_t|$ is the absolute value of the overnight United States return on the S&P 500 stock index which is only activated at 10.05 a.m. and 10.10 a.m.. This variable is included to test whether the volatility from the United States market, which acts as a proxy for overnight public information arrival, has an impact on the mispricing series in the smaller dependent Australian market.

$Volatility^n_t$ is the price volatility of SFE SPI 200™ futures where volatility is measured in accordance with Bessembinder and Seguin (1992) as:

$$Volatility_t^n = \left|\log(F_t^n) - \log(F_{t-1}^n)\right| \times \sqrt{\pi/2} \tag{6}$$

This variable is used to verify whether intraday price movements in the futures market have a significant impact on the mispricing series. Futures prices are more variable than for the index, consistent with previous research by Hill, Jain and Wood (1988), MacKinlay and Ramaswamy (1988) and Yadav and Pope (1990). This suggests that new information is incorporated with greater speed in the futures market. There does not appear to be any time to expiration pattern in the volatility of spot and futures prices, plotted in figure 2[25].

Figure 2
Time-to-futures-expiry patterns in price volatility and bid-ask spreads



$UVolume^n_t$ and $UVolume^c_t$ are unexpected trading volume of SFE SPI 200™ futures and their underlying stocks respectively. The measure of trading volume for the futures market in a given interval is simply the number of near maturity contracts traded. The stock market turnover ratio is used to proxy for the trading volume of the underlying stocks. It is calculated as the value of total shares traded divided by the aggregate float-adjusted market capitalisation of the index constituents. Following Bessembinder and Seguin (1993), ARIMA models are used to decompose volume into its expected and unexpected components[26]. Repeated tests on the sample do not give any firm evidence of improvement when moving beyond ARMA(1,2) for the futures maturities and ARMA(1,1) for the cash market volume series[27]. To the ARMA

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[25] This is consistent with prior research by Grammatikos and Saunders (1986) based on five different foreign currency futures traded on the International Monetary Market, which finds that while maturity has a strong effect on volume of trading, no such relation could be found for price volatility. Likewise in the spot equity market, Bessembinder and Seguin (1992) find no evidence that S&P 500 volatility varies systematically with the time until maturity of equity index futures contracts. Figure 2 appears to confirm that information arrival in the spot and futures markets is random across contract maturity.

[26] The stationarity of each time series was assessed using augmented Dickey-Fuller tests. The existence of a unit root is rejected for all sixteen futures maturities and the cash market volume series.

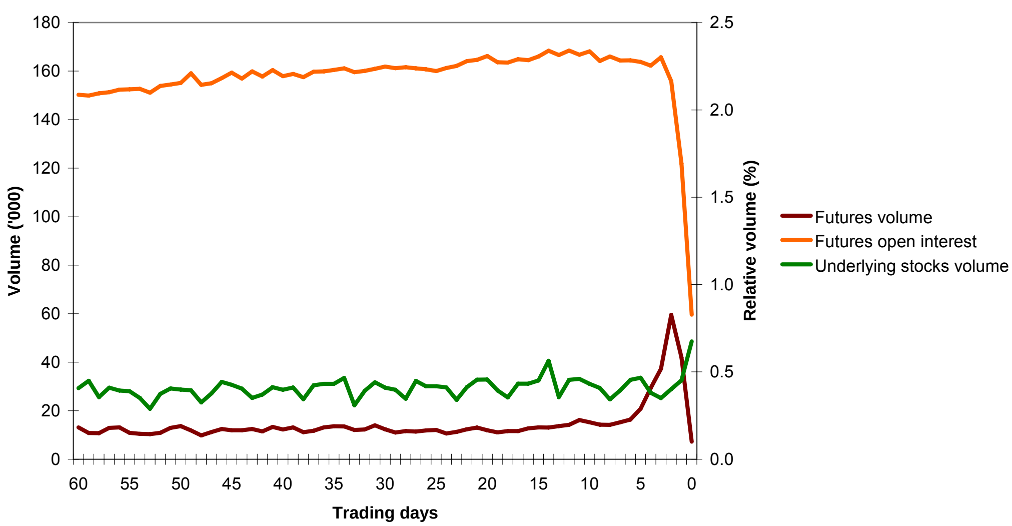
[27] Schwarz's Bayesian criterion is used to determine the orders of the autoregressive and moving average parts in the ARIMA models. Regressions are run using a number of different ARIMA specifications and these do not seem to influence the results.

models dummy variables are added for the opening and close of stock trading[28]. Denoting the raw trading volume as V_t, unexpected volume is expressed as:

$$UVolume_t = \log(V_t) - \log E(V_t) \qquad (7)$$

The level of trading activity in both the futures and stock markets varies cyclically, with the highest levels of activity occurring near contract expiration. Mean spot and futures trading volume for each of the sixty days to expiration are shown in figure 3. Futures trading volume is relatively stable, then increases rapidly and peaks on the third last trading day as traders close out positions in the near contract. Spot trading volume is typically higher at the end of calendar months and on futures expiration days[29].

Figure 3
Time-to-futures-expiry patterns in trading activity



Close$_t$ is a zero-one dummy variable for the close of stock trading at 4.00 p.m. to capture possible effects from traders exiting the market before closing in order to avoid the risk of holding positions overnight.

$TExpiry^n_t$ is time-to-expiry expressed as a fraction of a year, included to test for the time-dependent risks of index arbitrage that simultaneously improve the implicit option component in an arbitrage position.

$UDividend_t$ represents the uncertainty about the magnitude of dividends paid out by underlying stocks. Analyst-by-analyst fiscal year 1 dividend forecasts for all covered stocks are extracted from the I/B/E/S Daily Detail Earnings Estimates History

[28] The cash market volume series is also augmented with a dummy variable corresponding to extraordinarily high stock market turnover of AUD 11.8 billion (1.48 percent of market capitalisation) between 11:05 and 11:10 a.m. on 5 July 2005.

[29] A weekly pattern evident in figure 3 suggests that spot trading volume is lowest on Mondays (usually day 3, 8, 13 and so forth before the third Thursday of the expiry month), possibly due to the lack of an immediate lead from the New York Stock Exchange in resolving the implication of new information for equity prices.

database[30]. All estimates that are current on a particular day (indicated by the estimate date and review date) are used to calculate the standard deviation of dividend per share (DPS) forecasts for an individual stock. Two assumptions are made in proceeding to construct a measure of dividend uncertainty for the index as a whole from the standard deviations for individual stocks: (i) the spread of (equally weighted) analysts' forecasts represents the probability distribution for future dividends; and (ii) the DPS forecasts for individual stocks are uncorrelated. On the basis of these assumptions, dividend yield uncertainty for the index is given by the weighted average standard deviation of analysts' forecasts for constituent stocks:

$$UDividend_t = \frac{\sqrt{\sum_{i=1}^{200}\left(Shares_{i,t} \times StdDev\left(FDPS_{i,t}\right)\right)^2}}{\sum_{i=1}^{200}\left(Shares_{i,t} \times P_{i,t}\right)} \quad (8)$$

where $FDPS_{i,t}$ are analysts' fiscal year 1 dividend per share forecasts for stock i, $Shares_{i,t}$ is the number of shares of stock i included in the index calculation and $P_{i,t}$ is the closing price of stock i on day t. This variable is included to capture possible effects related to the dispersion of analysts' dividend forecasts. The mean dividend yield uncertainty as indicated by this measure is 0.07 to 0.08 percent throughout the contract life cycle as shown in figure 4.

$ADividend^n_t$ is an alternative measure of the time-to-expiry, defined as the proportion of total gross dividends paid by underlying stocks with ex-dividend dates falling within the current futures contract life cycle (from the expiry date of the previous contract until the expiry date of the current near contract) that are announced over the remaining life of the near contract[31]:

$$ADividend^n_t = \frac{\sum_{i=1}^{200}\sum_{a=t+1}^{T_1}\left(Shares_{i,t} \times DPS^n_{i,a}\right)}{\sum_{i=1}^{200}\sum_{w=T_0+1}^{T_1}\left(Shares_{i,t} \times DPS^n_{i,w}\right)} \quad (9)$$

where $DPS^n_{i,a}$ is the gross dividend announced for stock i on day a with the relevant ex-dividend date scheduled to occur before the near contract expires on day T_1 and $DPS^n_{i,w}$ is the gross dividend for stock i with an ex-dividend date w falling between the expiration of the previous futures contract on day T_0 and the expiration of the current near futures contract on day T_1. The announcement of dividend amounts and ex-dividend dates resolves uncertainty relating to both the magnitude and timing of dividends[32]. The scheduling of ex-dividend dates that accompanies dividend

[30] Each dividend forecast record contains broker and analyst codes, the forecast period end date, the estimated dividend in cents per share, the date the estimate was entered into the database (estimate date) and the most recent date that the estimate was confirmed as accurate (review date).
[31] A daily dividend series for individual stocks obtained from Bloomberg identifies the announcement dates, ex-dividend dates and payment dates associated with net and gross dividends per share paid by stocks in the S&P/ASX 200.
[32] Peters (1985) shows that the increasing efficiency of index futures markets through time appears to be due to better estimation of the dividend stream for each index and its uneven characteristics.

announcements could substantially reduce uncertainty, if it was unpredictable whether some dividends would be assigned ex-dividend dates before or after futures contract expiration relying upon the timing of corresponding dividends in previous years. Figure 5 shows the proportion of total gross dividends that remain unannounced against the time to maturity of the contract. The frequency of dividend announcements (reflected in the slope of the curve) increases around the middle of the futures contract life cycle, together with the periodic reporting of Australian company results. Almost all companies going ex-dividend before futures maturity have declared their dividends by three weeks out from maturity.

$IVInterest_t$ is the volatility implied in interest rate option prices, expressed as an annualised percentage. Interest rate option contracts based on 90 Day Bank Accepted Bills Futures are traded on the Sydney Futures Exchange and expire on the first Friday of the delivery month for the underlying futures contract. Up to six maturities corresponding to the bank bill futures quarterly maturity cycle and several exercise prices were available at any one time. The implied volatility estimates used in this study are those provided by market participants and used by the Sydney Futures Exchange to determine daily closing prices for nearest-to-expiry put and call options which are closest to being at-the-money. Ex-ante volatility is relatively greater in interest rates (0.12 percent) than dividend yields (0.08 percent) and may play an important role in determining the mispricing series. From figure 4, the implied volatility of interest rate options further out from maturity is higher than that close to maturity (taking into consideration that options on bank bill futures expire earlier in the delivery month than SFE SPI 200™ futures)[33].

$REconomic^n_t$ is another alternative measure of the time-to-expiry, defined as the proportion of economic releases falling within the current futures contract life cycle that are scheduled to occur over the remaining life of the near contract:

$$REconomic_t^n = \frac{\sum_{r=t+1}^{T_1} EIR_r^n}{\sum_{r=T_0+1}^{T_1} EIR_r^n} \qquad (10)$$

where EIR^n_r is the number of separate types of economic releases on day r between the expiration of the previous futures contract on day T_0 and the expiration of the current near futures contract on day T_1. Data for macroeconomic news releases were obtained from Bloomberg's *Economic Calendar*. The releases selected were those found by Connolly and Kohler (2004) to have a significant effect on interest rate expectations for Australia: the consumer price index, employment, the unemployment rate, gross domestic product, building approvals, the trade balance, inventories,

[33] In comparison, Amin and Morton (1994) determine a daily time series of forward rate volatilities most consistent with Eurodollar futures options prices on the Chicago Mercantile Exchange (CME). They find that the volatility of longer-term forward rates is higher than that of short-term rates. Similarly, Neely (2005) observes that long-horizon implied volatilities tend to be larger than short-horizon implied volatilities of options on Eurodollar futures.

investment and retail sales[34]. These types of economic releases resolve interest rate uncertainty because they provide information which enables market participants to reassess the likely outcome of subsequent Reserve Bank decisions on interest rates[35]. Figure 5 shows they are relatively evenly spread over the futures contract life cycle, except increase in frequency in the third last trading week and are never scheduled in the last week before expiration.

Figure 4
Time-to-futures-expiry patterns in dividend yield uncertainty and interest rate volatility

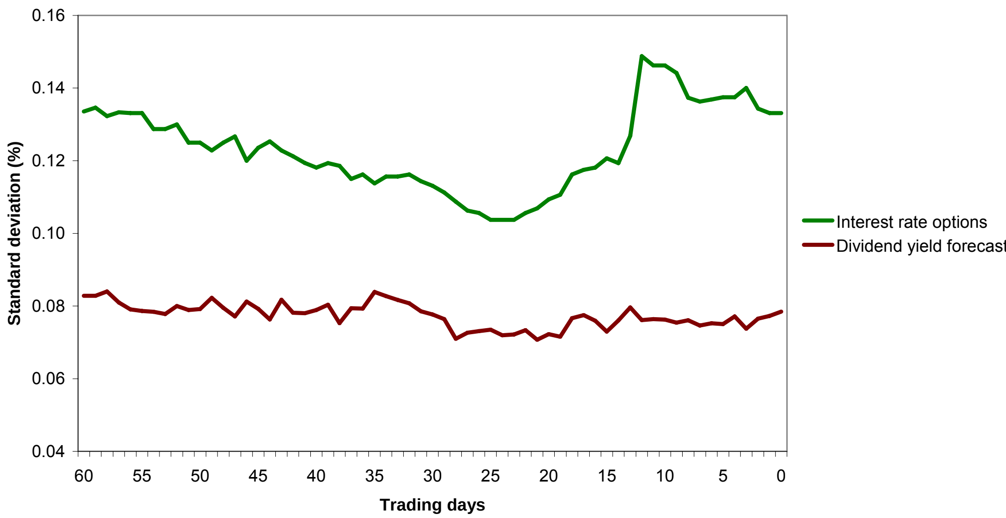
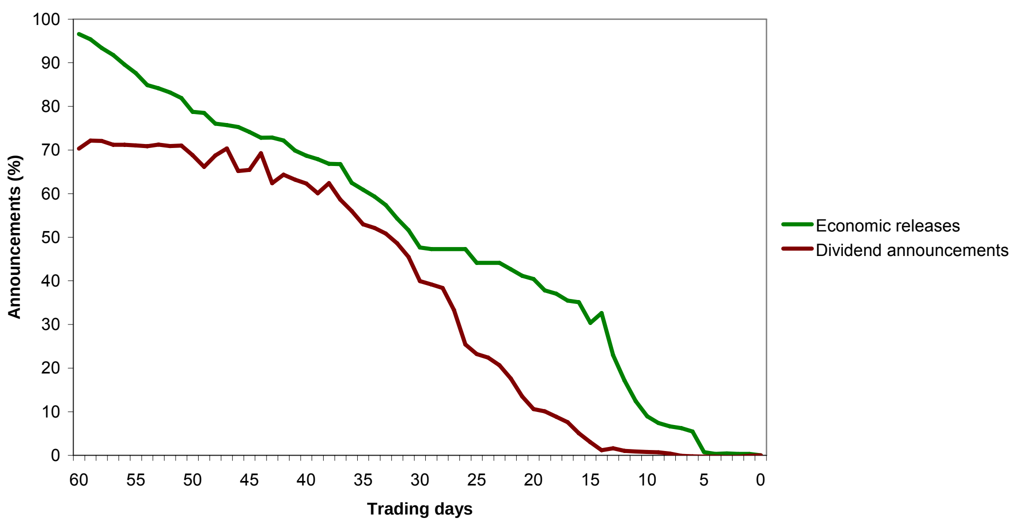


Figure 5
Time-to-futures-expiry patterns in dividend announcements and economic releases



[34] Although we confine ourselves to domestic economic releases in this study, Connolly and Kohler (2004) find that foreign market movements modelled as changes in United States interest rate futures prices are also important in explaining changes in interest rate expectations for Australia.
[35] The Reserve Bank Board formulates monetary policy with regard to developments in the Australian and international economies.

$MICost_t$ is the market impact cost involved in opening an index arbitrage position, measured as the sum of one-half the bid-ask spread in the stock market and one-half the bid-ask spread in the futures market[36]. A percentage bid-ask spread (*BAS*) is computed for every quotation as: $BAS = [(ask - bid)/(ask + bid)/2]$. Following McInish and Wood (1992), time-weighted bid-ask spreads for both futures and individual stocks in each time interval are calculated as follows:

$$BASpread_t = \frac{\sum_{j=1}^{n} BAS_j wt_j}{\sum_{j=1}^{n} wt_j} \tag{11}$$

where

BAS_j = the percentage quoted bid-ask spread;
wt_j = the length of time that spread j is outstanding; and
n = the number of different bid-ask spreads that occur during interval t.

In the case of the constituent stocks in the index, the percentage bid-ask spreads for individual stocks are further weighted according to the float-adjusted weight of each stock in the index, such that the bid-ask spreads of stocks with the greatest weight in the index have the greatest weight in the composite measure of index percentage bid-ask spread. The mean bid-ask spreads are approximately 0.03 percent in the futures market and 0.18 percent in the stock market throughout the contract life cycle as shown in figure 2. The substantially wider bid-ask spread for the underlying stocks than for the futures suggests it has a greater influence on the width of the trading band for futures prices. Bid-ask spreads are also more variable in the stock market than in the futures market.

$BCost_t$ is the minimum indicative fees for the use of borrowed securities reported by King (2005a) of 25 basis points per annum for ASX 200 index stocks and 5 basis points per annum for bank accepted bills. The stock borrowing fee for sell programs is applied when the mispricing is negative and the lower bank accepted bills borrowing fee for buy programs is applied when the mispricing is positive.

$Interest^n_t$ is the logarithm of the end-of-day open interest in SFE SPI 200™ futures measured in number of contracts. Open interest accumulates steadily across the contract life cycle and then dissipates rapidly from the third last trading day, as shown in figure 3. The correlation between the open interest and the time-to-expiry is -0.11 (see table 4, panel B).

[36] The bid-ask spreads and price impact costs of closing out both the stock and futures positions can be avoided by holding the positions until the last trading day and employing market-on-open orders in the stock market.

Table 4
Summary statistics for entire dataset

Panel A: Descriptive statistics

	Unit	Mean	Median	Std dev	*N*
Absolute tax-adjusted residual $\lvert\varepsilon_t(p)\rvert$	%	0.031	0.022	0.044	66,040
Overnight return on S&P 500 index $\lvert US_t\rvert$	%	0.805	0.609	0.755	64,239
Futures five-minute volatility	% x $\sqrt{\pi}/2$	0.048	0.036	0.081	66,040
S&P/ASX 200 index five-minute volatility	% x $\sqrt{\pi}/2$	0.043	0.026	0.063	66,040
Futures five-minute volume	Lots	108	71	118	66,040
Underlying stocks five-minute volume	%	0.004	0.003	0.006	66,032
Dividend yield uncertainty	% p.a.	0.077	0.074	0.034	66,040
Interest rate options implied volatility	% p.a.	0.123	0.110	0.044	65,685
Market impact cost	%	0.106	0.105	0.018	66,032
Borrowing cost	%	0.017	0.010	0.016	66,040
Futures open interest	Lots	159,531	156,755	22,933	65,627

Panel B: Correlation matrix

	$TExpiry^n_t$	$UDividend_t$	$ADividend^n_t$	$IVInterest_t$	$REconomic^n_t$	$MICost_t$	$BCost_t$
$UDividend_t$	0.048						
$ADividend^n_t$	0.826	-0.097					
$IVInterest_t$	-0.021	-0.412	0.083				
$REconomic^n_t$	0.953	0.147	0.769	-0.182			
$MICost_t$	0.012	-0.296	0.067	0.337	-0.074		
$BCost_t$	0.563	0.087	0.382	-0.033	0.536	-0.078	
$Interest^n_t$	-0.113	0.175	-0.212	-0.426	-0.002	-0.379	0.029

The explanatory variables which act as proxies for the unexpected arrival of information in the futures and stock markets and the close of trading in the stock market, while controlling for specific risks and transaction costs faced by arbitrageurs, are considered using equation 5. White's procedure is used to obtain heteroskedasticity-corrected standard errors of the parameter estimates (White, 1980). All *t*-statistics are adjusted accordingly. The results are presented in table 5.

Table 5
Estimation of the explanatory coefficients for the absolute value of the pre-filtered mispricing series employing the tax-adjusted cost-of-carry model

	Estimate	$\lvert t\rvert$	Variable
Coefficient			
α	0.002	1.47	Intercept
β_1	6.838	9.74*	Impact of overnight US return at 10.05 a.m.
β_2	5.744	13.61*	Impact of overnight US return at 10.10 a.m.
β_3	32.447	28.62*	Volatility of SFE SPI 200™ futures
β_4	0.001	2.70*	SFE SPI 200™ futures unexpected volume
β_5	-0.002	5.72*	Underlying stocks unexpected volume
β_6	0.005	5.98*	S&P/ASX 200 close at 4.00 p.m.
β_7	0.005	2.82*	Time-to-expiry
β_8	0.049	0.14	Dividend yield uncertainty
β_9	0.968	3.17*	Interest rate options implied volatility
β_{10}	9.770	7.52*	Market impact cost
β_{11}	0.388	0.47	Borrowing cost
adj R^2	0.62		
N	63,871		

*Denotes significance at the 1% level. Coefficients are multiplied by 10^2.

The coefficients on the variables designed to capture the impact of volatility from the United States stock market (β_1 and β_2) are positive and significant. An overnight price movement of one percent in the United States stock market is associated with increases in the absolute residual mispricing of 0.07 percent at 10.05 a.m. and 0.06 percent at 10.10 a.m. immediately after the opening of the local stock market. The increased mispricing spread at 10.05 a.m. is consistent with the impact of opening procedures in the stock market lasting nine minutes. Beyond the first interval, the persistently higher mispricing spread at 10.10 a.m. supports the proposition that foreign market movements signal increased trading risk, which in turn dampens opening arbitrage activity. The impact of volatility in SFE SPI 200™ futures prices is positive and highly statistically significant[37]. A price movement of one percent in the futures market is associated with an increase in the mispricing spread of $0.32447/\sqrt{\pi/2} = 0.26$ percent. This result is consistent with the hypothesis that market-wide information is incorporated with greater speed in the futures market relative to the underlying stock market. The impact of surprise trading volume in the futures is also positive and statistically significant. In contrast, surprise trading volume in the underlying stocks is negative and statistically significant[38]. This suggests that trading activity in executing the cash leg of arbitrage transactions dominates trading activity based on firm specific information in moving spot prices. Surprise volume in the underlying stocks more often signifies the presence of arbitrageurs acting to narrow price discrepancies relative to the futures market[39].

Although the coefficient which accounts for the close of trading (β_6) is statistically significant, the increase in the mispricing spread at the close of the stock market is inconsequential in magnitude.

The coefficients on the volatility implied in interest rate option prices (β_9) and the time-to-expiry (β_7) are positive and significant, implying that the higher the ex-ante interest rate volatility and the longer the time-to-expiry, the higher is the mispricing spread. The finding with respect to time-to-expiry is robust to the three different time measures ($TExpiry^n_t$, $ADividend^n_t$ and $REconomic^n_t$). The variable which proxies for dividend yield uncertainty is statistically insignificant. These results indicate that ex-ante interest rate volatility is the primary source of risk faced by arbitrageurs when they act upon deviations from theoretical pricing levels for longer times to maturity. As the absolute residual mispricing measures the volatility of the irregular component of the mispricing series, these results also imply that ex-ante interest rate volatility in combination with the time until contract expiration are the source of the implicit option value in arbitrage positions. Through its influence on interest rate volatility,

[37] The contemporaneous relationship documented here portends the intraday temporal relationship characterised by Chan and Chung (1993) in the United States: higher intraday volatility is *followed* by a significant decrease in the arbitrage spread, probably because higher market volatility invites more arbitrage services or enables faster price adjustments which, in turn, narrow the spread.

[38] Regarding the relationship between explanatory variables, Merrick (1987) provides strong evidence that cash index return volatility causes aggregate cash market volume. Therefore, in attempting to discern the relationship between the intraday mispricing spread and surprise trading volume in the underlying stocks, it is appropriate to have employed a measure of intraday price volatility to help control for volume surprises unrelated to arbitrage motives or firm specific information.

[39] This finding is consistent with the evidence provided by Furbush (1989) that index arbitrage responds to basis error and has the effect of eliminating it, thus aligning cash and futures prices. It also complements the evidence of a significant unidirectional relationship running from the futures contract mispricing spread to cash market volume found by Merrick (1987), using daily data for the New York Stock Exchange Composite index market.

public information arrival has a more lasting effect on the mispricing spread than from the faster speed of adjustment of intraday futures prices relative to stock prices.

The coefficient on the market impact cost involved in opening up index arbitrage positions (β_{10}) is positive and significant. An increase of one percent in the market impact cost is associated with an increase in the absolute residual mispricing of 0.10 percent. This result with respect to implicit transaction costs demonstrates that fluctuations in the cost of immediacy in the stock and futures markets have the most important influence on the width of the arbitrage bounds for index futures. In contrast, the securities borrowing cost coefficient (β_{11}) is positive and insignificant. While the positive coefficient on the borrowing cost implies that short arbitrage positions are more expensive to maintain over longer holding periods, there is only weak evidence that the pricing of the near contract deviates from its theoretical level more frequently as a consequence of the cost of borrowing index stocks.

3.3 Robustness tests

Additional regression analysis is reported in this section to provide results that are directly comparable with Brailsford and Hodgon's (1997) examination of stock index futures pricing using the former Australian All Ordinaries Share Price Index futures contract. In particular, Brailsford and Hodgson implicitly assume that investors face the same marginal tax rate on all forms of income; they do not obtain any reduction in the cost of financing the set of shares of the underlying index through the tax deductibility of interest on loans ($\tau_1 = 0$), the full cash value of the dividend is employed ($\gamma_1 = 1$) and the imputation tax credits are not priced in index futures ($\gamma_2 = 0$). Based on those assumptions, equation 1 for the theoretical price of a futures contract can be reduced as follows:

$$f_{t,T}(c) = S_t \mathrm{e}^{r(T-t)} - \sum_{s=t+1}^{T} D_s \mathrm{e}^{r(T-s)} \tag{12}$$

where $f_{t,T}(c)$ is the fair value at time t of an index futures contract with cash dividends. The unadjusted mispricing series is defined as:

$$M_t^n(c) = \log F_t^n - \log f_{t,T}(c) \tag{13}$$

where F^n_t is the actual futures bid-ask midpoint price and $f_{t,T}(c)$ is the theoretical futures price at time t for a contract expiring at time T using the unadjusted cost-of-carry model.

For the unadjusted series, the overall mean pricing error is negative (-0.047 percent) with a standard deviation of 0.112 percent as shown in table 6 panel A. This result is consistent with the hypothesis that the unadjusted forward pricing model gives an upward biased estimate for the futures price[40]. Select results for the time series

[40] Several overseas studies find evidence of substantial and sustained mispricing using the cost-of-carry pricing model without adjustment for the taxation treatment of interest and dividends relative to capital gains on stocks. In the United States, Cornell and French (1983), Figlewski (1984a) and Arditti, Ayaydin, Mattu and Rigsbee (1986) report that stock index futures were priced at a discount to the levels predicted by the carrying cost relationship, while Bhatt and Cakici (1990) and Chung (1991)

analysis using equation 4 on the unadjusted mispricing series are shown in table 6 panel B. The estimated coefficients are similar to those obtained using the tax-adjusted cost-of-carry model and also confirm Brailsford and Hodgson's (1997) finding that the mispricing series in Australia is highly predictable[41]. The intraday mispricing series evolves more gradually; higher autoregressive coefficients at subsequent lags compensate for a lower coefficient at the first lag of 0.390 than reported by Brailsford and Hodgson for All Ordinaries Share Price Index futures (0.689). Negative mispricing of All Ordinaries Share Price Index futures on Friday documented by Brailsford and Hodgson is prevalent throughout the latter part of the week (from Wednesday to Friday) in our study of SFE SPI 200™ futures[42]. Except for Wednesday, the day of the week effects are sensitive to whether the unadjusted or tax-adjusted model is used. The R^2 statistic of 0.81 is higher than for the time series components of the tax-adjusted mispricing series. This implies that the excess variation in the unadjusted mispricing series is explained by time series effects; any misspecification of the financing charge and dividend flow is serially correlated at consecutive points across the contract life cycle.

Results of estimating equation 5 with the absolute residuals after pre-filtering the unadjusted mispricing series are reported in table 7. The results are not materially different from those based on the tax-adjusted series. Brailsford and Hodgson's (1997) findings for All Ordinaries Share Price Index futures are verified for SFE SPI 200™ futures. In particular, the important role of both exogenous and endogenous futures price volatility in increasing the mispricing spread is confirmed for SFE SPI 200™ futures: the impact of volatility from the overnight United States stock market and the volatility of Australian futures prices are both positive and statistically significant. Moreover, unexpected futures trading volume is significant. The positive coefficient on the time-to-expiry documented by Brailsford and Hodgson is smaller and statistically insignificant in our sample. This result suggests that the inherent option value in the mispricing series has decreased as the pricing efficiency of the Australian market has improved in recent years. With the inclusion in the model of risks and transaction costs faced by arbitrageurs, the intercept of 0.002 percent is smaller than observed by Brailsford and Hodgson (0.030 percent).

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report they are priced at a premium. In Canada, Hong Kong, Korea, India, the United Kingdom, Germany and Finland respectively, Chamberlain, Cheung and Kwan (1989), Draper and Fung (2003), Gay and Jung (1999), Vipul (2005), Yadav and Pope (1990), Bühler and Kempf (1995) and Kempf (1998), Puttonen and Martikainen (1991) and Puttonen (1993) provide evidence that futures tend to be priced at discounts to theoretical values.

[41] In comparison, MacKinlay and Ramaswamy (1988), Lim (1992) and Bühler and Kempf (1995) find that mispricing levels are highly positively autocorrelated for S&P 500 futures across fifteen-minute time intervals, Nikkei 225 futures across five-minute intervals and DAX futures across one-minute intervals respectively.

[42] This result contradicts the divergence between cash and futures market behaviour on Friday reported by Yadav and Pope (1992) in the United Kingdom.

Table 6
Dynamic and fixed time series components of the unadjusted mispricing series

	$M^n{}_t(c)$	$\|t\|$	Variable
Panel A: Descriptive statistics			
Mean	-0.047		
Median	-0.040		
st. dev.	0.112		
N	66,040		
Panel B: Dynamic and fixed time series components			
β_1	38.979	100.18*	Mispricing lag 1 interval
β_2	14.480	34.70*	Mispricing lag 2 intervals
β_3	9.117	21.66*	Mispricing lag 3 intervals
β_4	6.686	15.83*	Mispricing lag 4 intervals
β_5	4.543	10.74*	Mispricing lag 5 intervals
β_6	2.768	6.54*	Mispricing lag 6 intervals
β_7	2.455	5.80*	Mispricing lag 7 intervals
β_8	1.692	3.99*	Mispricing lag 8 intervals
β_9	2.413	5.70*	Mispricing lag 9 intervals
β_{10}	1.593	3.76*	Mispricing lag 10 intervals
β_{11}	1.569	3.70*	Mispricing lag 11 intervals
β_{12}	1.371	3.24*	Mispricing lag 12 intervals
β_{15}	1.131	2.67*	Mispricing lag 15 intervals
β_{25}	1.147	2.95*	Mispricing lag 25 intervals
β_{27}	1.987	8.68*	Mispricing lag 2 days
β_{28}	0.001	2.17	Monday dummy
β_{29}	0.000	0.54	Tuesday dummy
β_{30}	-0.002	5.35*	Wednesday dummy
β_{31}	-0.002	3.31*	Thursday dummy
β_{32}	-0.002	3.38*	Friday dummy
adj R^2	0.81		
F	8,635.52*		

*Denotes significance at the 1% level. Coefficients are multiplied by 10^2.

Table 7
Estimation of the explanatory coefficients for the absolute value of the pre-filtered mispricing series employing the unadjusted cost-of-carry model

	Estimate	$\|t\|$	Variable
Coefficient			
α	0.002	1.40	Intercept
β_1	6.843	9.77*	Impact of overnight US return at 10.05 a.m.
β_2	5.747	13.64*	Impact of overnight US return at 10.10 a.m.
β_3	32.483	28.70*	Volatility of SFE SPI 200™ futures
β_4	0.001	2.63*	SFE SPI 200™ futures unexpected volume
β_5	-0.002	5.71*	Underlying stocks unexpected volume
β_6	0.005	5.96*	S&P/ASX 200 close at 4.00 p.m.
β_7	0.005	2.42	Time-to-expiry
β_8	0.033	0.10	Dividend yield uncertainty
β_9	0.946	3.10*	Interest rate options implied volatility
β_{10}	9.858	7.56*	Market impact cost
β_{11}	0.907	1.10	Borrowing cost
adj R^2	0.62		
N	63,871		

*Denotes significance at the 1% level. Coefficients are multiplied by 10^2.

4. Conclusion

A mispricing series using five-minute contemporaneous observations from the Australian S&P/ASX 200 spot index and SFE SPI 200™ futures market over a period of four years is constructed and analysed, using the time series and regression based approach of Brailsford and Hodgson (1997). A tax-adjusted cost-of-carry model, which accounts for the discrete and seasonal dividend payments of the underlying stocks, as well as the different taxation treatment of the financing charge and dividend flow relative to capital gains on stocks and the pricing of the imputation tax credits on franked dividends, is used as the valuation method for the futures contract. Overall, the results indicate that the mean pricing error is close to zero and noticeably less volatile than in other studies, confirming that the tax-adjusted market valuation model produces a relatively unbiased estimate for the futures price. Slightly more than half of the observations are negatively mispriced, consistent with the higher transaction costs involved in short selling stock.

Time series analysis confirms that the raw mispricing exhibits a high degree of autocorrelation and predictability. Mispricing based on the tax-adjusted series is significantly higher on Monday and significantly lower on Wednesday. After filtering out the dynamic and static time series components, a number of explanatory variables are significantly associated with the absolute residual mispricing. Overnight public information arrival modelled as volatility from the United States stock market and market-wide information arrival modelled as unexpected trading volume and the volatility of SFE SPI 200™ futures are confirmed to have a positive and significant impact on the mispricing spread. In addition, the negative impact of unexpected trading volume in the underlying stocks is consistent with the presence of index arbitrageurs acting to narrow price disparities relative to the futures market. In support of the differential information hypothesis, this finding highlights that the adjustment of the underlying stock market to macroeconomic information is facilitated by price discovery in the futures market.

Indicated by its impact on the mispricing spread, ex-ante interest rate volatility is the primary source of risk faced by arbitrageurs when they act upon deviations from theoretical pricing levels further out from maturity. From the standpoint of the central bank therefore, the efficiency of the arbitrage mechanism is improved by smoothing short-term interest rates. In contrast, the impact on the near contract of dividend yield uncertainty based on the dispersion of analysts' forecasts for index constituent stocks is statistically insignificant and appears to be trivial. The implicit transaction cost represented in bid-ask spreads involved in opening up stock and futures positions have the most important influence on the width of the arbitrage bounds for index futures. Arbitrageurs require greater compensation to step into the market when bid-ask spreads for the index constituents are large. This follows because bid-ask spreads for the underlying stocks are wider and more variable than in the futures market. There is little evidence that the pricing of the near contract deviates from its theoretical level more frequently due to the cost of borrowing stocks. From the standpoint of securities exchanges and regulators therefore, the efficiency of the arbitrage mechanism is improved by increasing the level of liquidity in the stock market; thereby strengthening the most vulnerable point relied upon to maintain the price linkage between stock index futures and their underlying shares.

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