
A COMPARISON OF FUTURES PRICING MODELS IN A NEW MARKET: THE CASE OF INDIVIDUAL SHARE FUTURES

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INTRODUCTION

The pricing of futures contracts has received much attention in the literature, particularly in regard to stock index futures. Most of these studies generally involve a comparison of traded futures prices with prices generated from a theoretical model. Financial economists typically rely upon the concept of arbitrage and argue that any mispricing of a futures contract will not be prevalent, systematic, or sustained, because the actions of arbitrageurs will ensure that prices revert to correct levels. In contrast to this, however, there is documented evidence of pricing errors in stock

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index futures. Indeed, the literature has begun to focus specifically on the behavior of the mispricing series [e.g., Miller, Muthuswamy, and Whaley (1994), Vaidyanathan and Krehbiel (1992), Yadav and Pope (1992, 1993)].

The prevalence of mispricing as a persistent feature of futures markets is difficult to accept from a theoretical viewpoint, because it implies that the pricing models are incorrect and/or the market is inefficient. Researchers have tended to argue that observed mispricing is due to research method problems in implementing empirical tests of theoretical models. As such, each new piece of research has generally refined the method of previous work and sought to eliminate potential biases. It is reasonable to say, however, that much of this research is subject to two inherent problems. First, existing research is subject to Black's (1993) criticism of data mining. This issue is especially present in the research area of stock index futures, as there is a relatively short history of trading compared to other financial time series. Furthermore, there is only a small number of markets in which index futures are traded. The second problem is that index futures have inherent features that make pricing tests problematic.¹

In this article the issue of futures pricing is examined in the context of individual share futures (ISFs). These contracts have recently been listed in Australia and represent futures contracts on individual stocks. The purpose of the article is twofold. First, new evidence is provided on the pricing of equity futures with the use of ISFs that have characteristics that overcome some of the research-method deficiencies of index futures pricing studies. Therefore, a cleaner experiment can be conducted. The article compares three alternative pricing models. Previous tests of index futures pricing have tended to focus on the cost-of-carry model, with only a few studies [e.g., Bailey (1989), Cakici and Chatterjee (1991), and Hemler and Longstaff (1991)] comparing this model with an alternative. In this article three models are tested, including a modified cost-of-carry. The method provides an explicit comparison of pricing errors against which each of the models can be evaluated. Furthermore, the article enables an assessment of how a new market performs.

The results of this study provide evidence of frequent but small pricing errors before transaction costs, but a low frequency of pricing errors in excess of transaction costs bounds, except for very illiquid contracts.

¹Problems associated with pricing tests of index futures include the general inability to trade the underlying index as an individual security, thin trading in the constituent stocks of the index, and the inability to adjust for all dividend payments in the underlying index. These problems are discussed in detail later.

These findings imply that sustained arbitrage profits are unlikely to exist. The results are consistent across all three pricing models. Hence, the market for ISFs is generally efficient. With respect to the relative performance of the three pricing models, the evidence supports the Hemler-Longstaff model, although there is no clear superiority over the other models. Finally, the mispricing series is found to be a function of time to expiry and the presence of dividends on the underlying stock. This latter finding is consistent with the view that the Australian market has difficulty in determining the value of dividends under the imputation tax system.

PRICING OF EQUITY FUTURES CONTRACTS

The behavior and pricing of index futures contracts has been studied extensively in relation to futures exchanges in various markets.² Most of this empirical work has focused on the cost-of-carry model, or some variant thereof, following the seminal work of Black (1976).³ Empirical studies generally compare observed prices (F_t^*) with theoretical prices (F_t) generated by a pricing model to arrive at a pricing error, namely,

$$e_t = F_t^* - F_t. \quad (1)$$

Most of the studies have found frequent, but small, pricing violations. [See Kolb (1994, p. 412) for a summary.] Early research by Modest and Sundaresan (1983) and Modest (1984) indicated that arbitrage profits were available for some traders. More recently, the evidence has been mixed, with variations in the sign of the pricing error (and hence the boundary of violation). Some studies [e.g., Bhatt and Cakici (1990), Cakici and Chatterjee (1991), Klemkosky and Lee (1991), and MacKinlay and Ramaswamy (1988)] have found the mean of e_t to be positive such that index futures trade at a premium. Other studies [e.g., Bailey (1989) and Figlewski (1984)] report that the mean of e_t is negative. A further group of studies [e.g., Lim (1992), Twite (1991), and Stulz, Wasserfallen,

²For example, the pricing of index futures has been examined in Australia by Bowers and Twite (1985), Heaney (1995), and Twite (1991); in Japan by Bailey (1989) and Lim (1992); in Switzerland by Stulz, Wasserfallen, and Stucki (1990); and in the U.S. by Bhatt and Cakici (1990), Cakici and Chatterjee (1991), Cornell and French (1983), Figlewski (1984), Hemler and Longstaff (1991), Klemkosky and Lee (1991), MacKinlay and Ramaswamy (1988), Modest and Sundaresan (1983), and Stoll and Whaley (1988), among others.

³Note that the cost-of-carry model is actually a forward, not futures, pricing model. Accordingly, in using the model to price futures contracts, an implicit assumption is made that forward and futures prices are equal. Cox, Ingersoll, and Ross (1981) showed that this will be the case where certain conditions, such as the assumption that interest rates are nonstochastic, hold. The issue of stochastic interest rates is examined in more detail later in this article.

and Stucki (1990)] is characterized by the common conclusion that the mean of e_t is not different from zero after allowing for transaction costs.

Because violations of the pricing relationship signal that arbitrage opportunities may be available, the presence of violations is *prima facie* inconsistent with an efficient market. This conclusion is of substantial concern to policymakers since it lends support to the argument that futures trading induces irrational pricing. However, researchers typically have argued that the observed violations are attributable to problems inherent with the model specification and/or testing method.

Specifically, at least six arguments have been put forward to explain the observed stock index futures pricing violations. First, studies typically have used daily price data on both the futures and stock index series. These data are associated with problems of nonsynchronous trading between the futures and spot indices⁴ and nonsynchronous trading in the constituent stocks of the underlying index. Studies that have attempted to overcome this problem through the use of intraday data have still documented pricing errors [e.g., Chung (1991), Klemkosky and Lee (1991), and MacKinlay and Ramaswamy (1988)]. Furthermore, Miller et al. (1994) show that nonsynchronous trading in the stock market induces autocorrelation in market index changes, which affects pricing errors. These problems are not present when examining ISFs provided a matched transaction data set is used, which is the case in this study.

Second, many stock indices on which index futures are traded are not tradeable instruments. The result of this feature is that, in practice, an exact position in the underlying asset is not possible and specification risk is introduced that may induce violations of the pricing relationship. An advantage of ISFs is that this risk is not present, by definition.

Third, the pricing of index futures requires an assumption that dividends are known. In the case of stock index futures, pricing models are often applied under the (unrealistic) assumption that the index earns a dividend yield that is constant and continuous. The impact of this assumption can be substantial, as demonstrated by Harvey and Whaley (1992), who show that large pricing errors can result from dividend misspecification. To overcome the dividend problem, the model is typically operationalized by tracking the daily dividend yield on the underlying basket of stocks [e.g., MacKinlay and Ramaswamy (1988), Bailey (1989), Bhatt and Cakici (1990), and Yadav and Pope (1990)].⁵ However, it is

⁴In some markets, the futures and spot indices do not trade over identical hours and have different closing times.

⁵Bhatt and Cakici (1990) found that pricing errors on the S&P 500 index contract are significantly related to the daily dividend yield. In contrast, Yadav and Pope (1990) find that dividend misspecifications of up to 50% only induce a change in fair value of less than 1%.

clear that this method of dividend measurement is more susceptible to error in the case of stock index futures than for individual stocks. Accordingly, the known dividend assumption will generally hold in the case of ISFs, because of the lead time relating to dividend announcements.⁶

A separate complication arises in respect of dividends paid by Australian companies, due to Australia's dividend imputation system of taxation. This system is described in Appendix 1.⁷

Fourth, Cornell and French (1983) argue that tax timing options can create a difference between observed and theoretical futures prices. However, the value of this option is expected to be small, as shown by Bhatt and Cakici (1990), and institutional differences in the U.S. and Australian taxation systems mean that the theoretical basis of the argument is unlikely to apply to the case of ISFs contracts.⁸ Moreover, the empirical evidence generally does not support tax timing options as an explanation of pricing errors in index futures [e.g., Cornell (1985) and Twite (1991)].

Fifth, as noted earlier, the standard cost-of-carry model invokes the assumption of nonstochastic interest rates. Under this assumption, forward and futures prices are identical. However, if interest rates are stochastic, Cox, Ingersoll, and Ross (1981) show that forward and futures prices can be divergent. This issue has been addressed by either directly testing traded futures and forward prices⁹ or by using a framework that incorporates stochastic interest rates.

Two models that incorporate stochastic interest rates have been subject to empirical tests but not directly compared with each other. The

⁶In a minority of cases, trading in very long-dated ISFs contracts will occur without certain knowledge of future dividends. In these circumstances, the assumption of a known dividend may be invalid. This issue is further addressed in the empirical tests.

⁷The potential problem introduced by this system relates to the determination of the value of the dividend to include in the pricing equation. This value is bounded by the cash amount of dividend received (such that the value of the imputation tax credit is zero) and the cash value plus the full value of the imputation credit (where the value of the imputation tax credit is the amount of corporate tax already paid). The market is likely to value the dividend at somewhere between these bounds, depending on the effective tax rate of the marginal investor.

⁸One difference is that marking to market of futures contracts at fiscal year end is not required for tax purposes in Australia. Another difference is that arbitrageurs are subject to the same income-tax treatment on gains and losses realized on all trading activities (i.e., both physical stock and futures trades). These issues were first noted by Bowers and Twite (1985) and remain applicable under existing Australian taxation law.

⁹The evidence from such tests is inconclusive. Cornell and Reinganum (1981) find no significant difference between forward and futures prices in foreign exchange markets, whereas French (1983) reports statistically significant (albeit relatively small) differences between forward and futures prices for silver and copper. Park and Chen (1985) find no significant differences between the two prices in foreign exchange markets, but statistically significant differences for gold, platinum, silver, and copper markets. Muelbroek (1992) reports statistically significant relationships consistent with a price difference in forward and futures prices in the Eurodollar market. Unfortunately, forward contracts for equity products are generally not available, and thus this test cannot be undertaken.

first, the Ramaswamy and Sundaresan (1985) model, has been applied by Bailey (1989) and Cakici and Chatterjee (1991), among others.¹⁰ The other stochastic interest rate model is that of Hemler and Longstaff (1991). The empirical tests in the Hemler and Longstaff study indicate that their model is superior to the cost-of-carry model. In the present study, both the Ramaswamy–Sundaresan and Hemler–Longstaff models are tested and compared with each other and the adjusted cost-of-carry model.

Finally, in general, pricing models do not explicitly incorporate transaction costs. The costs of trading include brokers' fees, duties and exchange levies, and costs associated with the bid–ask spread. The existence of transaction costs may induce pricing errors, such that the fair pricing equation is not one of equality, but one in which bounds are defined by transaction costs. This issue is typically addressed by first establishing the error series and then comparing the series to the level of transaction costs. A similar approach is adopted in this article.

From the above discussion, it is clear that many of the reasons advanced for the observed mispricing in index futures are not applicable in the case of ISFs. The three issues that remain to be addressed when pricing ISFs are the value of the dividend, the magnitude of transaction costs, and the appropriate pricing model. The smaller number of pricing complications in the case of ISFs when compared to index futures arguably results in an *a priori* expectation that fewer violations of the pricing relationship will be observed in ISFs as compared to index futures. However, ISFs are a new instrument and a counterargument [first used by Figlewski (1984)] is that pricing errors may be prevalent, since the market requires time to mature. Prior research has documented that pricing errors are more prevalent at the commencement of trading in a new instrument. Saunders and Mahajan (1988), Bhatt and Cakici (1990), and Cakici and Chatterjee (1991) all report that pricing errors in the U.S. stock index futures have diminished over time. Similarly, Bailey (1989) and Brenner, Subrahmanyam, and Uno (1989) report that the largest pricing errors in Japanese index futures markets are observed in the first year of listing. Bowers and Twite (1985) report a similar result in relation to the Australian stock index futures market.

¹⁰Bailey (1989) tested the Ramaswamy–Sundaresan model on Japanese index futures and reported no substantial difference between its performance and that of the cost-of-carry model. Cakici and Chatterjee (1991) tested the model on S&P 500 index futures and found that there was no significant difference between the pricing of futures under this model and the basic cost-of-carry model in the years 1982–1985, but that a significant difference emerges in the later period of 1986–1987.

INSTITUTIONAL BACKGROUND

In Australia, both financial and commodity futures contracts are traded on the Sydney Futures Exchange (SFE), which commenced operations in 1960. In 1983, the SFE introduced equity futures in the form of a share price index futures contract (SPI) which has proven to be a liquid contract.¹¹ However, although the SPI futures contract allows access to the aggregate market, it does not give investors access to a futures position in shares of individual stocks. To redress this situation, in 1994 the SFE listed ISFs contracts. This introduction of ISFs has been claimed as the world's first, because such products have never been traded previously on anything other than a trial basis.¹²

Accordingly, the introduction of ISFs trading is viewed as an experiment both within the Australian market and by overseas markets. The three stocks on which ISFs were initially listed were carefully selected, and trading in these (and subsequent) contracts has been closely monitored as the SFE continues to expand the range of stocks on which ISFs are listed. If the contracts prove successful in terms of liquidity, volume, and efficiency, the planned next step is to introduce ISFs contracts on overseas stocks. In particular, the SFE has publicly made known its intention to list contracts on large American stocks such as General Motors and IBM.¹³ Existing U.S. legislation effectively prohibits American exchanges from trading share futures-type products. In this regard, there is significant interest by overseas investment houses. Indeed, such talk created somewhat of a controversy in the U.S. One senior official at a U.S. exchange was quoted as saying "if the SFE began to trade US futures contracts in any volume, we'd have to respond," (see the *Wall Street Journal*, 16 May 1994).

The foregoing indicates that analysis of the ISF market is important not only from an Australian perspective, but from an international perspective. It provides insight for international investors and exchanges to the possible success of similar products overseas. For example, if ISFs

¹¹The SPI is a futures contract on the all ordinaries index (AOI), which is an index consisting of approximately the largest 300 stocks, and covering around 90% of total market capitalization. The AOI is the most widely followed market index in Australia (but the index is not *per se* a tradeable asset). The SPI has quarterly expiry dates and has a nominal value of 25 times the AOI points level. In 1994, over 2.5 million SPI contracts were traded at an average of around 10,000 contracts per day, with a total nominal value of over \$A128 billion (around \$US94 billion).

¹²Individual share futures had been given a brief trial in Australia in 1985 by a subsidiary of the Australian Stock Exchange. However, those initial contracts were delisted after a short life because of a failure to secure a long-term clearing house. Finland also tried ISF-type contracts in the 1980s. The London exchange listed share futures contracts on selected Swedish stocks, but there was little trading in these products.

¹³The introduction of contracts on overseas stocks is currently subject to regulatory approval.

trading is successful in Australia, then other exchanges may be encouraged to change restrictive exchange rules to establish their own ISFs market.¹⁴

Two main reasons have been advanced to explain why other futures exchanges have been reluctant to introduce individual share futures-type contracts. First, there is a perceived lack of sustainable liquidity and volume of trading. These factors are clearly important to the success of a market because liquidity affects the cost of trading. Second, there is a fear of speculative trading and the creation of excess volatility, which is perceived to drive stock prices away from fundamental values. Although this latter issue has received substantial attention in recent times, much of this has been unwarranted and arises from a lack of understanding of the dynamics of futures markets. [See Miller (1991) and Stoll and Whaley (1988).]

INDIVIDUAL SHARE FUTURES CONTRACTS

Individual share futures are futures contracts on the shares of companies listed on the Australian stock exchange. Each contract represents 1,000 shares of the underlying stock. The contracts are available on a 3-month expiry cycle with only the two near-dated contracts listed for trading at any time. Over the period of this study, ISFs contracts are cash settled only.¹⁵

The first ISFs contracts were listed for trading on May 16, 1994. Trading was initially limited to contracts on three of the largest stocks: The Broken Hill Proprietary Company (BHP), National Australia Bank (NAB), and News Corporation (NCP). Eight further ISFs contracts have since been listed,¹⁶ and one of these subsequently delisted.¹⁷ The 10 stocks on which ISFs now trade represent around 40% of the total Australian stock market capitalization. Around 190,000 ISFs contracts were traded in the period from May, 1994 to November, 1995, representing around 190 million shares and over \$A1 billion in nominal contract value.

¹⁴An informal indicator of the early success of the Australian ISFs experiment is that the Hong Kong and London exchanges have both subsequently introduced share futures trading in relation to some of their domestic stocks.

¹⁵In 1996, exchange rules were modified to allow for settlement by physical delivery of shares.

¹⁶After the initial three ISFs contracts, the next ISFs contracts to be listed were shares of BTR-Nylex (BTR), M.I.M. Holdings (MIM), Westpac Banking Corporation (WBC), and Western Mining Corporation (WMC), in September, 1994. Three further ISFs contracts were listed in March, 1995: Australia and New Zealand Banking Group (ANZ), CRA and Fosters Brewing Group (FBG). The most recent ISFs contract, on Pacific Dunlop (PDP), was listed in October, 1995.

¹⁷Pursuant to the takeover of BTR-Nylex by its U.K. parent company in late 1995, ISFs contracts on BTR ceased trading in November, 1995.

The introduction of ISFs allows a choice of markets in which to trade: either in the traditional manner through the stock exchange, or in ISFs through the futures exchange. The SFE argues that the latter are the preferred vehicle for share trading because of concentrated liquidity in the futures market, lower transaction costs of trading (0.6% compared to 2–3% in the stock market) and the additional leverage afforded by a smaller up-front cash outlay.¹⁸

DATA

This study uses transactions data to ensure that the conditions of simultaneous trading implied by the arbitrage relationship models are met. The data set is established by capturing all transactions in both the ISFs and underlying stocks as they occur, along with relevant data on trading time and volume. The study investigates the first 10 ISFs contracts listed and covers the first 18 months following the introduction of ISFs trading.¹⁹ As the time of each trade is recorded, it is possible to match the ISFs trades with underlying stock trades in the same minute.²⁰ In the event that there is more than one trade per minute at different prices, the price with the heaviest volume for that minute is selected.²¹

Other data are required by the research method, including information on dividend payments and observations on a risk-free proxy. Information obtained relating to dividends includes the date and time of the announcement, ex-date, payment date, and amount. It is unclear whether the dividend value should be set at the cash payment or include a value for the imputation tax credit, which is available to domestic investors under the Australian dividend imputation system.²² The issue is

¹⁸ISFs require an initial deposit of between A\$50 and A\$900. They are also subject to margin calls because the contracts are marked to market on a daily basis.

¹⁹The sample period covers May 16, 1994 to November 26, 1995, inclusive. The 10 ISFs stocks in the sample are BHP, NAB, and NCP (listed May 16, 1994); BTR, MIM, WBC, and WMC (listed September 26, 1994); and ANZ, CRA, and FBG (listed March 7, 1995). The eleventh ISFs (PDP, listed on October 18, 1995) is not included in the sample because of insufficient trading. Data could not be obtained for NCP in September and October 1995 and WMC in April and May, 1995.

²⁰In Australia, futures trading takes place by way of open outcry in trading pits. Traders record their transaction on chits, which are subsequently gathered for recording by the SFE. There has been some argument that the transaction time recorded by the SFE is sometimes inaccurate because of delays in processing the chits. However, this argument is invalid, as traders are required to record the actual time of trade on the chits, and it is this time that is recorded by the SFE. Accordingly, the data-recording problem outlined in MacKinlay and Ramaswamy (1988, p. 143) and persistent in many stock index futures studies is avoided in this study.

²¹Less than 2% of ISFs matched trades occurred at different prices in the same minute.

²²Because the dividend imputation system has only been in operation in Australia for a relatively short period of time, there is little conclusive evidence as to the manner in which the market values imputation tax credits attaching to dividends. This is discussed in more detail in Brown and Clarke (1993). The dividend imputation system is outlined in Appendix 1.

TABLE I
Descriptive Statistics of Share Futures Trading (from Listing
to November 1995)^a

	<i>Expiry months of contracts</i>	<i>No. of contracts traded^b</i>	<i>No. of underlying shares traded (in thousands)</i>	<i>Correlation between ΔF_t^* and $\Delta S_t^{c,d}$ (prob. value)</i>
ANZ	Jan/Apr/July/Oct	152	549,852	0.95
BHP	Mar/June/Sept/Dec	37,770	1,344,668	0.78
BTR	Mar/June/Sept/Dec	28,835	1,712,246	0.99
CRA	Mar/June/Sept/Dec	1,563	233,970	0.95
FBG	Jan/Apr/July/Oct	43	390,619	0.86
MIM	Jan/Apr/July/Oct	26,231	1,490,374	0.92
NAB	Jan/Apr/July/Oct	20,657	1,046,148	0.77
NCP	Feb/May/Aug/Nov	56,799	1,800,460	0.95
WBC	Jan/Apr/July/Oct	4,366	803,632	0.86
WMC	Mar/June/Sept/Dec	13,142	956,336	0.91
All	—	189,558	10,328,305	0.98

^aSources: SFE Quarterbooks—1994–95; and *Equinet*.

^bBased on contracts traded from May 16, 1994 to November 26, 1995 for BHP, NAB, and NCP; from September 26, 1994 to November 26, 1995 for BTR, MIM, WBC, and WMC; and from March 7, 1995 to November 26, 1995 for ANZ, CRA, and FBG.

^cPearson correlation coefficients are based on intraday price changes from matched observations.

^dEach of the correlations is significant at the 0.001 level.

examined by separately testing the models with the use of both lower and upper bounds on the value of dividends.

To avoid possible mispricing resulting from the known dividend assumption, those trades that occurred with certain knowledge of the dividend amount and payment date are identified. Trades that occurred before the dividend announcement (which comprised only 7.8% of the total sample) are assumed to occur with knowledge of the dividend provided by brokers' forecasts.²³

In Australia, there is some difficulty in finding an actively traded security that represents an appropriate proxy for default-free bonds. In this study, three risk-free interest-rate proxies are used: the 30-day and 90-day bank accepted bills (BABs) series, and the 5-week treasury note

²³The assumption of known future dividends can be important. For one stock in the sample (NAB), initial trading was conducted for 3½ days before declaration of the next dividend. The declared dividend was about 40% higher than the previous year's corresponding dividend and also higher than brokers' expectations. The incorrect assumption of the actual dividend as the known dividend for these 3½ days can lead to pricing errors that are substantially greater than pricing errors obtained under the correct assumption of a forecast (but unknown) dividend.

series.²⁴ The 90-day BAB series is the risk-free interest rate proxy most commonly used in Australian studies.

Descriptive statistics relating to the sample data are contained in Table I. The number of contracts traded from the respective listing dates to November 26, 1995 is shown, along with the number of physical shares traded in the underlying stock. Recalling that one ISFs contract covers 1,000 shares, these figures indicate a reasonable volume of ISFs trading in absolute terms. However, in relative terms trading volume appears low, ranging from around 0.5% of the volume in the underlying stock (WBC) to just over 3.1% of such volume (NCP).

Table I also presents the correlation between daily price changes in ISF and the underlying stocks. The correlation coefficient of intraday price changes between the stock and futures is highly significant and generally exceeds the correlation found between the spot market and stock index futures [e.g., Chan, Chan, and Karolyi (1991)]. This difference may be due to the removal of specification risk and/or the elimination of nonsynchronous trading.

EMPIRICAL TESTS OF FUTURES PRICING MODELS

The Pricing Models

Three alternative pricing models are employed. First, the cost-of-carry model can be used to establish the theoretical ISFs prices (before transaction costs). The model that allows for dividend payments is

$$F_t = S_t e^{r(T-t)} - D e^{r(T-x)} \quad (2)$$

where F_t is the futures price at time t , S_t is the underlying asset price, r is the risk-free rate of interest, T is the maturity date, x is the dividend payment date, D is the value of known dividends, and t is the current date.

Observed ISFs prices (F_t^*) are compared to theoretical ISFs prices (F_t) generated by expression (2) with the use of the matched transactions data.

The assumption of nonstochastic interest rates results in equality between forward and futures prices [Cox, Ingersoll, and Ross (1981)]. This assumption is often used to support the application of the cost-of-carry model for forward prices to the pricing of futures contracts. How-

²⁴Note that none of these securities provides a series where maturity can be exactly matched with the expiration of the futures contracts.

ever, if the assumption does not hold (i.e., if interest rates are stochastic) then the cost-of-carry model may be invalid with respect to the pricing of futures contracts. Hence, the study examines two alternative models.

The second model is the continuous-time model of Ramaswamy-Sundaresan (1985), which follows from Cox, Ingersoll, and Ross (1981, 1985; hereafter CIR). The model assumes that the stock price follows a log-normal process:

$$dS = (\alpha - \delta) S dt + \sigma_1 S dz_1 \quad (3)$$

where S is the stock price, δ is the dividend yield, α and σ_1 are the drift and volatility of the stochastic process, and dz_1 is a standard Weiner process.

All uncertainty in the term structure of interest rates is captured by movements in the instantaneous risk-free rate, which is given by the well-known CIR square-root equation:

$$dr = \kappa(\mu - r)dt + \sigma_2 \sqrt{r} dz_2 \quad (4)$$

where r is the risk-free rate of interest; κ , μ , and σ_2 are the speed of adjustment, long-term mean, and volatility of the stochastic process; and dz_2 is a standard Weiner process.

If bonds are priced according to the local expectations hypothesis, then the futures price is governed by a partial differential equation, which Ramaswamy and Sundaresan show can be reduced to²⁵

$$F_t = S_t a_t e^{b_t r} \quad (5)$$

where

$$a_t = \left[\frac{2\gamma e^{(\gamma+\kappa)(T-t)/2}}{2\gamma + (\gamma + \kappa)(e^{\gamma(T-t)} - 1)} \right]^{2\kappa\mu/\sigma_2^2} [e^{-\delta(T-t)}]$$

$$b_t = \frac{2(e^{\gamma(T-t)} - 1)}{2\gamma + (\gamma + \kappa)(e^{\gamma(T-t)} - 1)}$$

$$\gamma \equiv \sqrt{[\kappa^2 - 2\sigma_2^2]} > 0$$

The unknown parameters are κ , μ , and σ_2 . To solve for these parameter values, a procedure similar to Brown and Dybvig (1986) is followed in

²⁵The pricing equation holds under the assumption that the covariance (ρ_{d1}) between dz_1 and dz_2 is zero. For nonzero values of ρ , there is no closed-form solution of the futures pricing equation. Ramaswamy and Sundaresan find no significant difference in their results from changing the value of ρ from 0.2 to -0.2. Furthermore, Cakici and Chatterjee (1991) report that the pricing errors are generally insensitive to the value of ρ . Given this evidence and the explosive nature of the permutations of analysis in this study, the value of ρ is assumed to be zero.

which it is first assumed that eq. (5) generates futures prices (F_t) that differ from observed futures prices (F_t^*) by a mean of zero.²⁶ The parameters are then estimated with the use of a nonlinear least-squares procedure and applied to the data.

The third model is also a continuous-time model and is based on Hemler and Longstaff (1991). This model follows from the work of CIR and develops a closed-form general equilibrium in a continuous-time economy, characterized by both stochastic interest rates and stochastic market volatility. The closed-form solution to the futures price is given by eq. (14) in Hemler and Longstaff (1991). The model is operationalized by the following regression equation:

$$L_t = \alpha + \beta r_t + \gamma \sigma_{st} + \xi_t \quad (6)$$

where $L_t = \log(F_t^a/S_t)$; F_t^a is the dividend-adjusted futures price; S_t is the stock price; r_t is the interest rate to expiry T ; and σ_{st} is the level of asset return volatility. Note that the adjusted cost-of-carry model is nested within (6). The restrictions imposed by the adjusted cost-of-carry model on the regression coefficients imply that $\alpha = 0$; $\beta = T$ (average term to expiry); and $\gamma = 0$ as market volatility should have no explanatory power.²⁷

If these restrictions hold then (6) collapses to

$$\log(F_t^a/S_t) = r_t T \quad (7)$$

which can be rearranged to establish (2), the adjusted cost-of-carry model.²⁸

The empirical implementation of the Hemler–Longstaff model involves a two-stage procedure. First, similar to the test of the Ramaswamy–Sundaresan model, it is initially assumed that (6) provides futures prices (F_t) that differ from observed futures prices (F_t^*) by a mean of zero. Hence, resultant parameter estimates for α , β , and γ are obtained.²⁹ The

²⁶Ideally, the unknown parameters could be estimated within the sample and then applied out of the sample. The problems with this approach include instability in the parameter estimates [as noted by Brown and Dybvig (1986) and Cakici and Chatterjee (1991)] and the loss of a significant amount of data.

²⁷There is evidence that pricing deviations from the cost-of-carry model are related to the volatility of underlying asset prices in some financial futures markets. [See Resnick and Henniger (1983) and Kamara (1988).] Accordingly, inclusion of market volatility in the Hemler–Longstaff model allows futures prices to depend upon the variance of market returns.

²⁸Brailsford and Cusack (1995a) test the restrictions implied in the Hemler–Longstaff model with the use of data similar to that employed in this study. They report mixed results across various contracts and conclude that there is only weak support for the cost-of-carry model.

²⁹The Hemler–Longstaff model can be tested by categorization of the sample into subsamples on the basis of time to expiry. The main tests reported in this article are based on the full sample, and hence α is restricted to zero.

second stage involves applying the parameter estimates to the data with the use of (6) to generate estimates of L_t . The estimate of the futures price is then obtained by inferring F_t from L_t . After the adjustment for dividends, pricing errors can again be examined by comparing F_t with the observed futures price (F_t^*).³⁰ The additional data required to test the Hemler–Longstaff model are estimates of σ_{st} . The implied standard deviation from traded stock options is used for each of the stocks in the sample.³¹

Empirical Results

Table II reports summary statistics on the pricing errors for each stock and the total sample across the three pricing models. In the absence of transaction costs, the mean pricing error should be zero. Recall that misestimation of the inputs could arise from the value of the dividend and/or the risk-free proxy. Initially, the cash value of the dividend is employed and the 90-day BAB rate is used as the risk-free interest rate. Sensitivity to these variables is reported in the next section.

As a general observation from Table II, the mean pricing errors are negative in the total sample for all three models and are generally negative for individual stocks. That is, in general, the ISFs appear to trade at a discount. The frequency of negative errors is significant for both the cost-of-carry and Ramaswamy–Sundaresan models in the total sample.

The mean pricing error is relatively small in all cases, with the largest mean error observed for WBC. As the value of the pricing error in Table II is in cents per share, the dollar value per contract is obtained by multiplying by 10. For example, the mean pricing error for the total sample under the cost-of-carry model translates to a dollar amount of \$8.69 per contract, on average. Generally, the pricing errors fall within the bounds of $\pm \$20$ per nominal contract value. The economic significance of these pricing errors can be gauged by examining the mean absolute percentage error (MAPE) in Table II.³² In only one case does the MAPE exceed more than 1%.³³

The relatively low values of the MAPE metric initially indicate that the pricing errors do not give rise to arbitrage opportunities after allowing

³⁰The procedure used to obtain the pricing errors can lead to systematic biases in the error series if the errors are ordered with respect to the conditioning variable, S_t . This issue is examined by regressing the OLS residuals on the series, S_t , and conducting a t -test of the significance of the coefficient estimate. In all cases, this test indicates insignificance.

³¹The Black–Scholes implied standard deviation from at-the-money call options with 90 days to maturity is used as the measure of volatility (σ_{st}).

³²The MAPE metric is used in subsequent analysis.

³³This is the FBG contracts, but note the small sample size.

TABLE II

Descriptive Statistics of Pricing Errors for Individual Share Futures Contracts from the Cost-of-Carry, Ramaswamy–Sundaresan, and Hemler–Longstaff Models.

Pricing errors are given by $e_t = F_t^* - F_t$, where F_t^* is the observed traded price of the futures contract at time t and F_t is the theoretical value of the futures contract at time t given by the respective models^a

Stock	N ^b	Cost-of-Carry			Ramaswamy–Sundaresan			Hemler–Longstaff		
		No. of $e_t > 0$ (prob.) ^c	Mean e_t	MAPE ^d (%)	No. of $e_t > 0$ (prob.)	Mean e_t	MAPE (%)	No. of $e_t > 0$ (prob.)	Mean e_t	MAPE (%)
ANZ	13	8 (0.87)	1.749	0.583	8 (0.87)	1.914	0.616	7 (0.71)	0.121	0.266
BHP	2,080	861 (0.00)	−0.964	0.175	870 (0.00)	−0.894	0.175	1,046 (0.61)	0.042	0.170
BTR	26	12 (0.42)	0.036	0.859	12 (0.42)	0.078	0.865	11 (0.28)	−0.256	0.818
CRA	65	26 (0.07)	−1.690	0.313	26 (0.07)	−1.648	0.307	33 (0.60)	0.168	0.278
FBG	9	5 (0.75)	0.247	1.564	5 (0.75)	0.279	1.589	5 (0.75)	0.361	1.445
MIM	100	53 (0.76)	0.296	0.691	52 (0.69)	0.279	0.698	35 (0.00)	−0.310	0.703
NAB	686	315 (0.02)	−1.233	0.351	313 (0.01)	−0.883	0.388	355 (0.83)	−0.316	0.352
NCP	450	232 (0.76)	0.127	0.310	231 (0.73)	0.029	0.309	224 (0.48)	−0.087	0.302
WBC	58	35 (0.96)	0.991	0.420	26 (0.26)	−0.205	0.383	26 (0.26)	−0.001	0.390
WMC	142	46 (0.00)	−2.539	0.537	46 (0.00)	−2.644	0.542	69 (0.40)	−0.125	0.475
All	3,629	1,593 (0.00)	−0.869	0.269	1,589 (0.00)	−0.796	0.276	1,811 (0.46)	−0.058	0.261

^aThe cost-of-carry, Ramaswamy–Sundaresan, and Hemler–Longstaff models are given by expressions (2), (5), and (6), respectively, in the text.

^bN represents the number of matched transactions.

^cBinomial probability that the frequency of positive errors is different from 50%.

^dMAPE is mean absolute percentage error calculated as $(1/T) \sum_{t=1}^T 100|e_t|/F_t$.

for transaction costs. When trading ISFs, round-trip transaction costs are around 0.6% of the value of the contract, irrespective of whether the position is long or short.³⁴ When trading in the underlying stock, the level of transaction costs depends on the position. For a high-volume institutional trader, a long position in the stock may involve transaction costs of only around 0.5%, which comprise brokers' fees and stamp duty. A

³⁴Transaction costs in ISFs trading consist of broker fees, a clearinghouse fee, and an exchange levy.

short position in the stock is more expensive, as the scrip must be borrowed. Generally, the additional cost of a short position is around 1–3%. In summary, transaction costs for a short futures-long stock position can be around 1%, and for a long futures-short stock position about 2–4%. Thus, arbitrage is more expensive when the futures are trading at a discount, and hence violations of this bound are more tolerable, which is consistent with the findings in Table II.³⁵

In terms of model rankings, on the basis of both mean error and MAPE, the preferred model is generally Hemler–Longstaff, followed by the cost-of-carry and then Ramaswamy–Sundaresan, although these rankings are not consistent across individual stocks. For example, the cost-of-carry is preferred for MIM and NAB, whereas Ramaswamy–Sundaresan is preferred for WBC. However, the primary focus is on the total sample and the first three listed contracts (BHP, NAB, and NCP) which clearly have the heavier volume. For the total sample, BHP and NCP, Hemler–Longstaff ranks first. However, in general, all models appear to yield similar MAPE metrics. The lack of clear superiority of the models with stochastic interest rates may be due to the market using the cost-of-carry model to price ISFs, and hence the relative effectiveness of the cost-of-carry model becomes a self-fulfilling prophecy.³⁶ Alternatively, the assumptions concerning the stochastic interest rate process may be inappropriate.

The above discussion has focused on average pricing errors, but what is of interest to investors (in particular, arbitrageurs) is not necessarily the average pricing error, but the frequency and magnitude of the large pricing errors. As indicated earlier, it is difficult to precisely identify the magnitude of transaction costs. Hence, the approach of Chung (1991) and Klemkosky and Lee (1991) is followed, whereby only errors that exceed a critical boundary are examined. The transaction cost boundary is set at 0.5% and 1.0%.³⁷ Tables III and IV report the frequency and MAPE of violations of these respective transaction costs bounds.

From both Tables III and IV, there is some evidence of frequent violations of the transaction costs bounds. The main focus is again on the total sample and the three stocks on which ISFs were initially listed:

³⁵Indeed, short sellers of Australian stock are generally unable to use the short-sale proceeds, so the apparent arbitrage opportunity from the mispricing does not really exist, consistent with the findings of Modest and Sundaresan (1983).

³⁶Literature from the SFE and practitioners indicates that the cost-of-carry model may be used by the market to price ISFs. [See Ord Minnett (1994) and Pedersen (1994).]

³⁷The general discussion of transaction costs tends to overstate their impact on exchange members. In certain circumstances, exchange members executing principal trades face lower transaction costs due to the removal of brokers' fees and other costs. Hence, conservative values of 0.5% and 1.0% are set as the boundary.

TABLE III

Futures-Price Boundary Violations of $\pm 0.5\%$ Transaction Costs for Individual Share Futures Contracts from the Cost-of-Carry, Ramaswamy-Sundaresan and Hemler-Longstaff Models.

Pricing errors are given by $e_t = F_t^* - F_t$, where F_t^* is the observed traded price of the futures contract at time t and F_t is the theoretical value of the futures contract at time t given by the respective models^a

Stock	Cost-of-Carry		Ramaswamy-Sundaresan		Hemler-Longstaff	
	No. of violations (percent of sample)	MAPE of violations ^b	No. of violations (percent of sample)	MAPE of violations	No. of violations (percent of sample)	MAPE of violations
ANZ	7 (53.8)	0.880	7 (53.8)	0.946	3 (23.1)	0.734
BHP	56 (2.7)	0.578	48 (2.3)	0.593	45 (2.2)	0.574
BTR	18 (69.2)	1.144	18 (69.2)	1.159	15 (57.7)	1.233
CRA	12 (18.5)	0.703	12 (18.5)	0.680	8 (12.3)	0.708
FBG	9 (100.0)	1.564	9 (100.0)	1.590	9 (100.0)	1.445
MIM	45 (45.0)	1.255	45 (45.0)	1.262	62 (62.0)	1.009
NAB	168 (24.5)	0.777	186 (27.1)	0.847	165 (24.1)	0.757
NCP	84 (18.7)	0.660	83 (18.4)	0.660	77 (17.1)	0.669
WBC	18 (31.0)	0.825	13 (22.4)	0.780	14 (24.1)	0.788
WMC	53 (37.3)	0.950	57 (40.1)	0.930	61 (42.9)	0.836
All	470 (12.9)	0.828	478 (13.2)	0.859	459 (12.6)	0.798

^aThe cost-of-carry, Ramaswamy-Sundaresan, and Hemler-Longstaff models are given by expressions (2), (5), and (6), respectively, in the text.

^bMAPE is mean absolute percentage error calculated as $(1/T) \sum_{t=1}^T 100|e_t|/F_t$.

BHP, NAB, and NCP. From Table III, the frequency and the MAPE of violations are similar across the three models, with the Hemler-Longstaff model being marginally preferred. It is notable that the contracts with low trading volumes tend to have a higher frequency of violations.³⁸ As Chung (1991) notes, the existence of potential arbitrage may act as a

³⁸Brailsford and Cusack (1995b) report on the relative level of trading volumes in new Australian derivative instruments. They conclude that sustainable trading volume in ISF is probably restricted to BHP, NAB, NCP, and possibly MIM.

TABLE IV

Futures-Price Boundary Violations of $\pm 1.0\%$ Transaction Costs for Individual Share Futures Contracts from the Cost-of-Carry, Ramaswamy-Sundaresan, and Hemler-Longstaff Models.

Pricing errors are given by $e_t = F_t^* - F_t$, where F_t^* is the observed traded price of the futures contract at time t and F_t is the theoretical value of the futures contract at time t given by the respective models^a

Stock	Cost-of-Carry		Ramaswamy-Sundaresan		Hemler-Longstaff	
	No. of violations (percent of sample)	MAPE ^b of violations	No. of violations (percent of sample)	MAPE of violations	No. of violations (percent of sample)	MAPE of violations
ANZ	1 (7.7)	1.484	2 (15.4)	1.299	0 (0)	0
BHP	1 (0.1)	1.151	1 (0.1)	1.155	1 (0.1)	1.069
BTR	12 (46.2)	1.389	12 (46.2)	1.410	10 (38.5)	1.495
CRA	1 (1.5)	1.236	1 (1.5)	1.231	1 (1.5)	1.126
FBG	8 (88.9)	1.658	7 (77.8)	1.794	7 (77.8)	1.593
MIM	27 (27.0)	1.596	30 (30.0)	1.537	25 (25.0)	1.494
NAB	43 (6.3)	1.155	58 (8.5)	1.199	22 (3.2)	1.158
NCP	3 (0.7)	1.321	3 (0.7)	1.322	2 (0.4)	1.506
WBC	6 (10.3)	1.217	2 (3.4)	1.175	3 (5.2)	1.230
WMC	23 (16.2)	1.357	23 (16.2)	1.372	16 (11.3)	1.253
All	125 (3.4)	1.352	139 (3.8)	1.352	87 (2.4)	1.355

^aThe cost-of-carry, Ramaswamy-Sundaresan, and Hemler-Longstaff models are given by expressions (2), (5), and (6), respectively, in the text.

^bMAPE is mean absolute percentage error calculated as $(1/T) \sum_{t=1}^T 100|e_t/F_t|$.

signal for arbitrageurs to enter the market. If trading volume is thin, then traders may be prevented from realizing gains from arbitrage even if apparent arbitrage opportunities exist. Conversely, contracts in which there is heavy volume, such as BHP have a relatively low frequency of violations. Similar results are reported for the 1% transaction costs bound in Table IV. In summary, the results from Tables III and IV appear to indicate that arbitrage opportunities are possible, yet infrequent. Again, there is no clear difference between the three models.

TABLE V

Results from Sensitivity Analysis of Pricing Errors to the Value of Dividends and the Risk-Free Proxy for Individual Share Futures Contracts from the Cost-of-Carry, Ramaswamy–Sundaresan, and Hemler–Longstaff Models. Pricing errors are given by $e_t = F_t^* - F_t$, where F_t^* is the observed traded price of the futures contract at time t and F_t is the theoretical value of the futures contract at time t given by the respective models^a

Stock	Cost-of-Carry MAPE (%) ^b			Ramaswamy–Sundaresan MAPE (%)			Hemler–Longstaff MAPE (%)		
	Imputed Dividend	30-day BAB	5-week T-note	Imputed Dividend	30-day BAB	5-week T-note	Imputed Dividend	30-day BAB	5-week T-note
ANZ	0.642	0.612	0.619	0.690	0.644	0.652	0.319	0.310	0.319
BHP	0.226	0.174	0.175	0.236	0.175	0.176	0.173	0.173	0.173
BTR	1.097	0.850	0.861	0.916	0.856	0.867	0.822	0.817	0.822
CRA	0.388	0.314	0.310	0.352	0.309	0.304	0.280	0.279	0.280
FBG	1.564	1.583	1.587	1.589	1.626	1.629	1.445	1.473	1.478
MIM	0.691	0.709	0.714	0.698	0.715	0.720	0.703	0.697	0.699
NAB	0.431	0.357	0.359	0.604	0.397	0.398	0.537	0.390	0.359
NCP	0.314	0.319	0.323	0.314	0.318	0.321	0.306	0.306	0.306
WBC	0.468	0.470	0.487	0.435	0.373	0.375	0.378	0.377	0.378
WMC	0.548	0.530	0.526	0.557	0.534	0.530	0.482	0.482	0.482
All	0.319	0.272	0.274	0.355	0.279	0.280	0.299	0.270	0.265

^aThe cost-of-carry, Ramaswamy–Sundaresan, and Hemler–Longstaff models are given by expressions (2), (5), and (6), respectively, in the text.

^bMAPE is mean absolute percentage error calculated as $(1/T) \sum_{t=1}^T 100|e_t/F_t|$.

Sensitivity Analysis

The possibility of measurement error exists in the cases of (a) dividends—due to the imputation tax system, and (b) the risk-free interest-rate proxy. The analysis is repeated for the ISFs contracts on dividend-paying stocks, with the use of the cash dividend plus the full value of the imputation tax credit (i.e., the upper bound on the value of the dividend). Similarly, the analysis is repeated with the use of the (a) 30-day BAB rate, and (b) the 5-week Treasury Note rate as the risk-free interest rate proxy. Table V reports these results.

The sensitivity of the results to measurement error in the value of dividends can be gauged from the first column under each model in Table V. Since FBG and MIM paid unfranked dividends over the sample period, their error metrics are unchanged.³⁹ For the other eight stocks, the MAPE

³⁹Dividends that carry the imputation tax credit are known as *franked dividends*. If a dividend is paid from profits that have not been subject to tax at the corporate level, they are referred to as *unfranked dividends*.

measures are generally higher than their counterparts in Table II. For the combined sample, the MAPE values are higher for every model. This evidence supports the view that the market does not fully price imputation tax credits.⁴⁰

The sensitivity of the pricing errors to the risk-free proxy are given by the MAPE values in Table V for the 30-day BAB and 5-week T-note series. In the majority of cases and for the overall sample, the MAPE measures are higher than their 90-day BAB counterparts in Table II. It is notable that these MAPE measures are generally close to each other. For all three models, the MAPE values diverge by less than 10% across the three interest-rate variables.

Explanatory Factors

Following Cakici and Chatterjee (1991), the relationship between various explanatory factors and the pricing error is now examined. As discussed earlier, studies of index futures [e.g., Bailey (1989), Cakici and Chatterjee (1991), and MacKinlay and Ramaswamy (1988)] have found that the average pricing error is a function of time-to-expiry. This issue is examined here also.

The next possible explanatory factor relates to trading volume. It is based on the argument that if arbitrage opportunities arise, there may be an impact on trading volume. There are competing hypotheses relating to this variable. The signal for arbitrage may attract trading volume, and hence a positive relationship between the absolute magnitude of the pricing error and trading volume is expected. Conversely, heavy trading volume may be indicative of a liquid and efficient market in which arbitrage opportunities do not arise. Bessembinder and Seguin (1992) and Brown-Hruska and Kuserk (1995) report evidence consistent with the view that active futures markets enhance the liquidity and depth of the spot market. Specifically, futures trading volume is associated with spot volatility, and the conduit between these variables is index arbitrage. In the latter case, a negative relationship between pricing errors and absolute trading volume is expected.

It is also possible that the market has taken time to mature. To examine whether observed pricing errors are concentrated around the commencement of trading, a 0–1 dummy variable for the first month of trad-

⁴⁰In Australia, the marginal arbitrage trader is likely to have an effective tax rate somewhere between the two extremes of 0% and 33% tested in this study. For example, superannuation (pension) funds and life offices are taxed at 15%. The comparison of results from Tables II and V are consistent with this view. Precise identification of the effective tax rate of the marginal trader is impossible.

ing is included. Given the arbitrary nature of aligning this variable to the first month, sensitivity analysis is conducted whereby the first 2 and 3 months of trading are also used to define the dummy variable.

Finally, the impact of dividends on the mispricing series is tested also. A 0–1 dummy variable is set to unity if the underlying stock is trading cum dividend such that the dividend becomes relevant to the determination of the ISFs price.

The following regression is estimated:

$$|e_t| = \alpha + \gamma_1 T_t + \gamma_2 V_t + \gamma_3 \text{START}_t + \gamma_4 \text{DIV}_t + \varepsilon_t \quad (8)$$

where e_t is the pricing error for the three pricing models as defined in expression (1); T_t is time to expiry (in years); V_t is the number of traded ISFs contracts; $\text{START}_t = 1$ if t falls in the first month of trading of a contract, and zero otherwise; $\text{DIV}_t = 1$ if the stock is trading cum dividend such that the dividend is relevant to pricing the ISFs contract, and zero otherwise; and $\varepsilon_t \sim N(0, \sigma^2)$.

Table VI reports the results of the regression in (8) for the three initial stocks (BHP, NAB, and NCP) and the overall sample. The other contracts are not considered individually, given the relatively small sample sizes and short trading histories. From Table VI, there is evidence of a significant positive relationship between the absolute pricing error and the time to expiry in every regression. This evidence is consistent with the findings for stock index futures. The positive relationship implies that longer dated contracts are relatively more mispriced. The consistency of this finding across all three pricing models means that it is not due to the failure of any one model.

The relationship between the absolute pricing error and trading volume is significantly positive for BHP but significantly negative for NCP. In the overall sample, the variable is insignificant. These findings are consistent across all three pricing models. These results are difficult to interpret given the mixed signals. However, as noted above, there are conflicting hypotheses with respect to the sign of this variable and the empirics are unable to distinguish among the hypotheses.

The magnitude of the absolute pricing errors is not significantly related to the first month of trading except for BHP under the two models with stochastic interest rates. Hence, there is little evidence supporting a market learning period, other than perhaps for BHP. Sensitivity analysis that which involves changing this variable to represent the first 2 and 3 months of trading is conducted. When defining the variable to represent the first 2 months of trading, the variable is again generally insignificant.

TABLE VI

Multivariate Regression of Pricing Errors for Individual Share Futures Contracts from the Cost-of-Carry, Ramaswamy-Sundaresan, and Hemler-Longstaff Models. Pricing errors are given by $e_t = F_t^* - F_t$, where F_t^* is the observed traded price of the futures contract at time t and F_t is the theoretical value of the futures contract at time t given by the respective models^a

$$|e_t| = \alpha + \gamma_1 T_t + \gamma_2 V_t + \gamma_3 \text{START}_t + \gamma_4 \text{DIV}_t + \varepsilon_t$$

Where e_t is the pricing error as defined in expression (1); T_t is time to expiry (in years); V_t is the number of traded ISF contracts; $\text{START}_t = 1$ if t falls in the first month of trading of a contract and 0 otherwise; $\text{DIV}_t = 1$ if the stock is trading cum dividend such that the dividend is relevant to pricing the ISF contract and otherwise; and $\varepsilon_t \sim N(0, \sigma^2)$.

Stock	α (<i>t-stat.</i>) ^b	γ_1 (<i>t-stat.</i>)	γ_2 (<i>t-stat.</i>)	γ_3 (<i>t-stat.</i>)	γ_4 (<i>t-stat.</i>)	F stat (<i>prob. value</i>)
Panel A: Cost-of-Carry						
BHP	-1.008 (-5.25)*	3.524 (2.37)*	0.011 (2.91)*	0.465 (1.90)	-2.870 (-10.10)*	39.487 (0.001)*
NAB	-2.919 (-9.43)*	22.714 (8.67)*	-0.011 (-1.48)	1.184 (1.56)	-3.977 (-7.74)*	15.586 (0.001)*
NCP	-0.803 (-3.09)*	6.310 (3.52)*	-0.002 (-2.68)*	-0.223 (-0.47)	-0.081 (-0.18)	4.766 (0.001)*
All	-1.355 (-10.59)*	6.683 (7.05)*	-0.001 (-0.11)	0.510 (1.81)	-2.174 (-9.11)*	32.413 (0.001)*
Panel B: Ramaswamy-Sundaresan						
BHP	-1.366 (-6.91)*	5.606 (3.67)*	0.013 (3.40)*	0.544 (2.20)*	-2.301 (-7.91)*	24.414 (0.001)*
NAB	-3.239 (-10.46)*	24.607 (9.39)*	-0.009 (-1.27)	0.765 (1.00)	-3.252 (-6.23)*	14.957 (0.001)*
NCP	-0.853 (-3.27)*	5.986 (3.32)*	-0.002 (-2.69)*	-0.219 (-0.46)	-0.055 (-0.12)	4.378 (0.002)*
All	-1.543 (-11.89)*	7.485 (7.74)*	-0.001 (-0.01)	0.393 (1.40)	-1.663 (-6.92)*	22.337 (0.001)*
Panel C: Hemler-Longstaff						
BHP	-0.246 (1.30)	5.478 (3.77)*	0.009 (2.56)*	0.809 (3.35)*	-3.126 (-11.25)*	46.742 (0.001)*
NAB	-1.630 (-5.42)*	21.189 (8.13)*	-0.011 (-1.53)	-0.162 (-0.28)	-4.038 (-7.85)*	24.951 (0.001)*
NCP	-0.436 (-1.68)	2.471 (1.37)	-0.002 (-2.65)*	0.162 (0.34)	-0.106 (-0.23)	1.824 (0.123)
All	-0.400 (-3.23)*	6.403 (6.79)*	-0.002 (-1.88)	0.192 (0.86)	-2.471 (-11.47)*	46.634 (0.001)*

*Significant at the 5% level.

^aThe cost-of-carry, Ramaswamy-Sundaresan and Hemler-Longstaff models are given by expressions (2), (5), and (6), respectively, in the text.

^bStandard errors calculated with the use of White's (1980) heteroscedastic-consistent covariance matrix.

However, when defining the variable to represent the first three months of trading, the variable is significant in the overall sample. Further analysis reveals that this result applies only to BHP. This finding is unlikely to imply economically significant pricing errors, given the earlier findings in Tables II–IV that BHP is generally fairly priced.

The final variable is that which captures the effect of dividends. This variable is significant for the overall sample and for most stocks in all pricing models, which implies that pricing errors are affected by the underlying stock carrying dividend entitlements. Univariate analysis reveals that the dividend-affected sample yields pricing errors that are, on average, about twice the size of pricing errors from the remainder of the sample.⁴¹ This evidence is consistent with the sensitivity results reported in Table V, which show that the dividend imputation tax credit affects the magnitude of the pricing errors. Again, the conclusion is that the market has difficulty with valuing the dividend component.

SUMMARY

This study examines the pricing of equity futures using a unique data set with characteristics that overcome some of the research-method weaknesses of prior studies on stock index futures. The pricing performance of three models are compared: an adjusted cost-of-carry and two models that incorporate stochastic interest rates. An evaluation of error metrics allows a direct comparison of the performance of the models.

There is evidence of frequent but small pricing errors in ISFs contracts, which is consistent across all models. This implies that prior findings of pricing errors in stock index futures are unlikely to be solely due to research-method problems, data mining, or the specific model. The potential for arbitrage opportunities is found to be limited, because the frequency of pricing errors which exceed transaction costs bounds is low, except for illiquid contracts in which arbitrage is unlikely to be possible because of the illiquidity. Hence, ISFs contracts generally appear to be fairly priced. The three models that are compared provide similar results, and none is clearly preferred, although the Hemler–Longstaff model generally ranks first in terms of both mean error and MAPE. It is arguable that, for simplicity reasons, the cost-of-carry model will generally suffice when pricing these contracts. Finally, the pricing errors are related to

⁴¹The comparative mean error measures for the dividend-affected sample and the remainder of the sample are, respectively, -1.958 versus -0.741 (cost-of-carry), -1.474 versus -0.846 (Ramawamy–Sundaresan), -1.436 versus 0.119 (Hemler–Longstaff). The differences in mean errors are all significant at the 1% level with the use of a *t*-test for equal means.

time to expiry and, where applicable, dividends on the underlying stock. The former finding is consistent with evidence from stock index futures and implies that there is potentially some risk premium associated with further-dated contracts that is not captured by the pricing models. The latter finding is consistent with the view that the market has experienced difficulty in the valuation of dividends under the imputation tax system.

APPENDIX 1. THE DIVIDEND IMPUTATION TAX SYSTEM IN AUSTRALIA

The Australian dividend imputation tax system has been in operation since July 1, 1987. Under this system, companies pay income tax on their taxable income at the corporate rate (currently 36%, but 33% for much of the period of the study), and then pay dividends to shareholders from the net income remaining after tax. Recipient shareholders (who are Australian residents for taxation purposes) are then assessed income tax on the dividend which is grossed up by the value of the corporate tax already paid. A credit is then allowed for this prepaid corporate tax, known as the imputation tax credit. The effect of this taxation system is that in most cases the tax paid at the corporate level is effectively a prepayment of the recipient shareholder's tax liability. The final tax rate applicable to the pretax corporate income is therefore governed by the shareholder's marginal tax rate. (Note that nonresident shareholders are still taxed at both the corporate and individual levels.)

Dividends that carry the imputation tax credit are known as *franked dividends*. If a dividend is paid from profits that have not been subject to tax at the corporate level, they are referred to as *unfranked dividends*.

For a more detailed description of the Australian dividend imputation tax system, refer to Officer (1990).

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