

**Are Warrants Redundant? Spanning Tests and Price Discovery**

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## **Are Warrants Redundant? Spanning Tests and Price Discovery**

### **Abstract**

The paper investigates whether investors can extend their efficient set by investing in equity warrants. We find that equity warrants are not redundant, in that the inclusion of this derivative instrument in an investor's portfolio can provide diversification benefits through an enlargement of the minimum variance frontier. We then examine the relative contribution of equity warrants and options written on the same underlying asset to price discovery using the common factor approach of Gonzalo and Granger (1995). We find that statistically significant price discovery occurs in both the equity warrant and options markets. The equity warrant market accounts for the majority of the price discovery for thirty percent of the sample firms while the options market accounts for the majority of the price discovery in the remaining firms.

*JEL Classification Code:* G14, G24, G32

*Keywords:* Market microstructure; spanning tests, price discovery; options; warrants

## 1. Introduction

Over the last two decades, a proliferation of new financial instruments has emerged across various exchange-traded markets. Merton Miller (1986) characterized the surge of new financial instruments as a twenty-year “revolution” in financial innovation. Examples of these instruments include options, financial futures, options on futures, options on indices, and, more recently, equity warrants issued by investment bankers. Since the recent launch of the covered warrants market on the London Stock Exchange (LSE) in October 2002, £97 million traded in the first year and 823 covered warrants have been issued. Industry commentators anticipate that this growth will continue in the next few years. In the Asia-Pacific region, there has been remarkable growth in the derivative warrants market in Hong Kong, since its launch in September 1989. For instance, the number of derivative warrants issued in the Hong Kong Stock Exchange (HKSE) in 2002 and 2003 were 644 and 687, respectively, compared to 279 new warrant issues in 2000.

Whether the creation of these new financial instruments has social or private value is of central concern for both policy makers and scholars. Critics argue that financial innovations have a negative impact on financial markets, by allowing more investors to take highly leveraged speculative positions. By contrast, advocates argue that these new financial instruments make markets more complete, reduce transaction costs, allow quicker arbitrage, and lead to a more optimal allocation of risk in the economy.

Given that equity warrants are very similar in design to existing exchange-traded options, it is an open question whether adding this additional derivative contract to the markets will increase investors' opportunity sets allowing them to attain more efficient portfolios. We use spanning tests (Huberman and Kandel, 1987) to examine this issue using data for equity warrants and options traded on the Australian Stock Exchange. We also examine the relative importance of equity warrants vis-à-vis options on the same underlying security in contributing to price discovery. Our work is related to Chakravarty, Gulen and Mayhew (2004), who call for research into price discovery across competing option exchanges. Since the option listing wars of 1999 in the United States, most actively-traded options have been cross-listed on multiple U.S. exchanges (Fontnouvelle, Fische and Harris, 1999). Simaan and Wu (2003) analyze how much

price discovery occurs between cross-listed equity options on multiple option exchanges.<sup>1</sup> The present paper is unique in two ways: first, we address the relative price discovery of two derivative assets trading on one exchange. Second, we assess the redundancy of equity warrants by performing spanning tests. Equity warrants contribute more to price discovery than equity options in 30% and prove not redundant in 72% of the securities examined.

## **2. Background and related literature**

Equity warrants are transferable instruments that confer to the holder the right to buy or sell a specific underlying claim on (or before) a predetermined date. In this sense, they represent option-like securities that are usually issued by investment houses and other financial institutions. The underlying claim may be securities such as shares, baskets of shares, unit trusts, foreign currencies or share price indices. Warrant contracts can be best described as ‘investor-driven’ securities, as issuers fill in ‘pockets’ of investor demand by creating tailored securities, which are usually not available in an otherwise easy-to-trade and liquid form. The birth of the derivative warrants market came in the form of warrants issued by Japanese companies in the mid-1980s. The bulk of new Japanese warrant issues were denominated in U.S. dollars. They were issued and attached to Japanese corporate bonds, where the warrants were priced at values in excess of US\$25,000.

Other early Japanese derivative warrants were launched in the Swiss market to take advantage of the relatively high price Swiss investors were prepared to pay for these instruments denominated in their own currency. Although a wide range of Japanese warrants existed on the Over-the-Counter (OTC) Euro market, much of the Swiss demand came from retail investors who lacked the ability or inclination to access capital markets outside Switzerland directly. This presented an immediate arbitrage opportunity for intermediaries to purchase U.S. dollar denominated warrants and use them as a hedge, or “cover,” for their own issue of Swiss franc-denominated warrants. These warrants were issued on the same Japanese companies, often on the same terms as the U.S. dollar issue. The main difference was the issuer (i.e. usually an offshore financial

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<sup>1</sup> They find that the newly founded electronic options exchange, the International Securities Exchange (ISE) leads the other options exchanges in providing more informative quotes.

subsidiary of a leading investment bank), the currency denomination of the issue (i.e. Swiss francs as opposed to U.S. dollars) and the fact that the denomination in Swiss francs was kept small (i.e. one U.S. dollar warrants would hedge 10 Swiss-franc-denominated warrants). This latter feature significantly increased the popularity of derivative warrants among retail investors. Today, derivative warrants are traded in Germany, Italy, Spain, Switzerland, France, United Kingdom, Hong Kong, Singapore, Japan, Taiwan, South Africa, and Australia.

The information content associated with derivative trading in one market affects trading activity in other markets. Much of the empirical work in this area has been motivated to obtain an understanding of the price discovery linkages that should exist between related markets, by examining the speed at which new information is reflected between two related securities. Earlier empirical studies in this area focused their attention on determining whether there is a lead (or lag) relationship between price changes in the derivative and spot market, in an attempt to identify whether price discovery occurs in one market before the other. Manaster and Rendleman (1982) [hereafter MR] investigate this issue with the use of daily closing prices for actively traded options on the Chicago Board Options Exchange (CBOE) and their underlying stocks on the New York Stock Exchange (NYSE). They find that options lead the stock market by as much as a full trading day. Bhattacharaya (1987), Anthony (1988) and Diltz and Kim (1996) support MR's finding. Stephan and Whaley (1990) improve a shortcoming of MR's paper, with an investigation of intraday relations between price changes for a sample of options trading on the CBOE and their underlying stocks trading on the NYSE. A multivariate time-series analysis on five-minute intervals is used to estimate the lead/lag relation between the price changes in the option and stock market. In contrast to MR's paper, they conclude that stocks lead options by at least 15 minutes. Chan, Chung and Johnson (1993) use 5-minute intraday quotes and argue that the stock lead found by Stephan and Whaley (1990) is spurious.

A methodological deficiency of the above studies is that they suffer from a potential bias of using fixed time intervals when running lead-lag regressions to determine which market first incorporates new information. Finucane (1999) avoids this potential bias, by examining the direction and timing of the flow of information between CBOE call options and their underlying NYSE stocks using variable time length

intervals. He finds that stock quotes still lead option quotes, but the length of the lead is shorter than previously thought, ranging from a few seconds to 6 minutes. When options occasionally lead stocks, Finucane finds no evidence that the option lead exceeds three minutes.

Chakravarty, Gulen and Mayhew (2002) use a procedure suggested by Hasbrouck (1995) to estimate how much price discovery occurs in the option market and how much occurs in the underlying stock market. This methodology measures the information share of price discovery by the proportion of innovations to the efficient price occurring in each market. They find that some price discovery occurs in the options market, where the information share averages 17 percent with estimates for individual stocks ranging from 12 percent to 23 percent. Additionally, Chakravarty, Gulen and Mayhew find that more price discovery occurs in the options market when option volume is elevated and stock volume is lower, and when option effective spreads are narrower and stock effective spreads are wider.

Chang, Chung and Fong (2002) examine the intraday interdependence of order flows and price movements for actively traded NYSE stocks and their CBOE-traded options. They find that informed investors initiate trades in the stock market, not in the options market, but that stock and option quote revisions have predictive ability for one another. This suggests that while information in the stock market is contained in both quote revisions and trading prices, information in the option market is contained only in quote revisions. One interpretation is that option quotes affect the level of information asymmetry in the stock.

### **3. Institutional background**

#### *3.1. The Australian equities warrants market*

The equity warrant market in Australia commenced in 1991, fifteen years after the introduction of the first exchange-traded option (ETO). Equity warrants are underwritten by third parties, usually investment

banks, and not by the company whose stock constitutes the underlying asset.<sup>2</sup> They are governed by Section 8 of the Australian Stock Exchange (ASX) Business Rules and traded on the Stock Exchange Automated Trading System (SEATS).<sup>3</sup> A call (put) equity warrant gives the holder the right, but not the obligation, to buy (sell) the underlying stock at a predetermined price on or before the expiry date. For this right, the warrant buyer pays the warrant issuer a premium, which represents the market price of the warrant. While there exists similarities between warrants and ETOs, several distinctions remain, namely; (i) warrants are not allowed to be short sold; (ii) no margin payments are required by issuer's to cover their obligations under the warrant; (iii) investors can purchase non-standard contract sizes; and (iv) higher premiums are usually needed to enter the warrants market.

Warrants are traded on SEATS in the same manner as shares and have typical expiry terms ranging from three to eighteen months, with the length likely to be twelve months. Normal trading in SEATS takes place on a continuous basis from 10:00 to 16:00 on Monday to Friday. Prior to the commencement of trading a call market operates on the ASX, where investors through their brokers are invited (called) to submit orders to SEATS. During the call market, orders are queued according to price time priority, where no trading occurs until the end of the call. The call market takes place from 7.00 to 10:00. A unique set of market opening procedures is used on SEATS to commence normal trading each morning. Opening takes place at 10:00 and lasts for about 10 minutes. During this phase, SEATS determines whether bids are higher than or equal to asks. If there are bids higher than the lowest ask, an algorithm is employed to determine the opening price. From 10:00 to 10:09, opening times are staggered, depending on the starting letter of the ASX stock code. SEATS trading currently opens randomly for five different groups of stocks (in alphabetical order). Once stocks are opened, they trade continuously until 16:00 when trading ends. In order for third parties (hereafter termed issuers) to be granted trading status from the ASX, they are required to facilitate a market

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<sup>2</sup> Traditionally, warrants are issued (i.e., written) by a company that permits the holder to convert the warrant into the shares of the company, upon exercising the warrant contract. If the warrant is exercised, additional shares are required to be issued by the company. This corresponds to a dilution in the ownership of existing investors in the company and consequently changes the company's capital structure. In this paper, equity warrants considered are not issued by the company upon whose shares they are written, but instead are written by a third party. If a holder of ASX warrants decides to exercise his or her contract, no additional shares are issued from the company.

<sup>3</sup> SEATS is a competitive and open, electronic order book which trades continuously (from 10:00 to 16:00) from Monday to Friday. It allows brokers to clearly see bids and offers, place buy or sell orders, execute transactions, communicate with other brokers, and report any off-market transactions.

in the warrants issued by quoting prices, but they are not obligated to trade. Hence, the equity warrants market can be seen as a hybrid market, in which both limit-order traders and an unofficial designated dealer (i.e., the warrant issuer) establish prices.

The terms and conditions of a derivative warrant contract are set out in a document prepared by the warrant issuer called the Offering Circular. Generally, all warrants have standardized features with the underlying claim, exercise style, expiry date, exercise price, and settlement details outlined. The underlying claim may be securities such as shares, baskets of shares, unit trusts, foreign currencies or share price indices. The warrant contract may be exercised at any time during its life (American style) or only on the expiry date (European style). Equity warrants are typically issued with expiry terms ranging from three to eighteen months from the date of issue. Presently, the length is likely to be less than twelve months, with the contractual terms varying across issuers, the underlying stocks and over time. The majority of equity warrants listed on the ASX are, if exercised, settled with the physical delivery of the underlying shares.

The performance of the warrant issuer or the warrants issued is not guaranteed by the ASX or any of its subsidiaries. Instead, warrant holders are exposed to the credit risk of the issuer (or its guarantor). Consequently, investors rely on the financial strength, size and reputation of the warrant issuer to reduce counterparty risk. To assist investors in assessing the credit risk of the issuer, information on the financial situation of the issuer and guarantor is included in the Offering Circular document. Warrant issuers are not covered by margins or any other collateral lodged with the ASX, or Clearing House. However, warrant contracts may be 'covered', where the warrant issuer deposits the underlying stock in a trust or similar custodial arrangement, thereby guaranteeing any obligations to warrant holders.

Warrant issuers play an important role in the market. Though banks are not obliged to facilitate a market in their warrants issued, they have a material interest in ensuring a liquid and efficient market at the time of issue. Warrant issuers have developed a reputation for ensuring investors a liquid market place through active participation in the secondary market, while maintaining a tight after market price (i.e., narrow bid-ask spreads).<sup>4</sup> These trading activities have encouraged the use of warrants from smaller

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<sup>4</sup> ASX Market research on the warrants market during 1996 revealed that specific warrant issuers accounted for 42% to 57% of turnover for three of the most actively traded warrant series (by open position).

investors, enabling new issues of warrant series to be placed with their clients. Warrants issuers also have the right on issue to create and issue further warrants, and to purchase existing warrants that may be held, resold or cancelled. The vast majority of equity warrants listed on the ASX are of the non-collateralized type (i.e., not fully covered). In these circumstances, the warrant issuer usually dynamically hedges its warrant books using the underlying stock, options, and/or indeed their own warrants to eliminate any unnecessary risk exposure during the period when their warrant is alive. The hedge positions vary across warrant issuers and are kept confidential for strategic purposes of the issuer.

### *3.2 Descriptive statistics of the Australian equities warrants market*

The first listed warrant in Australia (an equity call warrant on the listed stock Boral) was issued by Macquarie Bank on 10<sup>th</sup> January 1991 and met with moderate success. By mid-1995, the ASX had four equity warrants trading, with negligible volumes. The growth in warrants turnover increased significantly after 1995, rising from millions a year to billions (see Exhibit 1). This success has been attributed to four primary factors (see Hunter, 1999). First, the warrant market has been able to utilize existing trading and settlement infrastructure at the ASX, meaning no additional overheads to stockbrokers. Second, strong retail participation in a rising or bullish underlying stock market created a large investor pool for equity warrants. Third, warrant issuers have effectively accessed distribution channels via stockbrokers through extensive promotional schemes. Finally, significant branding of warrants (i.e., a ‘Merrill Lynch’ warrant versus a ‘Deutsche Bank’ warrant) has supplemented the positive marketing efforts of warrant issuers.

Exhibit 1 indicates that equity call warrants are the most widely traded instrument in the equity warrant market but are a continuously declining percentage of total warrant volume. This suggests that market participants are trading other types of warrants more actively even in the market upturn of recent years. As of December 2002, there were 83 underlying stocks over which equity warrants were traded. During this period, 14 warrant issuers for derivative warrants dominated the warrants market. As of 2002, equity warrants trading volume represented 6.1% of the total stock market trading volume in the same period.

### *3.3 The Australian equities option market*

The equity option market in Australia commenced in 1976 and is managed by the Australian Stock Exchange Options (ASXO) division. Typically, option contracts that trade are American style and standardized by contract size (each contract representing 1,000 shares of the underlying stock), expiry date, and exercise price. The standardization of options permits easier transfer of rights and obligations of the contract. Expiration is usually nine months, though the ASXO occasionally lists spot monthly options and longer term options.

The options market operates using the Derivatives Trading Facility (DTF), which is a customized version of the CLICK system developed by the Swedish Options and Futures Exchange (SOFFEX). The DTF is a fully automated screen based system, which allows brokers to view and access the options market immediately. Normal trading in the options market occurs during two daily trading sessions: a morning session from 10:00 to 12:30 and an afternoon session from 14:00 to 16.15. The DTF consists of the Central Orderbook and the Bulletin Board. Market makers transact in all series of all classes of options through the Central Orderbook for their clients. The Bulletin Board enables market makers to advertise their interest in trading and transacting particular option strategies. Market makers are required to provide orders in the at-the-money and near-the-money series at a maximum spread for a minimum number of contracts.<sup>5</sup> Where a market does not exist, market makers are obliged to provide two-way quotes in other series upon request. An absence in liquidity in some option series may exist, dependent upon the level of activity in the underlying stocks and whether those option classes carry market-making obligations. Unlike SEATS, the DTF does not allow orders to be inputted prior to the opening and does not carry forward unexecuted orders to the next trading day. Though the options market opens at 10:00, each option class remains suspended until the underlying stock is opened in SEATS. All orders on the DTF are transparent to market makers and are executed automatically on a price-time priority basis.

## **4. Data and research method**

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<sup>5</sup> Market makers usually provide orders in the six option series, which have exercise prices closest to the current share price.

#### *4.1 Data sources*

We obtain data through the Securities Industry Research Centre Asia-Pacific (SIRCA). Data for individual warrant trades are obtained from the high frequency SEATS database, which provides full details of all equity warrant orders and trades placed on the Australian Stock Exchange (ASX). These records provide security code, price, volume, date, broker and time to the nearest one-hundredth of a second for every order and trade. Data for option contracts are obtained from the DTF database, which provides a complete time-stamped history of quotes and traded prices for all equity option series traded on the ASX. The ASX Signal E database is used to identify the listing dates, expiration dates, exercise price, conversion ratio, and security type for all warrant and option series traded. We also collect daily data for 1 January 1999 to 31 December, 2002 on the All Ordinaries Accumulation Index, which is adjusted for dividends and splits (as a proxy for the returns on the Australian share market).

#### *4.2 Sample selection*

We begin with a sample comprising 48 matched call warrant and option series written on identical underlying stocks. To avoid problems associated with non-trading in derivative assets, we employ a matching algorithm to identify the most actively traded options and warrants covering a particular stock. Each day, for a given underlying stock, the most actively traded call warrant series is paired with the most active call option series. Both the option and warrant must have at least 10 transactions for each trading day. Warrant and option contracts trading within 5 trading days or less of maturity are excluded to avoid any expiration effects. For each underlying stock, we identify a six-month period when both the option and warrant trade. During this period, there can be at most 123 days of observations. Option/warrant pairs with fewer than 16 days of observations are excluded. For each option and warrant time series of trades, we develop pairs of synchronous trades using the approach described in Section 4.4. For inclusion in our analysis, we require that there be at least 100 pairs of synchronous trades. Our final sample comprises matched equity warrant and options series written over 20 underlying stocks.

#### *4.3 Testing for mean-variance spanning*

To address the question of whether introducing warrants into the Australian marketplace enhances market efficiency, we perform tests for mean-variance spanning. The principles of mean-variance spanning were first developed by Huberman and Kandel (1987)<sup>6</sup> who statistically test whether the inclusion of a new set of risky assets (N) allows investors to improve the minimum variance frontier derived from a portfolio of base or benchmark assets (K). This test is generally referred to as a ‘spanning test.’ If extension of the efficient set is not possible, the mean-variance frontier of a set of K benchmark assets is said to “span” the minimum variance frontier of the K assets plus a set of N test assets. In our study, the new risky assets are equity warrants and the benchmark assets include the local market index, the underlying stocks, and the equity options. Before proceeding to spanning tests, we first perform regressions to adjust each equity warrant and equity option return series for its time to maturity and moneyness effects.

$$R_{EW,t} = \tau_1 (MATURITY_{EW,t}) + \tau_2 (MONEYNESS_{EW,t}) + e_{EW,t} \quad (1)$$

$$R_{EO,t} = \lambda_1 (MATURITY_{EO,t}) + \lambda_2 (MONEYNESS_{EO,t}) + e_{EO,t} \quad (2)$$

where:

$R_{EW,t}$  = return on the equity warrant (i.e. non-benchmark asset) in day  $t$ ;

$R_{EO,t}$  = return on the equity option in day  $t$ ;

$e_{EW,t}$  = the error term for the equity warrant in day  $t$ ;

$e_{EO,t}$  = the error term for the equity option in day  $t$ ;

$MATURITY_{EW,t}$  = time left to maturity (in days) for the equity warrant in day  $t$ ;

$MATURITY_{EO,t}$  = time left to maturity (in days) for the equity option in day  $t$ ;

$MONEYNESS_{EW,t}$  = the amount by which the equity warrant is in the money in day  $t$ ;

$MONEYNESS_{EO,t}$  = the amount by which the equity option is in the money in day  $t$ ; and

$\tau$  and  $\lambda$  = parameters to be estimated.

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<sup>6</sup> Mean-variance spanning tests have been used in studies such as Huberman and Kandel (1987) Hansen and Jagannathan (1991), Snow (1991), Bekaert and Urias (1996), Errunza, Hogan and Hung (1999), and DeRoos, Nijman and Werker (2001). All of these studies examine the benefits of extending an international portfolio into emerging markets and find that significant gains are obtained from such an extension of the universe of assets.

In particular, we compute the residual adjusted equity warrant returns ( $R_{ew,t}$ ) and residual adjusted equity option returns ( $R_{eo,t}$ ).

$$R_{ew,t} = \mathbf{t}_1(\text{MATURITY}_{EW,t}) + \mathbf{t}_2(\text{MONEYNESS}_{EW,t}) + R_{EW,t} \quad (3)$$

$$R_{eo,t} = \mathbf{I}_1(\text{MATURITY}_{EO,t}) + \mathbf{I}_2(\text{MONEYNESS}_{EO,t}) + R_{EO,t} \quad (4)$$

We then use Hansen's (1982) generalized method of moments (GMM) technique to test the following a priori multi-factor APT time-series model.

$$R_{ew,t} = \mathbf{a}_{ew} + \mathbf{b}_1 R_{MKT,t} + \mathbf{b}_2 R_{S,t} + \mathbf{b}_3 R_{eo,t} + \mathbf{b}_4 WSPR_t + e_{ew,t} \quad (5)$$

where for each trading day  $R_{ew,t}$  is the residual adjusted return on the equity warrant (i.e., non-benchmark asset);  $R_{MKT,t}$  is the return for the market (as proxied by the All Ordinaries Accumulation Index);  $R_{S,t}$  is the underlying stock return;  $R_{eo,t}$  is the residual adjusted return on the equity option;  $WSPR$  is the time weighted warrant spread;  $e_{ew,t}$  is the error term for the equity warrant, and  $\alpha$  and  $\beta$  are parameters to be estimated. The equity warrant examined is spanned by the benchmark assets only if the intercept ( $\alpha_{EW}$ ) is zero and the sum of the beta coefficients equals unity. We employ a GMM test of the joint hypothesis based on equation (5) that  $\mathbf{a}_{ew} = 0$  and  $S\beta = 1$ ; Kan and Zhou (2000) show that GMM spanning tests are preferred, especially when returns are not normally distributed. If the spanning test fails, and the intercept term is positive, then including the equity warrant in the benchmark portfolio improves the efficient frontier.

#### 4.4 Methodology for sampling synchronous trades

To examine the price movements between the warrant and option execution channel, we need to capture a synchronous time series of paired trade price observations (one from each channel) that are relatively contemporaneous. We utilize the MINSPAN data collection procedure of Harris, McInish,

Shoemsmith and Wood (1995), which was first developed when examining security price adjustments for Dow Jones stocks trading on the New York Stock Exchange and other regional exchanges. Following the MINSPAN procedure, we collect trades by each channel and match these trades so as to minimize the time span between the channels in order to minimize non-synchronicity and avoid spurious serial correlation.<sup>7</sup>

To construct matched pairs, we consider only cases for which there is a trade in channel W (the warrants channel) followed by a trade in channel O (the options channel) or a trade in channel O followed by a trade in channel W. Consider a time series of option and warrant trades arranged in chronological order to illustrate the MINSPAN procedure:

W <sub>1</sub>	O <sub>1</sub>	O <sub>2</sub>	O <sub>3</sub>	W <sub>2</sub>	O <sub>4</sub>	O <sub>5</sub>	W <sub>3a</sub>	W <sub>3b</sub>	W <sub>3c</sub>	O <sub>6</sub>
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Assuming all the trades done by channel W and O meet our preliminary screening requirements, then a possible pair, (W<sub>1</sub>,O<sub>1</sub>) is formed. We check ahead to see if a subsequent warrant trade can form a pair with O<sub>1</sub> that has a shorter time span than the original possible pair. If not, (W<sub>1</sub>,O<sub>1</sub>) becomes the first pair in the dataset. Searching for the next pair to include in the dataset, there are two possibilities, [(O<sub>3</sub>,W<sub>2</sub>) and (W<sub>2</sub>,O<sub>4</sub>)]. We add the one that has the shortest time span. If trade prices are the same for a given channel, we introduce the ‘collapse’ method. The collapse method treats W<sub>3a</sub>, W<sub>3b</sub>, W<sub>3c</sub> as one trade and hence combination (W<sub>3a</sub>,O<sub>6</sub>) is taken as a pair in the dataset rather than (W<sub>3c</sub>,O<sub>6</sub>).

It is important to stress that the censoring of data by the MINSPAN procedure has been examined in detail in the literature and shown not to bias results of the common factor estimations obtained using the Gonzalo and Granger (1995) approach. In particular, Tse (2000) compares results of the Gonzalo and Granger (1995) approach using the MINSPAN procedure with a one-second resolution of the data using interpolation and Hasbrouck’s (1995) estimation technique and finds that MINSPAN censoring of the data does not introduce bias. Tse (2000) demonstrates that all parameters in the two models are essentially identical. Despite this conclusion, Harris, McInish, and Wood (2002b) argue that the Gonzalo and Granger method is preferred because of the availability of statistical tests for this method. In contrast, the distribution of the information shares, which is the primary output of the Hasbrouck method, is unknown; consequently,

<sup>7</sup> As a preliminary screening of the dataset, we also omit all batch trades (i.e., in opening and closing trades).

as shown by Huang (2002), conclusions based on information shares must rely upon wide ranges of parameter values.

#### 4.5 Error correction approach to price adjustment dynamics with common stochastic trends

To understand the mechanics of price discovery across competing execution channels and detect the location of informed trades, we employ the common factor components approach proposed by Gonzalo and Granger (1995).<sup>8</sup> Again, this approach is preferred over the information shares approach proposed by Hasbrouck (1995) because of its ability to test the statistical significance of the price discovery parameters. The first stage of this approach involves determining whether the synchronous trading prices in the warrant and option execution channels ( $P_{EW,T}$  and  $P_{EO,T}$ ) are both I(1) series. If so, we assume each price series impounds the stochastic trend  $\sum w_t$  of the implicit efficient price as a Stock-Watson (1988) common trend:

$$P_{EW,T} = P_{EW,0} + \sum_{t=1}^T w_t + \varepsilon_{EW,T} \quad \text{and} \quad P_{EO,T} = P_{EO,0} + \sum_{t=1}^T w_t + \varepsilon_{EO,T}. \quad (2)$$

Thus, the price in each execution channel is dependent on a non-stochastic initial value, on a permanent stochastic trend of cumulative random information arrivals  $\sum_{t=1}^T w_t$ , and on a zero-mean covariance-stationary process that is transitory ( $\varepsilon_{EW,T}$  or  $\varepsilon_{EO,T}$ ). The  $\varepsilon_{EW,T}$  and  $\varepsilon_{EO,T}$  are disturbances to private values that reflect differences of opinion in assessing the same information or differences in market frictions.

Though the trade price sequences for each execution channel are non-stationary, the difference between their contemporaneous values is itself a stationary time series:  $(P_{EW,t} - P_{EO,t}) = \varepsilon_{EW,t} - \varepsilon_{EO,t}$ . Therefore, by the Granger Representation Theorem for cointegrated variables (Engle and Granger, 1987),  $\Delta P_{EW,t}$  and  $\Delta P_{EO,t}$  can be estimated as a vector error correction model (VECM). We include deterministic terms in our VECM to control for changes in warrant expiry price (wxp); option expiry price (oxp); warrant expiry date

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<sup>8</sup> Early research using the permanent-transitory model of Gonzalo and Granger (1995) in the United States stock markets includes Harris, McNish and Wood (2002a) and Tse (2000).

(wxd); option expiry date (oxd); and number of warrant issuers (wi) for our dataset. The VECM with deterministic terms that is utilized is specified below.

$$\begin{aligned} \Delta P_{EW,t} = & \left\{ \sum_{j=1}^2 \sum_{s=1}^S \mathbf{b}_{EW,j,t-s} \Delta P_{j,t-s} \right\} + \mathbf{g}_{EW} (P_{EW,t-1} - P_{EO,t-1}) \\ & + \left[ a_1 \text{wxp}_t + a_2 \text{oxp}_t + \sum_{k=1}^{n-1} b_k \text{wxd}_{k,t} + \sum_{k=1}^{n-1} b_k \text{oxd}_{k,t} + \sum_{k=1}^{n-1} b_k \text{wi}_{k,t} \right] + \mathbf{u}_{EW,t} \end{aligned} \quad (3)$$

$$\begin{aligned} \Delta P_{EO,t} = & \left\{ \sum_{j=1}^2 \sum_{s=1}^S \mathbf{b}_{EO,j,t-s} \Delta P_{j,t-s} \right\} + \mathbf{g}_{EO} (P_{EW,t-1} - P_{EO,t-1}) \\ & + \left[ a_1 \text{wxp}_t + a_2 \text{oxp}_t + \sum_{k=1}^{n-1} b_k \text{wxd}_{k,t} + \sum_{k=1}^{n-1} b_k \text{oxd}_{k,t} + \sum_{k=1}^{n-1} b_k \text{wi}_{k,t} \right] + \mathbf{u}_{EO,t} \end{aligned} \quad (3')$$

where  $j$  is the execution channel and  $S$  is the optimal lag length that minimizes the Akaike Information Criterion (AIC) for the corresponding vector autoregressive regression (VAR) system of price level equations. The deterministic terms include two continuous variables (wxp and oxp) and three dummy variables (wxd, oxd, and wi). Each dummy variable is set to 1 if that dummy variable for observation  $t$  corresponds to the  $k^{\text{th}}$  qualitative variable of interest, otherwise 0. The parameter ' $k$ ' can take a value between 0 and  $n$ , where  $n$  represents the number of categories in the dummy variable examined.

Writing innovations in the trading prices as  $\Delta P_{j,t-s} = w_{t-s} + \Delta e_{j,t-s}$  and substituting into (3) and (3').

$$\begin{aligned} \Delta P_{EW,t} = & \mathbf{a}_{EW} + \sum_{j=1}^2 \mathbf{b}_{EW,j} \sum_{s=1}^S w_{t-s} + \sum_{j=1}^2 \sum_{s=1}^S \mathbf{b}_{EW,j,t-s} \Delta e_{j,t-s} + \mathbf{g}_{EW} (e_{EW,t-1} - e_{EO,t-1}) \\ & + \left[ a_1 \text{wxp}_t + a_2 \text{oxp}_t + \sum_{k=1}^{n-1} b_k \text{wxd}_{k,t} + \sum_{k=1}^{n-1} b_k \text{oxd}_{k,t} + \sum_{k=1}^{n-1} b_k \text{wi}_{k,t} \right] + \mathbf{u}_{EW,t} \end{aligned} \quad (4)$$

$$\begin{aligned} \Delta P_{EO,t} = & \mathbf{a}_{EO} + \sum_{j=1}^2 \mathbf{b}_{EO,j} \sum_{s=1}^S w_{t-s} + \sum_{j=1}^2 \sum_{s=1}^S \mathbf{b}_{EO,j,t-s} \Delta e_{j,t-s} + \mathbf{g}_{EO} (e_{EW,t-1} - e_{EO,t-1}) \\ & + \left[ a_1 \text{wxp}_t + a_2 \text{oxp}_t + \sum_{k=1}^{n-1} b_k \text{wxd}_{k,t} + \sum_{k=1}^{n-1} b_k \text{oxd}_{k,t} + \sum_{k=1}^{n-1} b_k \text{wi}_{k,t} \right] + \mathbf{u}_{EO,t} \end{aligned} \quad (4')$$

Equations (4) and (4') make clear that the error correction parameter  $\gamma_j$  reflects the adjustment to cointegration equilibrium necessitated by transitory shocks idiosyncratic to each market ( $\epsilon_{j,t}$ ), whereas  $\Sigma\beta_{EW,j}$  or  $\Sigma\beta_{EO,j}$  refers to the long-run equilibrium impounding in  $P_{EW,t}$  or  $P_{EO,t}$  of lagged innovations in the common factor  $w_{t-s}$ . We report below Gonzalo and Granger's (1995) common factor weight that derives from the  $\beta$ s and can be shown to be proportional to the relative incidence of trading that avoids impounding transitory shocks (Yan and Zivot 2004, Harris 2005).

#### 4.6. Unit root tests on warrant and option series

Table 1 provides descriptive statistics for the synchronous warrant-option trading pairs constructed using the MINSPAN procedure. Across our dataset, the number of synchronous trading pairs ranges from a high of 1,254 to a low of 107. For the underlying stock with the fewest trading pair observations, there are approximately 5 synchronous trades per day. The mean time span from the first trade in each pair to the second trade in each pair ranges from 327 seconds to 850 seconds.

The time series properties of our paired warrant and option channel price series are reported in Table 2. Our first step is to confirm that both the option and warrant price series are difference stationary at the same order of integration  $I(n)$  while controlling for significant time trends and autoregressive lags, which is reported in column 7.<sup>9</sup> We estimate a single equation autoregression of the log price level for each warrant and option series. Starting with ten lags, all lags significant at 5% or less are included in the regression model. Using this lag structure, we then estimate a continuous returns model, specified as the first difference of the log prices. Two specification tests are performed on this continuous returns model. First, we report a  $t$ -test for the presence of time trends for each of our execution channels. We find that time trends are present for two of our option series (CWO, PAS) and one of the warrant series examined (CBA). Second, we perform a  $t$ -test on the intercept of the continuous returns function. Where the intercept is significant

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<sup>9</sup> Cointegration between two variables occurs when both series (or channels) are each integrated of order  $b$ , but some linear combination of the two series results in a third series, which is integrated of order  $a$ ,  $a < b$ . For practical purposes in finance,  $b=1$  and  $a=0$ . Thus, the cointegrated series will be  $I(1)$  and the linear combination of the two series will be  $I(0)$ .

(insignificant), the underlying price level series is a random walk with (or without) drift. We report that all of the option price series exhibit negative drift. Thirteen of the warrant price series are found to have negative drift, while the remaining seven warrant price series exhibit no drift. Negative drift in the option and warrant price series is to be expected as derivative contracts approach their expiration date.

After conducting the specification tests for the drift parameter, we next employ augmented Dickey-Fuller (ADF) test statistics to classify our channel price series into three types of autoregressive processes: simple random walks with or without drift, mean-reverting convergent price series, or explosive growth (decay) non-convergent price series. All warrant and option price series are either a simple random walk with first-degree serial correlation of log prices ( $\rho$ ) equal to 1.0 and covariance stationary residuals, or a mean-reverting sequence with positive fractional  $\rho$  in the log prices and covariance stationary residuals. The augmented Dickey-Fuller confidence intervals 95% confidence interval for a random walk with (i) no drift or time trend is -1.95 to +1.95 (ii) drift but no time trend is -2.86 to +2.86; and (iii) drift and time trend is -3.41 to +3.41.<sup>10</sup>

When examining the warrant return series written on the underlying stock CML, we observe that it has a  $\tau_{\mu}$  of -2.67, well inside the appropriate ADF critical values of +/-2.86, thereby indicating a simple random walk. In contrast, the option return series written for the same underlying stock has a  $\tau_{\mu}$  of -3.26 exceeding the ADF critical value of -2.86 and indicating a near unit root (i.e. fractional  $\rho$ ) that is characteristic of a mean-reverting series. In the latter case, the price and return series overshoot in response to positive information and undershoot in response to negative information, but in time they collapse back to their expected values (or expected trends). Both random walks and mean-reverting autocorrelation functions reflect inherently stable price dynamics that converge so that cointegration models are appropriate for these series. In the last column of Table 2, conclusions are drawn from the ADF tests about the autoregressive patterns for all the option and warrant series.

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<sup>10</sup> A summary of the critical values for the Dickey Fuller tests is contained in Enders (1995, Table A, p.419).

#### 4.7. Cointegration tests

Having confirmed the presence of integrated sequences with covariance stationary residuals, we proceed with cointegration testing on these pairs of price series for both warrants and options. Based on the assumption that intermarket arbitrage will rapidly remove any deviations in the most recent trading prices in warrants and options ( $P_{EW,t-1} - P_{EO,t-1}$ ), we expect  $P_{EW,t}$  and  $P_{EO,t}$  to be cointegrated  $C(1)$ . To confirm the appropriateness of these restrictions, we test for the cointegration of the warrant and option synchronous trade prices using the Johansen maximum eigenvalue tests. Unlike the single-equation modelling of the autoregressive sequences applied earlier, it is necessary to determine an optimal system lag length for use in the cointegration testing. For this analysis, we employ TSULMAR, which minimizes the Akaike Information Criterion (AIC) for the two price series ( $P_{EW}$  and  $P_{EO}$ ) as a system of equations.

Table 4 reports the optimal lag lengths and the results of Johansen's (1988) reduced rank regression procedure for testing possible cointegration. With two price series there can be at most one cointegrating vector ( $r = 1$ ). We test this alternative hypothesis against the null that  $r = 0$  with a maximum eigenvalue test statistic. The critical value for the maximal eigenvalue test at the 95% and 99% levels of significance (obtained from Enders 1995, Table B, p.420) are  $\lambda_{\max} = 14.59$  and 18.78. For all 20 warrant and option price series pairs, the test statistic is greater than these critical values. Hence, it is possible to reject the null hypothesis  $r = 0$  and conclude that there is only one cointegrating vector (i.e.,  $r = 1$ ). This result shows that there are not any persistent arbitrage opportunities between warrant and option pairs. The second column in Table 4 reports the sum of the cointegration vector for each price series pair. The statistics are reasonably large, with absolute values ranging from AUD0.013 to AUD1.139, with a mean of AUD0.224. These bounds indicate that although persistent arbitrage is unlikely, intermarket trading between warrants and options can be profitable.

## 5. Empirical results

### 5.1. Spanning test results

For each underlying stock we analyze whether the inclusion of an equity warrant in the benchmark portfolio enhances investors' efficiency set. Table 3 displays the results of the mean variance spanning tests. In the first column of the table, we show the symbol for the underlying stocks in our sample. The second and third columns display, respectively, the sample year used for the mean-variance regression and the number of matched warrant-option trading days within that year.<sup>11</sup> The fourth column reports the estimated intercept term ( $\alpha_{ew}$ ). The next three columns show the beta coefficients of our benchmark assets. The last column reports the GMM Wald test statistic and its associated significance level. These results reject the hypothesis that the returns on the market, the underlying stock and the equity option span the returns of the equity warrant.

The Wald test refers to the joint hypothesis that the intercept term ( $\alpha_{ew}$ ) is zero and the sum of the beta coefficients equals 1.0. For 18 of the 20 cases analyzed, the results reveal that spanning is rejected at the conventional levels of significance. We find that out of these 18 cases, 72 percent (13) have an intercept term that is positive,<sup>12</sup> averaging just under 1% (i.e., 0.95 %) and ranging from 0.2% to 8%. These findings indicate that even where an investor already holds a market index, underlying stock and equity options, the inclusion of equity warrants can provide enhanced diversification benefits. Therefore, warrants are not redundant assets for investors, but rather can enhance the market efficiency frontier. We now proceed to the related but distinctly different question of whether price discovery also occurs in the warrants market. If so, warrants are not redundant in this second, additional sense.

## 5.2. Estimation and testing of common factor weights

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<sup>11</sup> Recall, a one year period was chosen to have the highest number of matched trading days for the warrant-option pair for each underlying stock analyzed.

<sup>12</sup> Seven cases yield small but negative alphas; two of which arise in conjunction with statistically insignificant results from the spanning test.

Having satisfied ourselves that the execution channels are each  $I(1)$ , we apply Gonzalo and Granger's (1995) common factor components methodology (the GG method) to estimate the proportion of the common stochastic trend attributable to warrant trades versus option trades. When applying the GG method, the transitory disturbances are prevented from Granger causing permanent information arrivals and common factors are restricted to linear functions of current observed prices.

Table 5 provides estimates of the Gonzalo and Granger (1995) normalized common factor weights  $[f_1, f_2]$  of the execution channels, followed by a chi-squared test statistic and its associated level of significance. These common factor weights can be interpreted as the proportion of permanent price adjustment contributed by each execution channel (see Harris, McInish, and Wood, 2002a). For example, in examining BHP, we find that the warrant executed trades contribute 56% of the permanent price changes to the true equilibrium price, while option executed trades contribute 44%. Both of these parameters are found to be statistically different from zero at the 0.01 level. Likelihood ratio tests of the null hypothesis  $H_0: f = [0,1]$  against the one-tailed alternative  $H_a: f_1 > 0$  and  $f_2 < 1$  are employed to ascertain the statistical significance of the parameters.

We show that all of the common factor weights for both pairs of derivative instruments are significant at the 0.01 level, with the exception of the warrant prices series written on LHG. The equity warrant provides the majority of the price discovery in six cases and the option provides the majority of the price discovery in the remaining 14 cases. To determine whether options or warrants play a larger role in price discovery, we jointly ranked the 40 common factor weights and performed a mean difference t test on the ranks for the equity warrants and options. This is equivalent to a Wilcoxon rank sum test. The common factor weights for the options are significantly higher than for the warrants at the 0.01 level ( $t = 7.94$ ). Overall, our results reveal that both warrant and options play a part in contributing towards price discovery with options playing the larger role.

## **6. Concluding remarks**

A mean-variance spanning test is used to examine whether the availability of equity warrants allows an improvement in an investor's efficient set. We find that equity warrants are not redundant instruments, in that their inclusion in an investor's portfolio improves the mean-variance frontier. In 18 out of 20 cases considered, spanning is rejected, and in 13 of those 18 cases alpha is positive with an average just under 1%, ranging between 0.2% and 8%. This finding may explain the recent surge in the popularity of equity warrants in Asia and Europe despite their similarity to options previously trading in those markets.

We also investigate the relative contributions to price discovery of equity warrants and options on the same underlying asset using the Gonzalo and Granger (1995) common factor components methodology. We find that on average options contribute 58 percent and equity warrants contribute 42 percent of the price discovery. The common factor weights are statistically significant in 39 of the 40 stocks in our sample. In six of these 39 cases, the equity warrants contribute more to price discovery than the equity options. Clearly, the evidence on both spanning and price discovery supports the potential importance of including warrants among the instruments traded in equity derivative markets.

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Exhibit 1

Summary statistics of equity call warrants listed on the Australian Stock Exchange

Year	Total Equity Call Warrant Volume	Percentage Change	As a percentage of Total Equity Warrant Volume	As a percentage of Total Warrant Volume	Number of Underlying Stocks	Number of Warrant Issuers
1991	2,499,00		100.00	91.27	2	1
1992	9,539,00	281.71	100.00	93.83	2	1
1993	9,251,50	-3.01	100.00	95.80	2	1
1994	25,355,330	174.07	100.00	98.97	2	1
1995	211,486,752	734.09	100.00	99.96	9	3
1996	1,597,034,844	655.15	99.12	98.77	47	8
1997	3,116,207,879	95.12	87.89	86.65	65	10
1998	4,304,452,122	38.13	84.77	72.06	76	14
1999	4,421,843,282	2.73	91.15	77.04	79	14
2000	3,551,040,599	-19.69	93.30	76.13	83	14
2001	8,023,400,277	125.95	75.27	67.42	83	14
2002	6,817,723,923	-15.03	73.12	61.79	83	14

Source: The Australian Stock Exchange: Derivatives Division

**Table 1: Descriptive statistics for synchronous trade pairs constructed using MINSPAN.** For each underlying stock in our sample period, we construct pairs of synchronous trades of equity warrants (channel 1) and equity options (channel 1) using the MINSPAN collection procedure of Harris, McNish, Shoesmith and Wood (1995). The MINSPAN procedure is used because it mitigates the problem of nonsynchronicity by minimizing the time span between the trades in the execution channels, subject to having no intervening trades. The span is the length of time between a trade in channel 1 and a trade in channel 2. The sample period specified contains six months of data, which is used in our price discovery analysis. Descriptive statistics are also presented on the number of trading days, number of trading pairs, mean number of trades per day, and mean time span for each of the warrant-option trade pairs in the dataset.

<b>Underlying stock code</b>	<b>Sample period</b>	<b>Number of trading days</b>	<b>Number of trading pairs</b>	<b>Mean number of trades per day</b>	<b>Mean span (seconds)</b>
AMP	01/05/02 – 31/10/02	47	428	9.11	477
ANZ	01/09/01 – 28/02/02	54	569	10.54	448
BHP	01/01/01 – 30/06/01	74	850	11.49	358
BIL	01/04/02 – 30/09/02	18	131	7.28	591
CBA	01/07/02 – 31/12/02	93	1,148	12.34	368
CML	01/01/01 – 30/11/01	20	134	6.70	586
CWO	01/11/00 – 30/04/01	67	652	9.73	456
LHG	01/03/02 – 31/12/02	22	128	5.82	850
LLC	01/12/00 – 31/05/01	23	173	7.52	656
NAB	01/09/01 – 28/02/02	90	1,049	11.66	330
NCM	01/01/02 – 31/07/02	22	161	7.32	590
NCP	01/07/02 – 31/12/02	98	1,254	12.80	327
NDY	01/07/99 – 31/12/99	18	219	12.17	357
PAS	01/01/00 – 28/02/01	20	107	5.35	530
QAN	01/05/01 – 28/02/02	22	183	8.32	558
RIO	01/07/02 – 31/12/02	43	325	7.56	667
TLS	01/01/01 – 30/06/01	84	898	10.69	428
WBC	01/01/99 – 31/07/99	42	289	6.88	505
WMC	01/09/01 – 28/02/02	35	267	7.63	578
WOW	01/10/01 – 31/03/02	16	107	6.69	695

**Table 2: Time series properties of channel prices.** For each price series, a random walk with and without drift and with and without a time trend is estimated as follows:

$$\Delta P_t = rP_{t-1} + \sum_{i=1}^{10} b_i \Delta P_{t-i} + e_t \text{ (Random Walk)}$$

$$\Delta P_t = a + g + rP_{t-1} + \sum_{i=1}^{10} b_i \Delta P_{t-i} + e_t \text{ (Random Walk with Drift / Time Trend)}$$

For each derivative security on the underlying stock, we begin with ten lags and then discard the lags that are not significant at the 5% level. For each underlying stock, the equity option channel is presented in the first row and the equity warrant channel is presented in the second row. Columns two and three present the drift parameter and t-value. The conclusion concerning the drift parameter is presented in column four. The augmented Dickey Fuller test statistics with 95% critical values with and without drift of  $-1.95$  and  $-2.86$ , respectively, plus the first order autocorrelation coefficient (rho) are used to determine the type of autoregressive function. Positive rho significantly different from zero indicates an explosive time series. Rho not insignificantly different from zero indicates a simple random walk with or without drift. Negative rho significantly different from zero, but greater than  $-1$ , indicates a mean-reverting autocorrelation function. In the last column we provide conclusions concerning the autocorrelation pattern of expectational lags and the order of integration.

Underlying stock code	Drift		Drift conclusion	Dickey-Fuller test			Autocorrelation	
	Drift Parameter $\times 10,000$	T-Value		Tau	Tau $_{\mu}$	Order of integration	Rho Statistic	Conclusion
AMP	-2006.94	-5.66	Negative drift		-6.13	I(1)	0.8332	Mean-reverting
	-1352.48	-4.20	Negative drift		-4.51	I(1)	0.9072	Mean-reverting
ANZ	-1111.05	-4.87	Negative drift		-5.66	I(1)	0.8910	Mean-reverting
	-220.95	-2.59	Negative drift		-3.47	I(1)	0.9533	Mean-reverting
BHP	-1244.87	-5.77	Negative drift		-7.07	I(1)	0.8578	Mean-reverting
	21.24	0.53	No drift	-3.25		I(1)	0.9693	Mean-reverting
BIL	-3270.55	-3.97	Negative drift		-4.37	I(1)	0.7793	Mean-reverting
	-725.82	-1.67	No drift	-0.36		I(1)	0.9958	Random Walk
CBA	-830.81	-5.90	Negative drift		-7.09	I(1)	0.9093	Mean-reverting
	-231.23	-2.41	Negative drift		-5.34	I(1)	0.9502	Mean-reverting
CML	-2113.48	-2.87	Negative drift		-3.26	I(1)	0.8558	Mean-reverting
	-898.12	-2.08	Negative drift		-2.67	I(1)	0.9016	Random Walk
CWO	-1663.51	-4.34	Negative drift		-4.79	I(1)	0.9075	Mean-reverting
	-196.12	-1.82	No drift	-1.19		I(1)	0.9952	Random Walk
LHG	-6534.44	-4.09	Negative drift		-4.10	I(1)	0.7307	Mean-reverting
	-2063.62	-3.11	Negative drift		-3.13	I(1)	0.8664	Mean-reverting
LLC	-765.27	-2.34	Negative drift		-3.07	I(1)	0.8915	Mean-reverting
	-498.57	-1.28	No drift	-1.95		I(1)	0.9585	Random Walk
NAB	-863.75	-5.97	Negative drift		-8.11	I(1)	0.8678	Mean-reverting
	-9.58	-0.26	No drift	-2.48		I(1)	0.9853	Mean-reverting
NCM	-1276.25	-2.95	Negative drift		-3.21	I(1)	0.8624	Mean-reverting
	193.14	0.55	No drift	-2.48		I(1)	0.9374	Random Walk
NCP	-1069.92	-7.14	Negative drift		-7.89	I(1)	0.9056	Mean-reverting
	-81.41	-1.72	No drift	-1.62		I(1)	0.9947	Random Walk
NDY	-1379.01	-2.46	Negative drift		-2.43	I(1)	0.9440	Random Walk
	-583.08	-2.28	Negative drift		-2.44	I(1)	0.9571	Random Walk
PAS	-6509.66	-3.87	Negative drift		-4.10	I(1)	0.6816	Mean-reverting
	-2171.59	-2.40	Negative drift		-2.38	I(1)	0.8934	Random Walk
QAN	-4333.67	-4.83	Negative drift		-4.90	I(1)	0.7543	Mean-reverting
	-1140.41	-2.30	Negative drift		-2.34	I(1)	0.9006	Random Walk
RIO	-1225.57	-4.09	Negative drift		-5.40	I(1)	0.8240	Mean-reverting
	-335.03	-2.43	Negative drift		-2.54	I(1)	0.9561	Random Walk
TLS	-1961.47	-6.44	Negative drift		-6.60	I(1)	0.8975	Mean-reverting

Underlying stock code	Drift		Dickey-Fuller test			Autocorrelation		
	Drift Parameter × 10,000	T-Value	Drift conclusion	Tau	Tau <sub>μ</sub>	Order of integration	Rho Statistic	Conclusion
WBC	-215.79	-3.21	Negative drift		-3.37	I(1)	0.9785	Mean-reverting
	-1700.31	-4.14	Negative drift		-4.54	I(1)	0.8686	Mean-reverting
	-409.04	-2.42	Negative drift		-3.00	I(1)	0.9365	Mean-reverting
WMC	-1878.31	-3.51	Negative drift		-3.87	I(1)	0.8582	Mean-reverting
	-515.88	-2.90	Negative drift		-3.78	I(1)	0.8960	Mean-reverting
WOW	-1779.73	-2.89	Negative drift		-3.07	I(1)	0.8025	Mean-reverting
	-712.72	-2.44	Negative drift		-2.65	I(1)	0.7946	Random Walk

**Table 3: Spanning tests.** This table presents the results of mean-variance spanning tests to analyze whether the inclusion of equity warrants in an investor’s benchmark portfolio comprising the market, underlying stocks and equity options will span or enlarge the efficiency set. For each warrant-option trading pair written on the underlying stock, the following regression is estimated:

$$R_{ew,t} = \alpha_{ew} + \beta_1 R_{MKT,t} + \beta_2 R_{S,t} + \beta_3 R_{eo,t} + \beta_4 WSPR_t + e_{ew,t}$$

where for each trading day  $R_{ew,t}$  is the residual adjusted return on the equity warrant (i.e., non-benchmark asset);  $R_{MKT,t}$  is the return for the market (as proxied by the All Ordinaries Accumulation Index);  $R_{S,t}$  is the underlying stock return;  $R_{eo,t}$  is the residual adjusted return on the equity option;  $WSPR$  is the time weighted warrant spread in day  $t$ ;  $e_{ew,t}$  is the error term. The equity warrant examined will be spanned by the benchmark assets only if the intercept term ( $\alpha_{ew}$ ) is zero and the sum of the beta coefficients for the benchmark assets equals unity. A GMM Wald test statistic is employed to test this joint hypothesis, and is reported in the table with its associated level of significance. The intercept term and beta coefficients for the benchmark assets are also shown. A positive intercept indicates that including the equity warrant in a benchmark portfolio will improve the mean-variance efficient frontier.

Underlying stock code	Sample period	Number of trading days	Intercept term ( $\alpha_{EW}$ )	Market return (beta 1)	Underlying stock return (beta 2)	Adj. option return (beta3)	GMM Wald test statistic	
AMP	01/01/02 - 31/12/02	176	2.09	1.97	3.98	0.35	6.45	*
ANZ	01/01/00 - 31/12/00	190	0.33	1.83	2.04	0.05	8.91	*
BHP	01/01/02 - 31/12/02	183	1.39	0.19	3.64	0.32	8.38	*
BIL	01/01/02 - 31/12/02	154	-0.34	-0.23	4.01	0.14	1.83	
CBA	01/01/00 - 31/12/00	175	-1.33	0.41	5.15	0.05	12.83	**
CML	01/01/02 - 31/12/02	166	4.40	0.42	5.33	0.10	14.12	**
CWO	01/01/00 - 31/12/00	200	-0.63	3.18	3.21	0.03	45.76	**
LHG	01/01/02 - 31/12/02	185	1.41	1.52	1.77	0.14	9.72	**
LLC	01/01/00 - 31/12/00	213	5.34	0.66	4.09	0.11	30.9	**
NAB	01/01/00 - 31/12/00	186	0.22	1.16	4.48	0.13	16.07	**
NCM	01/01/02 - 31/12/02	172	5.63	2.04	3.95	0.18	12.68	**
NCP	01/01/00 - 31/12/00	175	8.84	7.60	3.13	0.00	44.68	**
NDY	01/01/00 - 31/12/00	246	3.15	0.33	3.86	0.12	21.44	**
PAS	01/01/00 - 31/12/00	245	0.29	0.59	2.52	0.05	7.96	*
QAN	01/01/00 - 31/12/00	214	-1.52	1.27	2.99	0.06	8.52	**
RIO	01/01/02 - 31/12/02	162	-3.23	0.22	6.49	0.23	3.09	
TLS	01/01/00 - 31/12/00	194	-0.39	2.30	4.01	0.03	25.94	**
WBC	01/01/02 - 31/12/02	184	3.10	1.18	5.16	0.13	11.33	**
WMC	01/01/00 - 31/12/00	212	1.52	-1.17	2.98	0.07	11.28	**
WOW	01/01/02 - 31/12/02	166	-1.26	-1.90	6.39	0.06	7.16	*

\*\* Significance at  $p < 0.01$

\* Significance at  $p < 0.05$

**Table 4: Cointegration tests.** For each underlying stock in our sample, we estimate the optimal lag length and cointegrating vectors for the two synchronous derivative trade prices. When the coefficients of the two cointegrating vectors sum to approximately zero, this indicates that the series satisfy the linear no arbitrage restriction. The sum of the coefficients of the cointegrating vector defines the equilibrium error in the VECM model specification. For each underlying stock, we also present the results of the maximum eigenvalue test of  $r=0$  against  $r=1$ . The 95% critical value for rejecting the null hypothesis of no cointegration is 14.59 (Enders 1995, Table B, p.420).

Underlying stock	Optimal lag length	Sum of the coefficients of the cointegrating vector	Test of $r = 0$ against $r = 1$ Maximum eigenvalue
BHP	1	-0.013	273.55
NCP	1	-0.045	148.77
NAB	1	-0.020	183.47
TLS	1	0.048	350.88
CBA	1	-0.113	194.72
ANZ	1	-0.022	447.56
AMP	2	-0.284	208.18
CWO	1	0.204	339.49
WMC	1	0.062	490.23
WBC	1	0.040	361.25
RIO	1	-0.237	255.46
NDY	1	0.321	338.07
QAN	1	-0.222	696.63
WOW	1	0.239	594.45
LLC	1	0.225	217.90
LHG	1	0.637	246.60
BIL	1	-0.496	376.17
CML	1	-0.046	732.76
NCM	1	-0.063	529.17
PAS	2	-1.139	275.47

**Table 5: Common factor weights.** For each underlying stock, we present the Gonzalo and Granger (1995) normalized common factor weights, a chi-squared test statistic, and its associated level of significance. The normalized common factor weights represent the proportion of price discovery occurring in the equity warrants or equity options execution channel. We test the null hypothesis that the factor weight is zero using the chi-square test statistic with one degree of freedom. We observe that both equity warrants and equity options attract informed trades.

Underlying stock	<i>Equity warrants</i>			<i>Equity options</i>		
	Common Factor Weight	Chi-Square Test		Common Factor Weight	Chi-Square Test	
BHP	56.08	80.44	*	43.92	61.62	*
NCP	44.14	37.70	*	55.86	62.11	*
NAB	60.49	67.98	*	39.51	45.82	*
TLS	34.26	94.60	*	65.74	175.19	*
CBA	56.08	45.39	*	43.92	64.57	*
ANZ	40.71	69.17	*	59.29	137.16	*
AMP	68.76	84.09	*	31.24	58.24	*
CWO	71.19	156.80	*	28.81	29.96	*
WMC	42.23	154.46	*	57.77	161.65	*
WBC	35.41	50.71	*	64.59	99.43	*
RIO	76.77	107.33	*	23.23	41.61	*
NDY	47.12	101.29	*	52.88	120.49	*
QAN	35.09	108.26	*	64.91	185.55	*
WOW	18.16	41.12	*	81.84	418.57	*
LLC	44.06	33.40	*	55.94	92.19	*
LHG	1.24	0.03	n.s.	98.76	100.74	*
BIL	41.54	53.94	*	58.46	204.82	*
CML	7.80	8.69	*	92.20	378.76	*
NCM	24.46	29.04	*	75.54	208.50	*
PAS	27.58	15.41	*	72.42	78.96	*
Mean	41.66			58.34		
Median	41.88			58.12		

\*Significance at  $p < 0.01$