THE INTRA-DAY PRICE DISCOVERY PROCESS BETWEEN THE SINGAPORE EXCHANGE AND TAIWAN FUTURES EXCHANGE

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This paper focuses on the increasing competition between exchanges for listing similar index futures contracts and the impact this has on information dissemination between various markets. Specifically, using both the Hasbrouck and Gonzalo–Granger methodologies for extracting the information content held in each market, a comparison of information efficiencies between the Singapore Exchange and the Taiwan Futures Exchange is examined for Taiwan Index Futures listed in both markets. The results show not only a common stochastic trend between index futures and their underlying indices, but also provide strong evidence to suggest price discovery primarily originates from the Singapore futures

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market. There are direct implications of this result for both financial exchanges and traders—in particular, that traders realize price determination can arise from both futures markets, and the need for exchanges to maintain a reputation as an information center for these similarly traded financial instruments. Jrl Fut Mark 22: 219–240, 2002

1. INTRODUCTION

The motivation for this paper is to illustrate how international exchange competition affects the intra-day price discovery process of futures contracts. The case in question is the Taiwan stock index futures market. The objective is to determine where price determination occurs between these markets and whether one exchange dominates this process. If a market listing a financial instrument cannot provide a convenient and cost-effective trading environment, traders will begin to look elsewhere for more competitive exchanges offering a similar product. The price discovery process will begin to favor the more competitive market, leaving alternative trading exchanges with fewer participants and effectively redundant in price determination.

One exchange that has been particularly active in competing with other exchanges and in promoting itself as a financial center for the Asia-Pacific rim is the Singapore Exchange.[1] A notable example of where it has been able to attract trading from other exchanges is its Nikkei 225 futures contract.

In January 1997 Singapore began to offer an MSCI Taiwan futures contract, the underlying instrument being a Taiwan Morgan Stanley Capital weighted stock index (TiMSCI). Despite an initial disappointing performance, trading in this futures contract rose dramatically to an average 8,800 contracts per day in 1999 and is now one of the most actively traded futures contracts in the Singapore Exchange Derivatives Trading (SGX-DT) market. The contract was introduced at a time when the Taiwan Stock Exchange (TSE) began to attract more foreign interest. In 1999, market capitalization of the 462 listed companies on the TSE was 11,803,524 million Taiwan dollars (TWD), with a total trading value of 29,521,108 million TWD.

Not until July 1998 did Taiwan introduce its own index futures contract, traded on the Taiwan Futures Exchange (TAIFEX), and based on the TSE Capitalization Weighted stock index. The Taiwanese were

[1]The Singapore Exchange was formed in 1999 through a merger of the Stock Exchange of Singapore and the Singapore International Monetary Exchange.

confident about the prospects of their new contract, despite the slow beginnings of similar products introduced in Singapore, Hong Kong, and Chicago.[2] To ensure success TAIFEX needed to attract a new clientele to ensure adequate trading volume, which seemed feasible because of perceived segmentation between the markets for Taiwanese equity derivatives in Taiwan and Singapore. This segmentation was primarily due to regulation whereby the Taiwan Ministry of Finance explicitly banned Republic of China nationals from trading Taiwan stock derivatives on SIMEX or CME. What materialized when TAIFEX futures were introduced showed there was sufficient interest to potentially support both contracts. Volume for TiMSCI futures in the 60 trading days immediately following the introduction of TAIFEX futures was 18.6% higher than the preceding 60 trading days.

As Taiwan has been able to successfully introduce a competing futures contract to Singapore, the question of how these markets interact with each other becomes pertinent to an understanding of the roles geography, investor segmentation, and trading conditions have in influencing information dissemination. Moreover, market traders will be interested to note where new information will first be reflected in prices. If an exchange is redundant in the price dissemination process—that is, it never reflects new information first—traders will gain no benefit from examining price changes in that market.

For Taiwan index futures it is not clear where price dissemination will originate. The Taiwan-based futures contracts should benefit from "home" market advantages in terms of local knowledge, proximity to news sources, and lack of language barriers. Garbade and Silber's (1979) work is representative of much of the literature on cross-listed securities which supports the hypothesis that price discovery predominantly originates in the local market. Evidence by Tse (1999a) on London JGB futures also suggests a similar home-market bias with futures contracts.

Singapore, however, also has a number of beneficial trading conditions that may lead to dominance in price discovery for these contracts. First, Singapore has a longer reputation for providing an easy means to transact Taiwan futures in a liquid trading environment. It also has a growing reputation for facilitating futures trading on a number of international stock indices. This is attractive to foreign traders who trade Taiwan futures along with other contracts.

[2]Contracts in Chicago and Hong Kong have traded with relatively little success. The Chicago futures contract has been phased out.

Second, there are differences in contract specification and levels of regulation between the markets. Specifically, position limits in Singapore are at least three times larger than in TAIFEX. Consequently, traders, particularly institutional investors, who wish to hold large positions in the market may prefer the Singapore exchange. Also, the Singapore contract is traded in U.S. dollars. Foreign traders may be keen to trade in this more familiar currency, depending on currency fluctuations. The degree of currency risk can often play a major role in determining which contract traders prefer.[3] Furthermore, general execution plus clearing costs are lower in Singapore. Execution fees (including settlement charges of US$1.53) in TAIFEX were US$2.60 for special members,[4] whereas the SGX-DT had a clearing fee of just US$0.30 for the public (less for members) with up to $1.00 for other execution expenses relating to the placement of trades. Moreover, the Taiwan government substantially taxed transactions until April 2000, which represented a further hindrance to trading.[5]

Although it is not the objective to test the transactions–cost hypothesis in this study, the fee structure between these two exchanges suggests Singapore is more cost-effective for trading than Taiwan.[6] Moreover, work by Huang, Kuo, and Shyu (1998) and Huang and Shyu (1998) has noted that since the initial introduction of Taiwan-based index futures the price discovery process originated primarily from the stock exchange. They argue that this is a result of initial higher transaction costs within the futures market.

Since it is possible that both futures markets and the underlying stock exchange may contribute to the price dissemination process, several econometric tests are performed to gauge the extent each market contributes in explaining price movements for these contracts. To do this the two underlying stock indices are first shown to be very good substitutes for each other. Also, a single stochastic trend is shown to adequately describe both the Singapore and Taiwan spot and futures markets. Following this, tests for econometric exogeneity plus Hasbrouck (1995)

[3]Currency risk will not be a major concern for a local hedger in the Taiwan market, but may be instrumental for foreign traders.

[4]A special member is a broker with whom the exchange deals with directly.

[5]The TAIFEX news information website at www.taifex.com.tw contains more detailed analysis of the taxation effect on trading volume and the reason for eventually reducing the tax margins.

[6]The trading cost hypothesis is more fully investigated in such recent studies as Kim, Szakmary, and Schwarz (1999) and Fleming, Ostdiek, and Whaley (1996) within the futures market literature. Along with bid-ask spreads not being available for each market the results in this paper do not distinguish price discovery separate to any reputation effects, and other microstructure differences (such as the position limits).

and Gonzalo-Granger (Gonzalo & Granger, 1995) information share results all suggest Singapore index futures dominate the price discovery process. Each futures contract is also found to have a larger information share than either of the spot indices, and both stock indices contain roughly the same information share. These results are consistent despite the fact that each method differs in its estimation and technical definition of price discovery. To detail this, the next section provides a review of the literature on price discovery within futures markets. This is followed by a description of the data and methodologies applied, along with their empirical results.

2. PRICE DISCOVERY AND SPOT-FUTURES MARKET INTERACTION

A wealth of literature exists that analyzes the theoretical relationship between futures contracts and their underlying spot indices. Most studies report a lead-lag relationship of up to 30 minutes from futures prices to the spot price. This includes work by Stoll and Whaley (1990) on the S&P 500 and the Major Market Index; Chan (1992) and Koutmos and Tucker (1996) on the S&P 500; Iihara, Kato, and Tokunaga (1996) on the Nikkei Stock Average; and Abhyankar (1995) on the FTSE 100.[7] The reasons for this lead-lag relationship includes the fact that futures markets tend to have less restrictive regulation and lower transaction costs than their stock market counterparts. Specifically, there tends to be increased liquidity and financial leverage due to fewer restrictions on short selling and marking to market trading. Also, index futures offer an easy means to speculate and hedge market-wide trends. In examining the price discovery process between spot, futures, and options prices Fleming, Ostdick, and Whaley (1996) observed that the market with the lowest trading costs will react more quickly to new information. This "trading cost hypothesis" can explain a number of results where stock prices tend to lag the futures market.

More recently, studies have focused on the interplay between various futures markets. Examples include Craig, Dravid, and Richardson (1995) and Tse, Lee, and Booth (1996) who show that futures contracts listed in different international markets transmit and impound information from other exchanges efficiently. Kim, Szakmary, and Schwarz (1999) examine the role that trading costs have when examining price discovery across the S&P 500, NYSE, and MMI futures with their

[7]These studies also tend to note the existence of a weak feedback from spot markets to futures markets.

respective spot indices. Finally, Sim and Zurbreugg (1999) find evidence of cross-market linkages where Japanese Nikkei index futures partially relay information to the Australian All-Ords futures market.

As interest in the interrelationship between markets has grown, new techniques have also been developed to measure price leadership and dissemination across markets. Work by Gonzalo and Granger (1995) and Hasbrouck (1995) provide measures that attempt to identify the price discovery process via the information share that each market holds relative to a common long-run factor. Capturing the information content revealed in each market explains the price leadership effects that exchanges have over each other. Papers that have applied these techniques to futures studies include Booth, So, and Tse (1999) and Tse (1999). Once a long-run, co-integrative relationship can be identified across markets for a similar product, transitory deviations from the long-run trend reveal how information is relayed.

3. DATA AND DESCRIPTIVE STATISTICS

The sample period extends from 11 January 1999 to 31 June 1999, which represents an important time in the life of both the TAIFEX and Singapore futures contracts. By January 1999 the TAIFEX contract had traded for six months and established a steady and significant volume. The average monthly volume for the sample period is around 97,000 contracts, compared with the average monthly volume of 55,000 in the first six months of trading. By observing this period it is possible to avoid results that may solely be a product of the market's initial reactions to the TAIFEX contract, rather than being truly representative of the dynamics of the established markets.

The data is provided by each of the respective exchanges under examination. This includes transaction data for Taiwan MSCI futures prices from the Singapore Exchange along with their corresponding TiMSCI index prices. The TiMSCI comprises around 75 stocks that aim to capture 65% of market capitalization on the TSE. For the Taiwanese markets, TAIFEX futures transaction data is provided by the Taiwan Futures Exchange and the underlying TAIEX index is published on the Taiwan Stock Exchange website on a minute-by-minute basis. The TAIEX index is broader than the TiMSCI, encompassing roughly 425 listed stocks on the TSE. However, the two indices are nearly identical in terms of their co-movements, having a correlation of returns on a 5-min interval in excess of 97%. Since both of these indices are subject to trading on the TSE they both have the same trading hours and dates. In contrast, trading times for the futures markets are slightly different, with TAIFEX futures trading in Taiwan being open for 15 minutes longer than the primary market and TiMSCI futures trading in Singapore being open for an additional 30 minutes over the TSE. Full contract details and trading times are provided in the Appendix.

From this data set a series of prices at 5-min intervals are constructed from 9:05 am to 11:55 am (Taiwan time) leading to a total of 3,944 observations per series. As the futures markets open and close at slightly different times to the Taiwan stock exchange, a 5-min interval is dropped from the beginning and end of each trading day. This will minimize the effects of trading behavior and lead-lag effects from these markets outside the times the stock market is open.[8]

For the transactions data the 5-min series are created by taking the average of the two closest prices either side of the 5-min marker. In this way any potential bias that may arise from simply taking the closest observation to the 5-min marker is avoided. Such a bias would be particularly evident for TAIFEX data where matching occurs at regular 20-s intervals leading to the closest price to the 5-min marker always occurring at a time after that marker. A further consideration must also be made for dealing with futures contract expiration. At any time there are multiple contracts that are traded for both TiMSCI and TAIFEX futures (see Appendix). To calculate futures prices, the contract nearest expiration is used until one week prior to expiration. This ensures that futures prices are quoted from the most liquid contracts and that trading behavior linked to expiration effects are minimized. In fact, intra-day returns during days when switching from one contract to another are not significantly different to any other day.

By processing the data this way the average distance between a price used to calculate prices on consecutive 5-min intervals, and the actual 5-min marker is 10.15 s. There are no significant lag differences between any of the price series with 90% of all prices utilized in this study being within a 20-s span of any 5-min marker.[9]

Finally, the Taiwanese markets traded at an average price level of approximately 7,000, while the Singapore product traded at an average price level of 300. To maintain equality in price levels, four new price

[8]As the focus of this paper is on intra-day price interactions the efficiency in which the markets impound information from each other due to different trading times is not considered. However, such an analysis would also be worthwhile investigating to determine market efficiency and has not been conducted on these markets as yet.

[9]90.01%, 89.13%, and 99.45% of all quotes used for calculating 5-min prices in the TAIFEX futures, TiMSCI futures, and TiMSCI spot, respectively, were within a 20-s span of each 5-min marker. TAIEX data was only available on a minute-by-minute basis and therefore no averaging was necessary.

TABLE I
Descriptive Statistics

	TAIEX Spot	*TAIFEX Futures*	*TiMSCI Futures (FX Adjusted)*	*TiMSCI Futures (Unadjusted)*	*TiMSCI Spot*
ADF (log prices)	−1.8799	−0.1740	−1.4942	−1.5001	−0.3180
ADF (returns)	−19.8101	−17.8732	−18.0276	−18.0781	−19.6738
Mean	0.0027	0.0028	0.0035	0.0035	0.0033
Std. Dev.	0.1196	0.1111	0.1275	0.1275	0.1322
Skewness	4.2124	5.9675	3.4461	3.4423	4.9081
Excess Kurtosis	108.0850	226.1899	93.9967	93.8977	107.1145

Note. 5-min returns are generated by $r_t = \log(x_t) - \log(x_{t-1})$ where x_t are prices.
The mean and standard deviations are expressed in percentage form.
ADF figures are Augmented Dickey–Fuller unit root tau-statistics including intercept and 10 lags. The 5% critical value from MacKinnon (1991) is −2.8628 to reject the null of a unit root.

TABLE II
Correlations of 5-min Returns

	TAIEX Spot	*TAIFEX Futures*	*TiMSCI Futures (FX Adjusted)*	*TiMSCI Futures (Unadjusted)*	*TiMSCI Spot*
TAIEX Spot	1				
TAIFEX Futures	0.834327	1			
TiMSCI Futures (FX adjusted)	0.768794	0.836794	1		
TiMSCI Futures (FX unadjusted)	0.768792	0.836789	0.999997	1	
TiMSCI Spot	0.97235	0.809612	0.775804	0.775803	1

series are constructed setting the starting values of all series to be 1,000 at 9:05 on 11 January 1999. Tables I and II provide summary statistics and correlations for the 5-min return series. Also, the tables contain statistics for foreign exchange (FX) and FX-adjusted TiMSCI futures returns,[10] which are required since TiMSCI futures are quoted in U.S. dollars whereas all other series are quoted in New Taiwan dollars (TWD).

Table I indicates that apart from all the series being stationary in returns, there are no significant differences at the 1% level between the FX adjusted and unadjusted return series for TiMSCI futures. Despite

[10]U.S. dollar and New Taiwan dollar (NTD) daily cross-rates were used to convert TiMSCI prices into NTD denomination, as no intra-day data were available. The cost of this data limitation is that FX adjustments made during the day are lost.

the Taiwan dollar being a floating exchange rate,[11] it has little impact upon returns. This is illustrated with the correlation being in excess of 99.9%. This is an important fact as it indicates that for the sample period under investigation the motives for traders to purchase either Singapore or Taiwan based contracts will not be strongly motivated by currency risk considerations. The overall change of the US$/TWD exchange rate between January and June of 1999 is less than 0.05%.[12] For this reason only adjusted TiMSCI futures prices are analyzed from hereon. Also worthy of note, the two futures markets are more highly correlated with each other than each futures contract is with its own respective spot market.

4. METHODOLOGY AND EMPIRICAL RESULTS

Three separate techniques are applied to examine the interplay between these four markets. A comparison of results will provide insight to any differences in how these techniques define and estimate price discovery. Moreover, it allows for a simple robustness test to ensure the results are not a circumstance of the methodology utilized.

Each method relies on the assumption that a long-run relationship exists between all four markets. As these series are explaining extremely similar financial products there should be a common factor between them. Specifically, the only way that either the Taiwan or Singapore spot-futures parity[13] condition will be broken, or that the two futures markets have contrasting price behavior is if there are severe restrictions upon and segmentation of these markets. A standard Johansen (1991) trace test is performed on all four series[14] to determine the number of long-run common trends. The trace test results tabulated in Table III displays the presence of three co-integrating vectors at the 5% significance level. This is indicative that a single long-run equilibrium is maintained between the markets as there is only one stochastic process driving these prices.[15] From this result, an initial pairwise analysis is now presented between

[11]The Taiwan dollar market is actually segmented into a domestic and an offshore market. The offshore market is a nondeliverable free float for foreign participants and the onshore market is a normal free float.

[12]Average daily FX changes were 0.001%, with a standard deviation of 0.086%.

[13]$F_t = S_t e^{(r-d)(T-t)}$; where r is the interest rate and d is the dividend yield.

[14]As all four series are stationary in first differences (returns) as indicated by the Augmented Dicky–Fuller test results, the Johansen trace test was performed using an $I(1)$ assumption with an optimal 10 lags, determined by the Akaike information criterion. This lag structure is utilized for the rest of the empirics performed.

[15]See Stock and Watson (1988) or Johansen (1991) for a thorough analysis of the relationship between cointegrating vectors and stochastic processes.

TABLE III
Johansen Cointegration Results

H_0	λ_{Trace}	p-value
$r = 0$	216.8725	<0.001
$r \leq 1$	80.4894	<0.001
$r \leq 2$	15.7620	<0.050
$r \leq 3$	1.0323	>0.100

Note. The results presented are the Johansen trace tests, which test the hypothesis that the system of equations contains at most r cointegrating vectors. λ_{Trace} is calculated as $\lambda_{Trace}(r) = -T\Sigma_{i=r+1}^{n}\log(1 - \lambda_i)$ where λ_i is the i-th largest eigenvalue. Results tabulated assume no trend component. Critical values are taken from Osterwald-Lenum (1992).

both futures markets, both spot indices, and between each futures market and its underlying index. This is followed by a trivariate analysis of the markets to provide a comparison of results.

4.1 Tests for Exogeneity

The first tests conducted are tests for block exogeneity on lagged returns for each combination of price series, and tests on the significance of the speed of adjustment coefficient within an error-correction model (ECM). To account for a common factor prevalent between each pair of prices an error correction term is utilized to differentiate between short- and long-run effects. For any market i, on market j, the ECM is expressed as:

$$\Delta p_{i,t} = \alpha(p_{i,t-1} - p_{j,t-1}) + \sum_{k=1}^{q} (\delta_{i,k}\,\Delta p_{i,t-k} + \delta_{j,k}\Delta p_{j,t-k}) + e_t \qquad (1)$$

where p_t are vectors of prices; α is the speed of adjustment coefficient between prices in the two markets (which are expected to be zero in the long-run), and δ_i plus δ_j are vectors of autoregressive coefficients for k lags on markets i and j, respectively. Although the error-correction component is a standard representation used for long-run spot-futures parity, it now also reflects price parity across the different futures contracts. As currency risk is minimal for the sample period and FX-adjusted prices are used, the parity condition should hold. A simple test for whether market j Granger causes market i is a joint test on the coefficients of δ_j being significantly different from zero. Alternatively, a test for whether market i influences price behavior in market j will be a joint significance test on the coefficients of δ_i from a regression where $\Delta p_{j,t}$ is the dependent series.

TABLE IV
Exogeneity Tests

H_0	*Block Test*	*Error Correction Terms*
TAIFEX Futures does not cause TAIEX Spot	12.5520[a]	6.10e-5 (0.89)
TAIEX Spot does not cause TAIFEX Futures	5.2944[a]	−5.17e-4 (−3.09)
TiMSCI Futures does not cause TiMSCI Spot	28.4946[a]	7.21e-5 (0.43)
TiMSCI Spot does not cause TiMSCI Futures	3.7614[a]	−7.83e-4 (−3.85)
TAIFEX Futures does not cause TiMSCI Futures	3.4556[a]	−1.78e-3 (−1.91)
TiMSCI Futures does not cause TAIFEX Futures	21.6208[a]	3.89e-4 (1.76)
TAIEX Spot does not cause TiMSCI Spot	10.1034[a]	−2.48e-5 (−2.35)
TiMSCI Spot does not cause TAIEX Spot	1.0232	2.48e-5 (2.05)

Note. Block exogeneity test figures are all *F*-statistics.
[a]Indicates significance at the 1% level.
Figures in parenthesis are *t*-statistics.

The results in the second column of Table IV indicate that there is a bidirectional relationship between each market. The one exception is that TiMSCI index returns play no significant role in determining TAIEX index price changes, which may be because the TAIEX encompasses more stocks than the TiMSCI and therefore potentially contains more market-wide information. Such a result does highlight that at least for the short-run the two spot indices cannot be considered to be completely identical.

Although the results show significant bidirectional information flows between each market at the 1% significance level, in absolute terms the *F*-statistics clearly indicate a stronger influence arising from each futures market to their underlying spot prices, and from Singapore futures to Taiwan futures. This is more clearly illustrated by focusing on the speed of adjustment coefficients for each market pairing. For cointegrated series, causality may also display itself via the speed of adjustment coefficient. In fact, a test for whether the coefficient is significant or not is also a test for weak exogeneity (see Johansen & Juselius, 1992). Some studies, such as Hall and Wickens (1993), also have interpreted weak exogeneity as evidence of long-run causality. Table IV reveals two important points. First, when looking at each market's spot-futures relationship, the error–correction terms for the futures markets are not significant and are less in magnitude than the spot market coefficients. This indicates that it is the spot market which is adjusting to futures prices, with no significant long-run causality running from futures to the spot market. Second, the two stock indices have approximately the same speed of adjustment coefficient and are both significant at the 5% level. This indicates that they adjust in roughly the same proportions when deviations occur from the long-run trend. This is not surprising, considering they are essentially measuring the same market.

4.2 Gonzalo and Granger Information Shares

The Gonzalo and Granger (1995) methodology measures the price discovery process in a more definitive manner. Where the block exogeneity tests provide a basis for examining the direction of information flows, Gonzalo and Granger focus on the contribution each market has in influencing an implicit efficient price that is common to all markets.[16] Price discovery then becomes the process by which a leading market influences others by having a larger contribution to the determination of the implicit efficient price. It utilizes the concept that the vector of market prices can be expressed as the sum of a permanent and transitory component:

$$p_t = f_t i_n + g_t \tag{2}$$

where f_t is a scalar representing the common factor, i_n is an $(n \times 1)$ unit vector and g_t is the $(n \times 1)$ transitory component for any n markets under investigation. Gonzalo and Granger suggest that the common permanent component $f_t i_n$ can be identified by two conditions. The first is that the common factor is a weighted average of current market prices; the second is the transitory component g_t has no long run impact upon prices p_t. The first condition implies equation (3), where Θ is a $(1 \times n)$ matrix of weights:

$$f_t = \Theta' p_t \tag{3}$$

The second condition identifies Θ, as Gonzalo and Granger observe that there is only one weighting vector, Θ, for which g_t has no long term impact on P_t. This is defined when $\Theta = \alpha^*$, where $\alpha^{*\prime} = 0$. That is to say, the weighting vector Θ can be estimated as a basis for the null space of the speed of adjustment coefficient vector, α. Once the elements of α^* have been normalized they comprise a useful measure of the contribution of each market to the common permanent factor and thereby to price discovery.

Table V contains the results from the Gonzalo–Granger procedure. These results present the weighting of information shares contained in each market. Each futures market leads its spot index by comparable amounts, with their role in price discovery being roughly nine times that

[16]The concept of an implicit efficient price can be traced back to Gabade and Silber (1979).

TABLE V
Gonzalo–Granger Information Share Results

Pairwise Info. Shares	*TAIEX Spot*	*TAIFEX Futures*	*TiMSCI Futures*	*TiMSCI Spot*
(1)		17.90%	82.10%	
(2)	10.54%	89.46%		
(3)			91.56%	8.44%
(4)	50.06%			49.94%

Note. G-G information shares are calculated from the entries in the vector α^* which satisfies $\alpha^{*\prime}\ \alpha = 0$, where α is the matrix of coefficients to the error correction term in the error correction model.

of their respective spot index. As a raw comparison with other spot-futures markets, it is noteworthy that roughly the same degree of information shares were noted in Tse (1999b) when examining the DJIA index and futures markets.[17] Also, the Gonzalo–Granger (G-G) results suggest that there is only a comparatively small role for the stock market in the price discovery process.

The results also show that Singapore index futures play a role in price discovery significantly greater than that of the TAIFEX futures. Although not as great as its role over the TiMSCI spot index, it still has four times the information share of TAIFEX futures. This result suggests that the majority of information is impounded first in Singapore and therefore will tend to be the more informationally efficient market. Finally, although the Block exogeneity tests note lagged returns from the TiMSCI index have little impact upon the TAIEX index, there now is an equal share of information contained in each index. As Gonzalo and Granger's technique focuses on the error–correction terms rather than the significance of the short-run autoregressive coefficients, these results are not necessarily contradictory. Moreover, as one would expect both indices to be very close, the G-G result is more sensible and shows that, for long-run effects, both series are roughly the same.

4.3 Hasbrouck Information Shares

The final methodology to be presented is one developed by Hasbrouck (1995). Like Gonzalo–Granger, it rests on the assumption of a common implicit efficient price. However, his information share is based on reactions to price shocks rather than movements from current market prices.

[17]Utilizing the Hasbrouck technique, Tse (1999a) identified an 88.29% information share to JGB index futures and 11.71% to the underlying stock.

Each market's contribution to price discovery is defined as the variation in efficient price innovations attributable to that market. Such an approach emphasizes each market's role in impounding new information. If a particular market is responsible for the majority of variance in innovations, that is to say that permanent price shocks emanate predominantly from one market, then that market is the dominant force in setting prices.[18]

Beginning with a standard error-correction model as in equation (1), it is inverted into a vector moving average (VMA) representation such as that in equation (4):

$$\Delta p_t = \sum_{k=0}^{r} \psi(k) e_{t-k} \tag{4}$$

where r is the number of moving average lags; and

$$\psi(k) = \begin{bmatrix} \psi_{11}(k) & \cdots & \psi_{1n}(k) \\ \cdot & & \cdot \\ \psi_{n0}(k) & \cdots & \psi_{nn}(k) \end{bmatrix} \tag{5}$$

The innovation vector e_t is presumed to have a zero mean, be serially uncorrelated, and have covariance matrix Ω. Each coefficient matrix $\psi(k)$ is an $(n \times n)$ matrix, where entry $\psi_{ji}(k)$ represents the impact of the innovation in the i-th market on the price of the j-th market in the $(t\text{–}k)$th period. The sum of the VMA coefficients can be defined as:

$$\psi(Sum) = \sum_{k=0}^{q} \psi(k) = \begin{bmatrix} \sum_{k=0}^{q} \psi_{11}(k) & \cdots & \sum_{k=0}^{q} \psi_{1n}(k) \\ \cdot & & \cdot \\ \sum_{k=0}^{q} \psi_{n1}(k) & \cdots & \sum_{k=0}^{q} \psi_{nn}(k) \end{bmatrix} \tag{6}$$

Hasbrouck proposes that the row vectors in $\psi(Sum)$ should be equal if the markets are cointegrated, as any disturbances to prices in the long run must be the same in all markets. Allowing ψ to represent this common row vector and combining ψ with an innovation vector from a

[18]Such a proposition makes the assumption that price shocks are a good proxy for the arrival of new information.

given period t produces ψe_t, which is the total long-run impact of the innovation in period t. Hasbrouck suggests that the sources of variance in this term is a measure of the contribution of each series to price discovery. The variance of ψe_t is presented as:

$$\mathrm{var}(\psi e_t) = \psi \Omega \psi' \tag{7}$$

As is likely to be the case that the innovations in both markets are correlated, a decomposition of the variances is required. Hasbrouck suggests that by triangularizing the covariance matrix, upper and lower information share bounds can be computed. The triangularization is performed by obtaining F, the Cholesky factorization of Ω (i.e., we find F such that $\Omega = FF'$), where F is the lower triangular. The variance attributable to a particular market j is then $(\psi F)_j^2$ and the information share of market j is:

$$IS_j = \frac{(\psi F)_j^2}{\psi \Omega \psi'} \tag{8}$$

Hasbrouck notes that such a factorization maximizes the information share of the first price and so one must calculate upper and lower bounds for each information share by changing the ordering of the markets in ψ and Ω.

The construction of information bounds constitutes one of the most obvious differences between the Gonzalo–Granger and Hasbrouck methodologies. The Gonzalo–Granger information share gives a single estimate, whereas the Hasbrouck method provides boundaries due to the lack of identification of the parameters when there is cross-equation correlation. Upper and lower boundaries are presented in Table VI along with the mean information shares attributable to each market.

The Hasbrouck results differ in some respects to those provided by the Gonzalo–Granger procedure, most notably concerning the Taiwanese spot index and futures market. The bounds are large but there is an indication that the TAIEX index contributes more to price discovery than does the TAIFEX futures market. Although this is a contradictory result, it does support the earlier research conducted by Huang et al. (1998) and Huang and Shyu (1998), which also suggest that due to transactions costs the spot market led the Taiwan futures market. The sample used in this study also incorporates the period of high taxation by the Taiwan government on the futures contracts.

TABLE VI
Hasbrouck Information Share Results

	TAIEX Spot	*TAIFEX Futures*	*TiMSCI Futures*	*TiMSCI Spot*
(1)		33.28% (0.42%, 66.14%)	66.72% (33.86%, 99.58%)	
(2)	54.30% (14.87%, 93.73%)	45.70% (6.27%, 85.13%)		
(3)			75.05% (50.24%, 99.85%)	24.95% (0.15%, 49.76%)
(4)	52.94% (5.90%, 99.98%)			47.06% (0.02%, 94.10%)

Note. Information share results are calculated as the proportion of the variance in the innovations to the implicit efficient prices attributed to each series. The figures in brackets below the information share values are the lower and upper bounds for that information share. 30 MA lags were applied to the VMA model.

However, and more importantly, the Hasbrouck information bounds for these two markets are extremely wide. Although this may suggest both markets influence each other, the result can also be partially due to the lack of identification. As the size of the lower and upper bounds are influenced by the correlation of innovations, the results are also indicative of a high correlation between price movements in the Taiwan market. These wide lower and upper bounds in both markets are also responsible for the mid-point to be roughly the same for both series. Furthermore, these bounds also illustrate that at any time period either market may hold a larger information share and does not necessarily indicate that the spot market will always be the dominant price leader. As more traders become accustomed to trading futures and the costs of trading on the TAIFEX are reduced this relationship can change. As a simple test for this the Hasbrouck procedure is re-run for the last month of the sample period and the information bounds narrow considerably between the TAIEX (15.92%, 80.51%) and TAIFEX (19.49%, 84.08%) markets.

The information shares in the other market pairings are comparable to those found from Gonzalo and Granger. The differences are limited to the fact that Hasbrouck assigns less extreme information shares to the market pairings (for example, the Singapore futures/spot information share ratio is 3:1 instead of the 9:1 assigned by Gonzalo and Granger). The Hasbrouck methodology also concurs with the Gonzalo–Granger outcome that TiMSCI index futures play the dominant role in price discovery. For the two spot indices, the results indicate a roughly equal information share.

From the above results, it is evident that since the introduction of Taiwan-based futures trading both the TiMSCI and TAIFEX index futures play a role in the price discovery process. Although Singapore futures prices seem to react more efficiently to incorporate new information, there is undoubtedly a proportion of information that is first revealed in the Taiwan futures market. The Gonzalo–Granger methodology estimates this to be approximately 18% and Hasbrouck 33%. From a traders viewpoint, this indicates that although Singapore still remains the main source of information, the TAIFEX market also contributes to the price discovery process and therefore is important to examine when determining price behavior.

4.4 Alternative Specifications

Finally, to illustrate that the results presented in the previous three sections are robust to how the cointegrative relationships between the markets are defined, Table VII shows Gonzalo–Granger information share results for when both futures markets and spot index are modeled in the same equation. The error–correction model remains the same

TABLE VII
Alternative Specifications

Gonzalo–Granger Information Share Results

G-G Information Share on 3 Series at a Time	*TAIEX Spot*	*TAIFEX Futures*	*TiMSCI Futures*	*TiMSCI Spot*
(1)	8.58%	20.37%	71.05%	
(2)		14.38%	83.38%	2.24%

AR(1) Purged Gonzalo–Granger Information Share Results

G-G Information Share on AR(1) Innovations	*TAIEX Spot*	*TAIFEX Futures*	*TiMSCI Futures*	*TiMSCI Spot*
(1)		14.00%	86.00%	
(2)	38.81%	61.19%		
(3)			53.11%	46.89%
(4)	58.14%			41.86%

Note. AR(1) purged G-G information shares are calculated from the entries in the vector α^* which satisfies $\alpha^{*\prime}\alpha = 0$. Here α is the matrix of coefficients to the error correction term in an ECM using the residuals from an AR(1) regression as a proxy for true market returns.

except that the error correction terms now comprise of two adjustment coefficients specifying equality between both futures markets and one underlying spot index.[19]

Also, there may be an argument that the results have been misconstrued due to microstructure issues. In particular, the influence of infrequent trading of the component stocks in the indices and bid-ask bounce effects that have not been examined. A frequently referenced methodology is presented in Stoll and Whaley (1990) who note that infrequent trading of a spot index and bid-ask bounce can introduce an autoregressive component and a moving average process into returns. One can account for these microstructure effects by first applying an autoregressive moving average (ARMA) model. While it must be noted that the autoregressive nature of returns is at the center of any study into lead/lag relationships, it is arguable that microstructure issues introduce excess ARMA effects which need to be accounted for. As such, the error terms from a simple AR(1) regression are used to proxy the true market returns. To provide an indication of the possible impact microstructure issues, the results from using such residuals on a Gonzalo–Granger methodology as utilized in Section 4.2 are presented in Table VII. Following Pizzi, Economopoulos, and O'Neill (1998), residual error terms are used on both sides of the ECM.

The qualitative outcomes from Table VII are the same as those presented previously. Neither analyzing the markets on a trivariate basis nor subjecting the raw returns to alternate AR(q) processes leads to differing results. The only real difference emerges from the AR(1) process reducing the spread of information shares one market has over others. However, this is an effect related directly to the fact part of the information utilized to capture the price discovery process has now been removed from the series, leaving only higher-order autocorrelated processes within the data.

5. IMPLICATIONS OF THE RESULTS AND CONCLUSION

Increasing competition between South-East Asian markets has brought to the fore questions about the impact of market efficiency, geographical distance, and "home" market advantages in determining information

[19] $\Delta p_{i,t} = \alpha_1(p_{i,t-1} - p_{j,t-1}) + \alpha_2(p_{i,t-1} - p_{l,t-1}) + \Sigma_{k=1}^{q}(\delta_{i,k}\Delta p_{i,t-k} + \delta_{j,k}\Delta p_{j,t-k} + \delta_{l,k}\Delta p_{l,t-k}) + e_t$ where i and j are the two futures markets and l is either the TiMSCI or TAIEX index.

flows and price discovery. Such a situation is evident in the market for Taiwan stock index futures, where a contract can be traded simultaneously in Taiwan and Singapore. One may propose competing hypotheses as to which of the markets involved in price discovery for Taiwan stock indices will be dominant. The Taiwan futures traded on TAIFEX have "home" market advantages in terms of local knowledge, proximity to news sources and no language barriers.

The competing Singapore market also has a number of advantages. Apart from an established reputation, general execution costs and taxes are lower over the sample period. Also, position limits are effectively three times larger than in TAIFEX. Finally, although currency risk is minimal for the sample period, foreign traders may prefer dealing in the more familiar currency of U.S. dollars, rather than the Taiwanese dollar. Together, these advantages may outweigh Taiwan's "home" market advantages.

The results of this study into the dynamic flow of information and price discovery between these exchanges show that futures prices interact considerably with each market. However, it is the Singapore Exchange, with a more established regime and seemingly lower costs, that dominates price discovery for Taiwan futures. This situation may change as the Taiwan futures exchange grows and continues to reduce disadvantageous costs of trading, particularly taxes. Also, if there is much currency fluctuation, more focus would be placed on currency risk considerations. As the contracts trade in different denominations, the choice by traders may also be dependent on this.

Importantly, particularly for traders, this paper shows that both futures markets now play a role in price discovery, although it is likely that Singapore prices will reflect new information first. For competing exchanges, the regulatory environment is a relevant factor in determining which markets are dominant in price discovery. The regulatory regime in Singapore has helped establish it as the dominant market for trading in Taiwan index futures. In addition, it has probably benefited from the fact that traders in Singapore can exchange numerous other contracts from alternative markets with ease, increasing its attractiveness as a center for traders in international futures contracts. The message for regulators in the face of increased exchange competition is that their decisions can help to overcome home market advantages. However, it is also important to understand that regulators must balance the desire for market dominance with the need for an adequate level of regulatory supervision.

APPENDIX

Contract Specifications

	TAIFEX Futures	*TiMSCI Futures*
Exchange	Taiwan Futures Exchange	Singapore Exchange Derivatives Trading
Underlying asset	Taiwan Stock Exchange Capitalization Weighted Stock Index	Morgan Stanley Capital Weighted Taiwan Index (Based on the Taiwan Stock Exchange)
Contract size	TWD 200 × TAIFEX futures Price	USD 100 × TiMSCI Futures Price
Trading hours (Taiwan time)	9:00–12:15	8:45–12:15
Contract months	Spot Month, next month and closest three of March, June, September, and December	Spot Month, next month and March, June, September, and December
Minimum fluctuation	1 index point	0.1 index point
Maximum fluctuation	7% of previous settlement price	7% of previous settlement price[a]
Expiry date	Third Wednesday of each month	Second last business day of the month
Final settlement price	Special quotation provided by the Taiwan Stock Exchange	Official closing price of the TiMSCI spot index
Position limit	1000 contracts	5000 contracts

[a]In addition to the maximum fluctuation quoted in the table, TiMSCI futures allows for greater fluctuation after a cooling-off period, following a breach of the 7% limit.

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