An investigation of the price discovery for cross-listed stocks: Evidence from New Zealand and Australian stock markets

Wajira Dassanayake, Xiaoming Li and Klaus Buhr
**Abstract:**

This study investigates the price discovery of selected cross-listed stocks on the Australian Stock Exchange (ASX) and the New Zealand Stock Exchange (NZX). It examines prices and exchange rates over the period 1\textsuperscript{st} January 2008 to 31\textsuperscript{st} December 2011 when both markets were in a bear trading phase. Using intraday data of three Australian stocks and five New Zealand stocks, we investigate the price discovery dynamics by evaluating the vector error correction mechanism (VECM), Hasbrouck’s (1995) information share (IS) and Grammig et al.’s (2005) conditional information share (CIS).

Consistent with previous research, we find that the price series of the sample of cross-listed stocks on the ASX and the NZX are cointegrated. We also find that the price discovery takes place mostly on the home market for the Australian domiciled firms and for all but one of the New Zealand domiciled firms. This is true in terms of both Hasbrouck’s (1995) information share and Grammig et al.’s (2005) conditional information share.

However, when we evaluate price discovery dynamics over time using the information share approach, our findings differ from those of Frijns et al. (2010). In bull market conditions they find an increasing trend in the significance of the ASX. In a bear market setting, we find the NZX growing in importance with a declining significance for the ASX for the Australian as well as New Zealand domiciled companies.

1. **Introduction:**

Reinkensmeyer (2007) and Langridge (2006) raise the question of whether investing strategies in stock markets should change during different trading phases. In this vein, researchers such as Miaoxin (2012) and Hodgson et al. (2003) have investigated whether price discovery dynamics change in bear versus bull markets. They generally find that price discovery varies with the trading phase.

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Much of the research on price discovery in cross-listed stocks on multiple exchanges has focused on U. S. markets. Most of these exchanges are dealer, or hybrid, markets with less than full automation. However, the New Zealand Stock Exchange (NZX) and the Australian Stock Exchange (ASX) are fully automated order-driven trading systems. Price discovery dynamics may be quite different in such a system. Recently, Frijns et al. (2010) examined price discovery dynamics in the New Zealand and Australian markets during a bull market. They find that both markets contribute to price discovery with the home market tending to be dominant.

The current study extends Frijns et al.’s (2010) research to examine price discovery dynamics in Australian and New Zealand markets during a bear market. The study examines the direction of the leadership in price discovery between the two markets to determine which one of the markets is dominant.

The study is topical because the NZX has expressed an interest in improving price discovery in the New Zealand market. This study provides a benchmark against which the recent movement to NASDAQ OMX X-stream trading platform can be measured in terms of enhancing price discovery on the NZX. The study

1. Appraises the existence of short and long term dynamic linkages between the selected cross-listed stocks in the NZX and the ASX.

2. Evaluates the direction of the price discovery relationships; that is whether, the home market tends to lead changes in the foreign market, or vice versa.


4. Provides a basis to compare whether the price discovery dynamics change in different trading phases.

Consistent with previous research, we find that the price series of the selected cross-listed stocks on the ASX and the NZX are co-integrated. Price discovery takes place mostly on the home market for the Australian domiciled firms and for all but one of the
New Zealand domiciled firms. This is true in terms of both Hasbrouck’s (1995) information share and Grammig et al.’s (2005) conditional information share.

When we evaluate price discovery dynamics over time using the information share approach, our findings differ from those of Frijns et al. (2010). In bull market conditions they find an increasing trend in the significance of the ASX and the NZX moving towards being a pure satellite market. In a bear market setting, we find that there is an upward trend in the significance of the NZX for the Australian as well as New Zealand domiciled companies. The increasing importance of the NZX during a bear trading phase means the NZX is deviating from being a pure satellite market. This is an important finding alerting financial institutions, policy makers and investors of the need to monitor information flows in the New Zealand market.

The rest of this paper is organised as follows. Section 2 reviews the existing literature on price discovery as related to the study. Section 3 discusses the methodology adopted for this research. Section 4 provides a description of the data set. Section 5 provides comprehensive analysis of the results obtained. Section 6 provides the main conclusions.

2. Literature Review:

Ever since Grubel’s (1968) research on internationally diversified portfolios there has been a growing interest on the interdependence between international stock markets. Subsequent to Black Monday (1987), the importance attached to the relationships amongst international stock markets has escalated. There has been wide interest amongst researchers, investors, academics and others to learn the nature of the interdependence and the interconnections between the international stock markets.

Many researchers have focused on the dynamic linkages amongst international stock markets and have managed to empirically identify price discovery dynamics. See for example Turkington and Walsh (2000), Eun and Sabherwal (2003), Zeynel and Esin (2007), Morana and Beltratti (2008) and Zeynel (2009). Others such as Longin and Solnik (2001) and Lukmanto et al. (2009) examine the existence of trends in correlation.


In the literature, two major approaches to determining price discovery of cross-listed stocks have been identified.

The first approach focuses on the lead/lag relationships between markets for cross-listed stocks. For example Eun and Shim (1989) examine the transmission mechanics of nine international stock markets using vector autoregression (VAR) systems. Harris et al. (1995) examine transmission of new information on price discovery for shares of IBM listed on three stock exchanges.

The second approach focuses on how new information is transmitted to different exchanges. Hasbrouck’s (1995) Information share (IS) approach and Gonzalo and Granger’s (1995) permanent transitory (PT) approach are two popular models that are used to investigate the price discovery process of cointegrated time series.

Many researchers such as Baillie et al. (2002), De Jong (2002), Lehmann (2002), Grammig et al. (2004), Grammig et al. (2005), Pascual et al. (2006), Yan and Zivot (2010) use the IS and the PT approaches. The vector error correction model (VECM) forms the basis for both the Hasbrouck and Gonzalo and Granger models. But IS and PT use different definitions for price discovery.

Most researchers studying price discovery across countries have treated the exchange rate as exogenous. That is, they convert all price series into a common currency prior to their analysis. For example Hupperets and Menkveld (2002) investigating Dutch stocks
that are cross-listed on the New York stock exchange (NYSE) converted all price series into Dutch Guilders. Similarly, Eun and Sabherwal (2003) analysed price discovery for 62 Canadian stocks listed on both the Toronto Stock Exchange (TSE) and on the U.S. exchange (NYSE, AMEX and Nasdaq). They converted all price series into Canadian Dollars.

But Grammig et al. (2005) argue that the effects of exchange rate fluctuations on stocks cross-listed in international markets cannot be properly measured if the exchange rate is treated as exogenous. Thus they emphasise that the exchange rate should be treated as endogenous in price discovery analysis of internationally cross-listed stocks. They propose a modification to the information share approach that they call the conditional information share approach.

Despite the abundant literature on price discovery dynamics for internationally cross-listed stocks, there is no clear conclusion as to where price discovery occurs. Harris et al. (1995) use an error correction model to evaluate price discovery for shares of IBM on the NYSE, Pacific, and Midwest stock exchanges to determine whether each exchange contributes to price discovery. They find that long run cointegration equilibrium occurs on all the exchanges and conclude that all three markets contribute to price discovery for IBM. In contrast, Hasbrouck (1995) uses data for thirty Dow stocks that have substantial trading on the NYSE and other regional exchanges and concludes that price discovery predominantly occurs on the NYSE with a median information share of 92.7%. Hupperets and Menkveld (2002) investigate Dutch stocks cross-listed on the Amsterdam stock exchange (ASE) and on the NYSE. They find mixed results with price discovery for some stocks primarily originating from the ASE whilst price discovery for other stocks primarily originates from the NYSE. Eun and Sabherwal (2003) evaluate the price discovery of 62 Canadian stocks listed on both the Toronto Stock Exchange (TSE) and on U.S. exchange (NYSE, AMEX and Nasdaq). They find that the prices are cointegrated. They find price discovery largely occurs in the home market but the U.S. exchange also contributes to the price discovery of Canadian stocks. Grammig et al. (2005) evaluate the price discovery dynamics of three blue-chip German stocks traded on the Exchange Electronic Trading (XETRA) in Germany and on the NYSE combined with an endogenized exchange rate. Their research finds that price discovery mainly
occurs in home markets with the NYSE taking a relatively small role. They also find that the New York prices bear almost all of the adjustment to exchange rate changes. Pascual et al. (2006) examine the price discovery of Spanish cross-listed stocks on the Spanish Stock Exchange (SSE) and the NYSE and find that the home SSE is dominant in price discovery. Su and Chong (2007) investigate price discovery of eight Chinese stocks on the NYSE and on the Stock Exchange of Hong Kong (SEHK) and find that the prices are cointegrated. Using permanent transitory (PT) and information share (IS) approaches, they find that the home exchange (SEHK) contributes more to the price discovery of those eight stocks. Flad and Jung (2008) use PT decomposition to evaluate price discovery dynamics for the Dow Jones Industrial Average (DJIA) and the Deutsche Aktien index (DAX) during overlapping trading hours. Using intraday data for the two indices they find that the DJIA contributes up to 95% of the total innovation of the common factor and that global economic news is first integrated in the U.S. and then transmitted to the German stock market.

A sizeable portion of the literature cited above deals with cross-listed stocks linked to U.S. markets [NYSE, American stock exchange (AMEX), Chicago board of trade (CBOT) and OTC] during bullish as well as bearish trends. However, most of these exchanges are dealer or hybrid markets with less than full automation.

The ASX and the NZX are fully automated order-driven trading systems. Only limited attempts have been made to study price discovery for cross-listed stocks in fully computerised competitive order-driven markets. Ding et al. (1999) use the PT approach to analyse price discovery on the Kuala Lumpur Stock Exchange (KLSE) and the Stock Exchange of Singapore (SES). Both exchanges are informationally linked, are fully automated and both countries are in the same time zone, thus both exchanges open and close at the same time. They find that approximately 70% of the price discovery for a stock occurs in the home country (Malaysian market) and the remainder of the price discovery is attributable to the SES. Further they find that there is evidence of strong error correction from Singapore prices to Malaysian prices but only a weak error correction from Malaysian prices to Singapore prices. Agarwal et al. (2007) use a sample of Hong Kong listed stocks that are also traded on the London Stock Exchange (LSE) to determine the source of price discovery. Both exchanges are fully automated.
and there is overlap in the trading hours of the LSE and the Hong Kong Stock Exchange. They find that prices are cointegrated, with London opening prices closely following Hong Kong’s closing prices. They conclude that Hong Kong trading determines the price discovery in London but not vice versa.

Two studies have focused on price discovery for cross-listed stocks on the Australian and New Zealand stock markets: Lok and Kalev (2006) and Frijns et al. (2010).

Lok and Kalev (2006) use intraday prices of 38 Australian and 25 New Zealand stocks to investigate the price discovery dynamics for these markets. They adopt an analysis of error correction mechanism and used data from May 2000 to December 2002. Their research confirms that the markets are integrated, that both markets contribute to price discovery but that a greater amount of price discovery occurs in the home market. They also confirm that no arbitrage opportunities were available in the trading of cross-listed stocks during the sample period.

Frijns et al. (2010) use Hasbrouck’s information share approach and Grammig et al.’s CIS approach to evaluate price discovery for cross-listed stocks in New Zealand and Australia. They used market data from January 2002 to December 2007 when both markets behaved bullishly. Frijns et al. (2010) find that the home market was dominant in the price discovery process during the bull market. Over the time horizon they also found that the larger Australian market became more important for price discovery suggesting that New Zealand is moving in the direction of becoming a pure satellite market.

The current study uses the same cross-listed stocks and the same econometric techniques as used by Frijns et al. (2010). However it evaluates the price discovery dynamics during the period January 2008 to December 2011. During this time period both markets were in a bearish trend.

3. **Methodology:**

Price discovery can be generally defined as the price adjustment process of an asset to accommodate and reveal new information. Three techniques are commonly used to
analyse price discovery: 1) the lead/lag approach, 2) the information share (IS) of Hasbrouck (1995) and 3) the permanent transitory (PT) of Gonzalo and Granger (1995). The current study uses the lead/lag approach and the IS of Hasbrouck (1995). However it uses Grammig et al.’s (2005) CIS approach. This is done to provide comparability to the Frjins et al. (2010) study where they utilise both the IS and CIS approaches.

3.1 Lead-lag approach

The lead-lag relationship simply confirms the existence of price discovery. To use Granger causality test to analyse the lead-lag relationship between the prices of the selected stocks on the NZX and ASX requires the data to be stationary. The standard unit root tests for stationarity are the Augmented Dickey Fuller (ADF) unit root test (Dickey, Fuller 1979, 1981) and the Phillips-Perron (Phillips-Perron 1988) non-parametric test (Enders, 2004). For robustness we use both unit root tests because Enders (2004) suggests that using both types strengthens the decision. The Engle-Granger (1987) cointegration Test and the Johansen (1991; 1995) cointegration test are used as cointegration tests.

Engle and Granger (1987) show that although the cointegrating equation between two variables integrated in order 1 accommodates the long run equilibrium relationship there can be deviations from the equilibrium in the short run. Thus at least one of the time series would correct for these deviations and this correction is called an error correction process. This means when two non-stationary variables are cointegrated; a vector auto regression (VAR) in the first difference becomes misspecified due to the existence of a common trend. As the source of causality cannot be explained with VAR, a vector error correction mechanism (VECM) is used in our study. Once a cointegrated regression is recognised, the model should incorporate one period lagged residuals from the vectors to generate a VECM.

\[
\Delta P_i^h = \alpha_0^h + \kappa^h u_{i-1} + \sum_{i=1}^n \delta_i \Delta P_{i-1}^h + \sum_{i=1}^n \sigma_i \Delta P_{-i-1}^f + \epsilon_{i}^h \hom \epsilon \\
\]

Equation 1

where \( u_{i-1} \) is the one period lagged error correction term from the cointegrated regression. If the prices on the NZX (\( P_i^h \)) and the prices on the ASX (\( P_i^f \)) are
cointegrated, then it is expected to have Granger causality in at least one direction which enables one variable to forecast the other (Granger, 1988). With the inclusion of a lagged error correction term ($u_{t-1}$), the VECM uncovers two likely channels for Granger causality to materialise, one through the sum of the lagged differenced causal variables and/or the other through a one period lagged error correction term from the cointegrated regression. The test of causality is performed with the standard Wald F test.

But the lead-lag relationship does not specify how the ASX prices and the NZX prices contribute to the price discovery. Thus our research concentrates on Hasbrouck’s (1995) information share and Grammig et al.‘s (2005) CIS to analyse the price discovery of cross-listed stocks on the ASX and the NZX.

3.2 Information share of Hasbrouck (1995)

Hasbrouck (1995) extracts the extent of price discovery using the variance of innovations to the common factor. This methodology assesses the information share of the price discovery by the proportion of innovations to the prices that occur on the ASX and NZX. Thus, the IS model measures each market’s relative contribution to this variance. The information shares are not distinctively defined if the price innovations on the ASX and the NZX are correlated; therefore it is necessary to compute upper and lower bounds for the information shares by attributing information to each market.

When estimating the price discovery model, we first use a restricted price vector, in which the exchange rate is treated as exogenous by first converting the prices into a single currency. Hasbrouck estimates the restricted regression that has a cointegrating vector, $\beta^* = (1, -1)$. This is Hasbrouck’s (1995) information share approach.

$$IS_i = \frac{\Psi_j C_{ji}'}{\psi' \Psi C \psi'}$$

*Equation 2*

where $\Omega = \text{var}(\epsilon_t)$ and $C$ is the lower triangular Cholesky factorization of $\Omega$ ($\Omega = CC$). If in the long run the domestic market and the foreign market value $\psi \epsilon_t$ differently, then both will still have an information share as given in the $IS_i$ equation above.
3.3 Grammig et al.’s (2005) conditional information share (CIS)

Grammig et al. (2005) expand Hasbrouck’s IS (1995) by endogenizing the exchange rate and evaluate the cointegration of the exchange rate, the home price series and the foreign price series. They estimate the unrestricted regression that has a cointegrating vector \( \beta^l = (1, 1, -1) \).

It is possible to calculate the information share of the market \( i \) with respect to price series \( j \), \( \text{CIS}_{ji} \).

\[
\text{CIS}_{ji} = \frac{\left[ (\Psi(1) C)^j \right]^2}{(\Psi(1) \Omega \Psi(1))} \tag{Equation 3}
\]

As there appears to be one cointegrating equation between three variables this would mean that the rows of \( \psi \) (1) are not identical. This means it is not possible to obtain one IS for each of the three series as in Hasbrouck (1995). Thus, Grammig et al. (2005) propose an information share for each market which they refer to as the conditional information share (CIS).

3.4 Impulse response functions (IRFs)

Yan and Zivot (2006) have extensively used IRFs in their analysis of the dynamics of price discovery. IRFs provide a channel to visualise the time path of how each market impounds the new information during the price discovery process.

The Impulse Response Function (IRF) is

\[
y_{i,t+n} = \sum_{j=0}^{\infty} \Psi_j \epsilon_{i,t+n-j} \\
\{\Psi_n\}_{i,j} = \frac{\partial y_{i,t+n}}{\partial \epsilon_{i,j}}
\]

the response of \( y_{i,t+n} \) to a time impulse in \( y_{i,t} \) with all other variables dated \( t \) or earlier held constant.

The IRF is derived using the Cholesky decomposition on stationary VAR residuals with the assumption that the preceding innovations in variable/s in the VAR will have considerable effects on the subsequent variables in the VAR.
4. **Data:**

Frijns et al. (2010) used four Australian firms [namely Australian Mutual Provident Society (AMP), Australia and New Zealand Banking Group (ANZ), Lion Nathan (LNN) and Telstra (TLS)] and five New Zealand firms [namely Auckland International Airport (AIA), Fletcher Building (FBU), Telecom (TEL), Tower (TWR) and Warehouse (WHS)] because their shares are frequently traded in both markets.

We intended to use the same firms as Frijns et al. (2010). However, Lion Nathan (LNN) was removed from the official list of Australian Securities Exchange and delisted from the market on 28 October 2009. Thus, we excluded LNN and used all the rest of the companies adopted by Frijns et al. (2010).

It is possible to use either the most recent transaction prices or quoted prices to analyse price discovery of cross-listed stocks. But the most recent transaction prices can suffer autocorrelation issues particularly when the transactions are infrequent. Because transactions in the NZ market are often infrequent we use quoted midpoints instead of transaction prices as used by Eun and Sabherwal (2003), Grammig et al. (2005), Buhr et al. (2007) and Frijns et al. (2010). As described in Roll (1984) this approach removes any spurious negative autocorrelation due to bid/ask bounce.

It would have been ideal to use the NZX and the ASX prices and currency exchange rates at one minute intervals as used in Frijns et al. (2010). However, during January 2008 to December 2011, the markets were in a bearish trend and the selected stocks were not traded regularly. Thus, the differenced time series will have a lot of zeros which may create serious econometric issues such as serial correlation. This would generate biased results leading to unreliable hypothesis testing and any statistical inferences about the populations could not be made reliably. After a careful investigation of the most frequent intraday data that can be used for our analysis without encountering these econometric issues, we use intraday data at one hour intervals in our study.

The intraday trade and quote data for the selected firms and the NZD/AUD exchange rate were obtained from Securities industry Research Centre of Asia-Pacific (SIRCA).
Trading days between 1\textsuperscript{st} January 2008 to 31\textsuperscript{st} December 2011 were selected excluding public holidays and days when there was no trading in either market.

This time period was chosen because it encompasses a bear market. This will allow a comparison to be made with the conclusions in Frijns et al. (2010) which investigated the price discovery of the same stocks in a bullish market (during 1\textsuperscript{st} January 2002 to 31\textsuperscript{st} December 2007).

Wellington (where the NZX is based) and New South Wales (where the ASX is based) are in different time zones. There is a two hour time difference. Figure 1A contrasts the ASX trading hours of 10.00 am to 4.00 pm Australian Eastern Standard Time (AEST) with the NZX trading hours from 10.00 am to 5.00 pm New Zealand time.

Thus, there are five hours of overlapping trading hours between 10.00 am AEST (12.00 noon NZ time) till 3.00 pm AEST (5.00 pm NZ time).

However, due to the slight differences in starting and ending days of daylight savings in Wellington and New South Wales, the actual overlapping trading hours can vary from 4 hours to 5 hours but for most of the analysis 5 hours of overlapping trading hours are observable.

The exchange rate data downloaded from Sirca are based on Greenwich Mean Time (GMT) thus they have been adjusted for the relevant time zones.
Figure 1B shows time series plots for the S&P/ASX 200 index and the NZX 50 Index. The S&P/ASX 200 index is the main investible equity index of Australia whilst the NZX 50 index is the major benchmark index for the New Zealand equity market. From January 2002 to December 2007, the graph portrays upward trends in both indices indicating a bull market trading phase. On the other hand, the graph depicts downward trends in both indices from January 2008 to December 2011 which indicates a bear market trading phase. Frijns et al. (2010) evaluate price discovery in the bull market period of 2002 – 2007. In contrast, we examine price discovery in the bear market of 2008 – 2011.

**Figure 1B:** Time series plots of S&P/ASX 200 Index and NZX 50 Index during January 2002 – December 2011


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5. **Results/Analysis/Discussion:**

5.1 **Descriptive summary statistics**

For the analysis of cointegration and Hasbrouck’s information share we converted all of the price series of the cross-listed stocks into Australian dollars (AUD). For the analysis of Grammig et al.’s conditional information share, we used three time series; namely the price series on the ASX in AUD, the price series on the NZX in NZD and the exchange rates.
Tables 1A and 1B provide the summary statistics of the overlapping time period for the three Australian domiciled firms (AMP, ANZ and TLS) and the five New Zealand domiciled firms (AIA, FBU, TEL, TWR and WHS) for the sample period January 2008 to December 2011.

Table 1A shows that for all of the Australian domiciled firms the average number of trades and the average daily trading volume are substantially higher on the ASX in comparison to the NZX. In terms of daily volume, TLS is the most active firm in both exchanges whilst in terms of average number of trades ANZ is the most active firm in both exchanges.

**Table 1A**: Summary statistics for Australian domiciled firms

<table>
<thead>
<tr>
<th>Australian domiciled firms</th>
<th>Average price</th>
<th>Average number trades</th>
<th>Average daily volume</th>
<th>Average bid-ask spread</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANZ</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASX</td>
<td>20.67</td>
<td>1,668.92</td>
<td>1,176,946.53</td>
<td>0.0002</td>
</tr>
<tr>
<td>NZX</td>
<td>26.01</td>
<td>2.61</td>
<td>34,523.56</td>
<td>0.0208</td>
</tr>
<tr>
<td>AMP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASX</td>
<td>5.73</td>
<td>605.68</td>
<td>1,097,804.50</td>
<td>0.0015</td>
</tr>
<tr>
<td>NZX</td>
<td>7.19</td>
<td>2.04</td>
<td>11,333.54</td>
<td>0.0242</td>
</tr>
<tr>
<td>TLS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASX</td>
<td>3.43</td>
<td>755.11</td>
<td>6,889,458.64</td>
<td>0.0027</td>
</tr>
<tr>
<td>NZX</td>
<td>4.27</td>
<td>1.96</td>
<td>127,096.99</td>
<td>0.0335</td>
</tr>
</tbody>
</table>

Table 1B shows that for all of the New Zealand domiciled firms the average daily trading volume is substantially higher on the NZX than on the ASX. The average number of trades for TEL, FBU and TWR are higher on the ASX in comparison to the NZX. TEL is the most active firm in terms of the average number of trades and the average daily volume.
Table 1B: Summary statistics for New Zealand domiciled firms

The Table 1B provides the summary statistics for five New Zealand domiciled firms (AIA, FBU, TEL, TWR and WHS) for the period January 2008 to December 2011.

The table shows the average price, the average number of daily trades, the average number of daily volume and the absolute average of bid-ask spread. The average prices in each market are reported in their local currency denomination.

<table>
<thead>
<tr>
<th>New Zealand domiciled firms</th>
<th>Average price</th>
<th>Average number trades</th>
<th>Average daily volume</th>
<th>Average bid-ask spread</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASX</td>
<td>1.62</td>
<td>4.87</td>
<td>15,429.24</td>
<td>0.0256</td>
</tr>
<tr>
<td>NZX</td>
<td>2.03</td>
<td>15.09</td>
<td>233,170.74</td>
<td>0.0014</td>
</tr>
<tr>
<td>FBU</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASX</td>
<td>6.05</td>
<td>86.28</td>
<td>74,126.85</td>
<td>0.0047</td>
</tr>
<tr>
<td>NZX</td>
<td>7.59</td>
<td>25.72</td>
<td>224,095.75</td>
<td>0.0032</td>
</tr>
<tr>
<td>TEL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASX</td>
<td>2.08</td>
<td>155.42</td>
<td>664,044.88</td>
<td>0.0034</td>
</tr>
<tr>
<td>NZX</td>
<td>2.60</td>
<td>29.55</td>
<td>980,312.24</td>
<td>0.0034</td>
</tr>
<tr>
<td>TWR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASX</td>
<td>1.42</td>
<td>7.3</td>
<td>14,256.21</td>
<td>0.0225</td>
</tr>
<tr>
<td>NZX</td>
<td>1.79</td>
<td>4.1</td>
<td>38,070.80</td>
<td>0.0096</td>
</tr>
<tr>
<td>WHS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASX</td>
<td>3.12</td>
<td>2.77</td>
<td>7,123.20</td>
<td>0.0609</td>
</tr>
<tr>
<td>NZX</td>
<td>3.90</td>
<td>5.49</td>
<td>29,695.71</td>
<td>0.0054</td>
</tr>
</tbody>
</table>

The co-movements of prices on the two exchanges are illustrated in Figures 2A and 2B. Figure 2A superimposes a graph of hourly prices on the two exchanges for Australian firm ANZ and Figure 2B for New Zealand firm FBU. A representative section is presented to observe the movements of the ASX and NZX price series more closely. Graphs for the other firms are similar and not reproduced here but are available on request. All the price series are converted into Australian dollars. Each chart shows that the ASX and the NZX prices tend to move together with minimal deviations. A similar pattern with minimal variations exists for each of the other companies evaluated in this study. This is a signal of a long term co-movement for the price series of each company. It is also a preliminary indication of a cointegration relationship between the price series on the ASX and the NZX.
**Figure 2A:** Plot of hourly closing prices of the Australian domiciled firm ANZ

The plot below shows the lead/lag relationship between the hourly closing prices of ANZ on the ASX and the NZX.

**Figure 2B:** Plot of hourly closing prices of the New Zealand domiciled firm FBU

The plot below shows the lead/lag relationship between the hourly closing prices of FBU on the ASX and the NZX.
5.2 Tests for Stationarity

The Augmented Dickey Fuller unit root test (ADF) (Dickey Fuller 1979, 1981) and Phillips-Perron (Perron 1987, Phillips-Perron 1988) nonparametric unit root test are carried out as two formal tests for stationarity. The ADF test is carried out with a linear trend on levels and first differences for spreads of up to thirty three lags in order to remove serial correlation. The Akaike Information Criteria (AIC) is carried out to ascertain the optimum number of lags for ADF and Phillips-Perron tests.

As an alternative unit root test, the Phillips-Perron (PP) nonparametric test diagnostic with bandwidth 2 (fixed using the bartlett kernel), corrected by the Newey-West autocorrelation consistent covariance matrix estimator, is carried out.

For both the ADF and Phillips-Perron tests we use MacKinnon (1996) one sided p-values as the basis for rejection of the unit root null hypothesis.

The ADF and Phillips-Perron test results for Australian and New Zealand domiciled firms confirm that the price series are not stationary at levels, however, the first difference of each of the price series are stationary based on MacKinnon one sided p-values at a 1% significance level (detailed results are available on request).

These results provide strong evidence that the price series examined in the study are integrated in order 1 I(1). Additionally, the ADF and Phillips-Perron tests strengthen each other.

5.3 Tests for Cointegration

Gonzalo and Lee (2000) point out that the Johansen and the Engle-Granger (1987) cointegration tests are based on two different rationales. Thus, Gonzalo and Lee (2000) recommend using both tests as a robustness check.

The Engle-Granger (1987) cointegration test is carried out to investigate whether the price series of each selected cross-listed stock in the home and foreign market are cointegrated of order one. The null hypothesis of no cointegration between the two price series is rejected at 1%, 5% and 10% level of significance for Australian and New Zealand domiciled firms confirming that each of the price series of Australian and New
Zealand domiciled firms on the ASX and the NZX are cointegrated. Thus, it is possible to conclude that the OLS regression generated from \( Y_t = a + bX_t + e_t \) is not subject to spurious regression. Therefore the residuals of the regression will be stationary and hence, the error correction regression can be estimated.

The Johansen (1991; 1995) cointegration test uses two distinct likelihood ratio tests: namely the trace test and maximum eigenvalue test. The trace statistic and eigenvalue test statistic for the Australian and New Zealand domiciled firms confirm rejection of the null hypothesis of “no” cointegrating relationship between the prices of the Australian and New Zealand domiciled firms on the ASX and the NZX at a 5% level of significance as the MacKinnon-Haug-Michelis (1999) p-value is less than 5%. However, the trace statistic and eigenvalue test statistic for the Australian and New Zealand domiciled firms confirm the null hypothesis of “at most one” cointegrating relationship between the prices of the Australian and New Zealand on the ASX and the NZX cannot be rejected at a 5% significance level as the MacKinnon-Haug-Michelis (1999) p-value is more than 5% (details of the cointegrating tests for each firm are available on request).

This confirms that each of the price series of Australian and New Zealand domiciled firms on the ASX and the NZX are cointegrated.

5.4 **Vector Error Correction and Granger Causality**

The ADF and Phillips-Perron tests for New Zealand and Australian domiciled firms confirm that the price series investigated in the study are integrated in order 1. The Engle Granger and Johansen cointegration tests for New Zealand and Australian domiciled firms confirm the presence of at least one cointegrating relationship in the prices of New Zealand and Australian domiciled firms on the ASX and the NZX. Thus, it is possible to conclude that each of the two non-stationary price series for the selected stocks are cointegrated. However, due to the effects of a common trend, the vector auto regression (VAR) model in the first difference becomes misspecified. As the price series of each selected stock exhibits at least one cointegrating relationship, the model must incorporate one period lagged residuals from the vectors to generate a VECM.
Once the cointegration between the time series has been found, it is evident that there exists a long term equilibrium relationship between them. However in the short run, there may be disequilibrium. Thus, with the inclusion of an error correction mechanism, the relative disequilibrium of one period is corrected in the subsequent period.

Table 2A provides the VECM and causality results of the prices on the ASX and NZX for Australian firm ANZ and Table 2B for New Zealand firm FBU (results for the other firms are similar and not reproduced here but are available on request). These coefficients are computed based on equation 1. An OLS estimation technique is carried out to estimate the regression. We have also used Ljung-Box Q statistics to investigate the presence of autocorrelation in the residuals. There were no autocorrelation issues for up to 20 lags and the number of lags to be used is restricted to two lags. The error correction term in VECM is constructed with the expectation that two identical dually listed stocks in two exchanges should depict long run equilibrium. As anticipated, the cointegrating vector between the price series in the VECM of every dually cross-listed stocks is close to \( (1, -1) \).

The critical coefficients to pay attention to in the VECM are the error correction terms \([ETC (-1)]\) in each price series of the cross-listed stocks on the NZX and the ASX.

The estimated vector error correction model for the Australian domiciled firms shows the influence of the ASX prices on the NZX prices. The estimated coefficients for the error correction terms are statistically significant and negative. This indicates that the NZX prices typically move towards the lagged ASX prices. These results provide strong evidence that the prices on the NZX are following the price discovery arising in the prices of the ASX.

Similarly, the estimated vector error correction model for the New Zealand domiciled firms shows the influence of the NZX prices on the ASX prices. The estimated coefficients for the error correction terms are statistically significant and negative. This indicates that the ASX prices typically move towards the lagged NZX prices. These results provide strong evidence that the prices on the ASX are following the price discovery inherent in the NZX.
Table: 2A: Vector Error Correction results for ANZ on the ASX and the NZX

The table shows the results of the error correction model for the change in the prices of home market and the change in the prices of foreign market. The error correction term \( u_{t-1} \) is introduced as a lagged residual of the cointegrated regression. \( \Delta P^h_t \) stands for change in home prices. Lags are denoted as (-1), (-2). The table shows the regression coefficients, t-statistics and P-values for the following equation in the ASX and the NZX prices.

\[
\Delta P^h_t = \alpha^h_0 + \kappa^h u_{t-1} + \sum_{i=1}^n \delta^h_i \Delta P^h_{t-i} + \sum_{i=1}^n \sigma^h_i \Delta P^f_{t-i} + \epsilon^h_t
\]

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>( \Delta ) ANZ listed on the ASX</th>
<th>Dependent variable</th>
<th>( \Delta ) ANZ listed on the NZX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regressor</td>
<td>Coefficient</td>
<td>t-statistic</td>
<td>P-value</td>
</tr>
<tr>
<td>( \Delta ) ANZ in ASX (t-1)</td>
<td>-0.2121</td>
<td>-6.3734</td>
<td>[.0000]</td>
</tr>
<tr>
<td>( \Delta ) ANZ in ASX (t-2)</td>
<td>-0.0629</td>
<td>-1.9454</td>
<td>[.0520]</td>
</tr>
<tr>
<td>( \Delta ) ANZ in NZX (t-1)</td>
<td>0.0019</td>
<td>0.0992</td>
<td>[.9210]</td>
</tr>
<tr>
<td>( \Delta ) ANZ in NZX (t-2)</td>
<td>-0.0170</td>
<td>-0.9257</td>
<td>[.3550]</td>
</tr>
<tr>
<td>ECT (-1)</td>
<td>-0.0325</td>
<td>-1.5122</td>
<td>[.1310]</td>
</tr>
<tr>
<td>( F_1 )</td>
<td>0.5276</td>
<td>[.5902]</td>
<td></td>
</tr>
<tr>
<td>( R_1^2 )</td>
<td>0.0509</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cointegrating vector</td>
<td>1.0000, -1.0022</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table: 2B: Vector Error Correction results for FBU on the ASX and the NZX

The table shows the results of the error correction model for the change in the prices of home market and the change in the prices of foreign market. The error correction term \( u_{t-1} \) is introduced as a lagged residual of the cointegrated regression. \( \Delta P^h_t \) stands for change in home prices. Lags are denoted as (-1), (-2). The table shows the regression coefficients, t-statistics and P-values for the following equation in the ASX and the NZX prices.

\[
\Delta P^h_t = \alpha^h_0 + \kappa^h u_{t-1} + \sum_{i=1}^n \delta^h_i \Delta P^h_{t-i} + \sum_{i=1}^n \sigma^h_i \Delta P^f_{t-i} + \epsilon^h_t
\]

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>( \Delta ) FBU listed on the NZX</th>
<th>Dependent variable</th>
<th>( \Delta ) FBU listed on the ASX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regressor</td>
<td>Coefficient</td>
<td>t-statistic</td>
<td>P-value</td>
</tr>
<tr>
<td>( \Delta ) FBU in NZX (t-1)</td>
<td>-0.2227</td>
<td>-4.8544</td>
<td>[.0000]</td>
</tr>
<tr>
<td>( \Delta ) FBU in NZX (t-2)</td>
<td>-0.0325</td>
<td>-0.7975</td>
<td>[.4250]</td>
</tr>
<tr>
<td>( \Delta ) FBU in ASX (t-1)</td>
<td>0.1021</td>
<td>2.3534</td>
<td>[.0190]</td>
</tr>
<tr>
<td>( \Delta ) FBU in ASX (t-2)</td>
<td>0.0109</td>
<td>0.2828</td>
<td>[.7770]</td>
</tr>
<tr>
<td>ECT (-1)</td>
<td>-0.1439</td>
<td>-3.8199</td>
<td>[.000]</td>
</tr>
<tr>
<td>( F_1 )</td>
<td>3.2778</td>
<td>[.0381]</td>
<td></td>
</tr>
<tr>
<td>( R_1^2 )</td>
<td>0.0655</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cointegrating vector</td>
<td>1.0000, -0.9972</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The Granger causality test is performed to determine whether the home market leads the foreign market or the foreign market leads the home market. That is, do the prices of Australian domiciled stocks on the ASX lead the prices of Australian domiciled stocks on the NZX or vice versa? A statistically significant (insignificant) coefficient for the prices of the stocks on the ASX would suggest that the prices of the stocks on the NZX lead (or do not lead) the prices of the stocks on the ASX.

Two tests need to be evaluated to determine Granger causality, namely the F statistic and the t statistic of the error correction term [ECT (-1)]. This is because VECM reveals two likely channels for Granger causality to transpire, one through the sum of the lagged differenced causal variables and/or the other through a one period lagged error correction term from the cointegrated regression. The F statistic with the null hypothesis of no Granger causality can be carried out to determine whether the home market leads the foreign market or the foreign market leads the home market. Even if the F statistic is insignificant, as long as the t-statistic of ECT (-1) is statistically significant, it is possible to conclude that Granger causality still exists.

Based on the results of F statistics and the t-statistics of ECT (-1) for all the companies under investigation have varying degrees of bi-directional Granger causality between New Zealand (Australian) prices and Australian (New Zealand) prices.

5.5 Information share of Hasbrouck (1995)

The results of Hasbrouck’s information shares for the Australian and New Zealand domiciled firms are presented in Table 3. The table shows the upper bounds, lower bounds and the averages of all permutations for the Cholesky factorization of information shares.

For each of the Australian domiciled firms, we find that the price discovery mostly takes place on the ASX (the home market). ANZ (90.58%), AMP (91.99%) and TLS (99.88%) yield a midpoint range of information share between 90.58% to 99.88% and the mean midpoint information share of 94.15% for the Australian domiciled firms. This confirms that during the sample period, the price discovery for Australian domiciled firms mainly
take place on the ASX. Our finding is in line with the findings of previous research by Frijns et al. (2010).

For the New Zealand domiciled firms, we find that the price discovery mostly take place on the NZX (the home market). With the average information shares for AIA (99.65%), FBU (76.08%), TWR (92.92%) and WHS (96.57%) confirming that the price discovery for these New Zealand domiciled firms mostly takes place on the NZX (the home market).

However during the sample period, a significant proportion of the price discovery for TEL (92.21%) takes place on the ASX (foreign market) and only 7.79% takes place on the NZX (the home market). This finding is different from Frijns et al. (2010) who find that 95.5% of price discovery for TEL takes place on the NZX (the home market). The midpoint of the information share for the New Zealand domiciled firms range between 7.79% (TEL) to 99.65% (AIA) and have a mean midpoint information share of 74.60%. The low information share for TEL (7.79%) has lowered the mean midpoint information share and led to a wider range of midpoint information share. We observe that TEL has very high trading activity on the ASX in comparison to the trading on the NZX. We also observe that the range between upper and lower bounds are not significantly different for all the stocks except FBU. This suggests that contemporaneous correlation does not generate serious econometric issues. Additionally the upper and lower bounds of the prices on the NZX and the ASX do not overlap and this means the home market is clearly dominant in price discovery.

The results in Table 3 confirm that more extensive price discovery takes place for Australian domiciled firms on the ASX than for the New Zealand domiciled firms on the NZX. These findings are consistent with Frijns et al. (2010).
Table 3: Hasbrouck (1995) information share results for the prices of Australian and New Zealand cross-listed stocks

The table below shows the lower bounds, upper bounds and averages (midpoints) of Hasbrouck’s (1995) information share (IS).

\[ S_j = \frac{\psi_j^2 \sigma_j^2}{\sum \psi_j^2 \sigma_j^2} \]  

Where the proportion of IS for market j relative to the total variance is defined as market j’s information share.

<table>
<thead>
<tr>
<th>Information Share for Australian and New Zealand cross-listed stocks</th>
<th>Percentage in ASX exchange</th>
<th>Percentage in NZX exchange</th>
<th>Cointegration relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Upper bound</td>
<td>Lower bound</td>
<td>Average (Mid point)</td>
</tr>
<tr>
<td>Australian domiciled Firms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ANZ</td>
<td>99.995%</td>
<td>81.167%</td>
<td>90.581%</td>
</tr>
<tr>
<td>AMP</td>
<td>97.378%</td>
<td>86.614%</td>
<td>91.996%</td>
</tr>
<tr>
<td>TLS</td>
<td>99.992%</td>
<td>99.773%</td>
<td>99.883%</td>
</tr>
<tr>
<td>New Zealand domiciled Firms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AIA</td>
<td>0.499%</td>
<td>0.196%</td>
<td>0.347%</td>
</tr>
<tr>
<td>FBU</td>
<td>41.581%</td>
<td>6.258%</td>
<td>23.920%</td>
</tr>
<tr>
<td>TEL</td>
<td>98.372%</td>
<td>66.039%</td>
<td>92.206%</td>
</tr>
<tr>
<td>TWR</td>
<td>13.627%</td>
<td>0.536%</td>
<td>7.082%</td>
</tr>
<tr>
<td>WHS</td>
<td>5.521%</td>
<td>1.345%</td>
<td>3.433%</td>
</tr>
</tbody>
</table>

5.6 Analysis of impulse response functions (IRF)

We use impulse response function (IRF) analysis to examine the dynamic response of one variable to an impulse in another variable in the system. The plots of the IRFs are useful to graphically compare the price discovery dynamics between the cointegrated markets. IRFs make it possible to distinguish a dominant from a satellite market by investigating the time paths of the speed of their price adjustments to establish a new fundamental value. With the aid of IRFs it is possible to visualise the time path of the price discovery process as each market impounds the new information. A faster convergence of the price response to a new equilibrium suggests the market is more efficient in the price discovery process. It is also strong evidence of cointegrated relationships amongst the markets in the long run as short term fluctuations from the equilibrium are momentary.

Figure 3A shows IRFs for the Australian domiciled firm ANZ (similar patterns prevail with the rest of the Australian firms). The IRFs for Australian domiciled companies show that a shock to the price of an Australian firm on the NZX triggers a weak response to its price on the ASX but a shock to the price of an Australian firm on the ASX generates a
strong reaction on the firm’s price on the NZX. These IRFs confirm that the ASX is dominant for Australian domiciled firms and strongly contributes to the price discovery. These results are in line with the findings from the IS analysis.

Figure 3B shows the IRFs for New Zealand domiciled firms FBU and TEL (other than TEL, the rest of the New Zealand firms portray pattern similar to FBU). Except for TEL, a shock to the price of a New Zealand firm on the NZX triggers a strong to moderate response on its price on the ASX. But a shock to the price of a New Zealand firm on the ASX generates a weak to moderate reaction to its price on the NZX. These IRFs confirm that the NZX is dominant for the New Zealand domiciled firms and contributes largely to the price discovery. However, a shock to the TEL price on the NZX triggers a weak response to its price on the ASX and a shock to the TEL price on the ASX generates a strong reaction on its price on the NZX. These IRFs confirm that the ASX is dominant for TEL and strongly contributes to the price discovery. These results are consistent with the findings from the Hasbrouck’s (1995) IS analysis.

**Figure 3A:** Impulse response function (IRF) for Australian domiciled firm ANZ

If a system of equations is stable any shock should quickly disappear whilst an unstable system of equations would produce an explosive time path.
Figure 3B: Impulse response function (IRF) for New Zealand domiciled firms FBU and TEL

If a system of equations is stable any shock should quickly disappear whilst an unstable system of equations would produce an explosive time path.

5.7 Information share (IS) of Hasbrouck (1995) over time

Subsequently we also evaluate how the information shares have varied over time. Table 4 shows the results of how the yearly midpoints for information shares have changed over time.

During the sample period, the trends in the information shares for the Australian domiciled firms on the ASX exchange are decreasing by varying degrees. TLS experienced the most significant downward trend and AMP encountered the least significant downward trend. However, somewhat mixed trends in the information shares exist for the New Zealand domiciled firms on the ASX. AIA, FBU and TWR experienced decreasing trends whilst TEL and WHS experienced increasing trends.
Table 4: Hasbrouck (1995) information share results for the prices of Australian and New Zealand cross-listed stocks over time

The table below shows the upper bounds, lower bounds and averages (midpoints) of Hasbrouck’s (1995) IS.

\[ S_j = \frac{\psi_j \sigma_j^2}{\psi \Omega \psi} \]

Where the proportion of IS for market j relative to the total variance is defined as market j’s information share.

Figures 4A and 4B depict the average of the midpoints of information shares for the Australian and New Zealand domiciled firms on the ASX and the NZX. They show the overall trend more clearly. Throughout the sample period there is a growing importance for the NZX and a declining significance on the ASX for both Australian and New Zealand domiciled companies. In addition, the information share of Telecom (TEL) is larger on the ASX (foreign market) in comparison to the NZX (home market) and it has also been growing significantly.

The above findings differ from those in Frijns et al. (2010). They find that the information shares of Australian and New Zealand domiciled firms on the ASX increased over time. In our study we find the information shares of Australian and New Zealand domiciled firms on the NZX have increased over time.

Although there were certain regulatory changes on the ASX and NZX during the bullish (2002 – 2007) and bearish (2008 – 2011) trends, none of them were differently and obstinately impacting on the price discovery of the companies in the current study. Thus these variations in the findings can be attributed to differences in investor sentiments, such as crowd psychology changes from optimism to pessimism and disparities in the role of the stock prices in bull and bear markets. It appears investors are more
optimistic that share prices will rise during a bull trading phase whilst they are more pessimistic during a bearish trend. These circumstances make it more likely for extreme overbought conditions and extreme oversold conditions to materialise. Thus, these differences influence changes in price discovery dynamics when the market changes from a bull trading phase to a bear trading phase or vice versa.

5.8 **Endogenizing the exchange rate and Conditional information share (CIS)**

As proposed by Grammig et al. (2005) we endogenize the exchange rate in the vector error correction model (VECM) and calculate the CIS per each market. The Johansen cointegrating test is conducted for all Australian and New Zealand domiciled stocks on the ASX and the NZX. With the variables ordered as NZX price (home market), exchange rate and ASX price (foreign market), the estimated cointegrating vectors need to be close to the vector $A' = [1 \ 1 \ -1]$ as proposed by the theory.

Two types of test statistics are examined; the trace statistic and the eigenvalue (characteristic) statistic. The trace statistic and eigenvalue test statistic for the Australian and New Zealand domiciled firms confirm rejection of the null hypothesis of “no” cointegrating relationship between the price on the NZX, the exchange rate and the price on the ASX at a 5% significance level as the MacKinnon-Haug-Michelis (1999) p-value is less than 5%. However, the trace statistic and eigenvalue test statistic for the Australian and New Zealand domiciled firms for the null hypothesis of “at most one” cointegrating relationship between the price on the NZX, the exchange rate and the
price on the ASX cannot be rejected at a 5% significance level as the MacKinnon-Haug-Michelis (1999) p-value is more than 5% (test statistics for the individual firms are available on request).

The data support one cointegrating vector and the estimated cointegrating vectors are close to the theoretical expectation of the vector $\mathbf{A} = \begin{bmatrix} 1 & 1 & -1 \end{bmatrix}$ for all the Australian and New Zealand domiciled firms.

5.9 Analysis of impulse response functions

Including the exchange rate in the analysis gives rise to three impulse response functions (IRFs). The first IRF shows the impact that a one unit shock in the exchange rate has on ASX and NZX prices. The second is the impact that a one unit shock in ASX prices has on the exchange rate and NZX prices, while the third is the impact of a one unit shock in NZX prices on the exchange rate and ASX prices. To confirm the convergence of the long run influence of a one unit of shock on other variables, we calculate the impulse responses for 5000 steps ahead.

The IRFs for the Australian domiciled firms are presented in Figure 5A. The plots in the first column show the impact of a one unit shock in the exchange rate on ASX and NZX prices. The plots show that the exchange rate shocks are not permanent. They also show a larger initial response to an exchange rate shock for the NZX prices than for ASX prices. This means that for the Australian domiciled firms, the NZX (foreign) prices are more sensitive to exchange rate shocks than the ASX (home) prices. This confirms that exchange rate shocks generate more correction in the prices of the NZX (foreign) market. This finding is consistent with Frijns et al. (2010) but differs from Grammig et al. (2005) who find that the reaction to exchange rate shocks is present only in the prices of the foreign market.

The second column of Figure 5A presents the plots for the IRFs which show the impact of a one unit shock in ASX prices on the exchange rate and on the corresponding NZX prices. Similar to the exchange rate shocks, the ASX shocks are not persistent for the Australian domiciled companies. However, the NZX prices adjust to the ASX shocks and then tend to follow the ASX prices. Additionally it is evident that the ASX shocks
have very little impact on the exchange rate. This is in line with Grammig et al. (2005) as well as Frijns et al. (2010).

The third column in Figure 5A provides the plots of the IRFs which show the impact of a one unit shock in NZX prices on the exchange rate and on the corresponding ASX prices. The NZX shocks are only momentary and the ASX prices and the exchange rate barely react to NZX shocks. These findings confirm that the ASX exchange (the NZX exchange) is the dominant (satellite) market for the Australian domiciled firms. These findings are in line with our earlier findings for the IRFs using two price series (single currency) as well as with the conclusions reached by Frijns et al. (2010).

The IRFs for the New Zealand domiciled firms are presented in Figure 5B. The first column exhibits the plots for the IRFs which show the impact of the exchange rate shock on ASX and NZX prices. Once again the exchange rate shocks do not persist. However, except for TEL, all the ASX prices show a larger initial response to the exchange rate shocks than the reactions of their corresponding NZX prices. Thus, the exchange rate shocks have a slightly larger impact on ASX prices for the New Zealand domiciled firms excluding TEL. Thus for these stocks, the ASX (foreign) prices are more receptive to exchange rate shocks than the NZX (home) prices. This confirms that more correction for exchange rate shocks occurs in the prices for the ASX (foreign) market.

This finding is again in line with Frijns et al. (2010) but differs from Grammig et al. (2005) who find that the response to exchange rate shocks is present only in the prices of the foreign market. However, the TEL prices on the NZX (home) respond more significantly to exchange rate shocks than the TEL prices on the ASX (foreign) exchange. For TEL, this is a confirmation that more correction for an exchange rate shock occurs in the home (New Zealand) market. This finding for TEL prices is in line with our earlier findings when analysing IRFs for two price series (single currency) and with the analysis of IS by Hasbrouck (1995). However, this finding for TEL prices differs from Frijns et al. (2010) who find that more correction for exchange rate shocks occurs in the prices for the ASX (foreign) market.

The second column in Figure 5B provides the plots for the IRFs which show the impact of a one unit of shock in ASX prices on the exchange rate and on NZX prices. Similar to
the exchange rate shocks, the ASX shocks are not permanent for all of the New Zealand domiciled companies. The ASX shocks are just momentary for AIA and WHS and the NZX prices and the exchange rate barely react to these ASX shocks. The ASX shocks for TWR and FBU persist for about 800 to 1,600 periods after the shock and the NZX prices react slightly to these shocks whilst the exchange rate barely reacts to the shock. However, the NZX price of TEL reacts significantly to the ASX shock and the exchange rate also moderately reacts to the ASX shocks.

The third column in Figure 5B shows the plots for the IRFs which show the impact of a one unit shock on NZX (home) prices on the exchange rate and on the ASX (foreign) prices. The NZX shocks are not permanent but the ASX prices for all the New Zealand stocks except TEL react significantly to the NZX shocks. These findings confirm that the NZX exchange (the ASX exchange) is the dominant (satellite) market for New Zealand domiciled firms except for TEL. These findings are in line with our earlier findings in the analysis of IRFs for two price series (single currency) and with the analysis of IS by Hasbrouck (1995). These conclusions are in line with the findings of Frijns et al. (2010) except for TEL.
Figure 5A: Impulse response functions (IRFs) for Australian domiciled firms (ANZ, AMP and TLS)

If a system of equations is stable any shock should quickly disappear whilst an unstable system of equations would produce an explosive time path.

Responses of ASX and NZX prices to a unit shock in the exchange rate
Responses of exchange rate and NZX prices to a unit shock in the ASX prices
Responses of exchange rate and ASX prices to a unit shock in the NZX prices
Responses of ASX and NZX prices to a unit shock in the exchange rate

Responses of exchange rate and NZX prices to a unit shock in the ASX prices

Responses of exchange rate and ASX prices to a unit shock in the NZX prices

Figure 5B: Impulse response functions (IRFs) for New Zealand domiciled firms (AIA, FBU, TEL, TWR and WHS)

If a system of equations is stable any shock should quickly disappear whilst an unstable system of equations would produce an explosive time path.
Responses of ASX and NZX prices to a unit shock in the exchange rate

Responses of exchange rate and NZX prices to a unit shock in the ASX prices

Responses of exchange rate and ASX prices to a unit shock in the NZX prices
Responses of ASX and NZX prices to a unit shock in the exchange rate

Responses of exchange rate and NZX prices to a unit shock in the ASX prices

Responses of exchange rate and ASX prices to a unit shock in the NZX prices
5.10 Grammig et al.'s (2005) Conditional information share (CIS)

To determine upper and lower bounds for the CIS we permute all six possible orderings of the three time series, namely the price series on the ASX (in AUD), the price series on the NZX (in NZD) and the exchange rates. However, due to the triangularization of the innovation variance-covariance matrix, specific ordering must be carried out to establish the upper and lower bounds of CIS. Similar to Grammig et al. (2005) and Frijns et al. (2010), the upper bound for the estimated information share of each variable is obtained by selecting the value that comes first in the ordering and the lower bound is obtained by taking the value that comes last in the ordering.

Tables 5A and 5B show the averages (midpoints) of the CIS. Each column in these tables shows how quoted prices in the selected market respond to different shocks whilst each row represents the informational role of each shock in the selected markets. Thus, each column shows the information share per market and therefore every column should add up to one. Each row shows the information share for the ASX, the NZX and the exchange rate. Thus the numbers in the first column indicate that ASX price changes contribute 82.71% of the price discovery for AMP on the ASX exchange; the NZX price changes contribute 14.07% of the price discovery for AMP on the ASX exchange and the changes in the exchange rate contribute the remaining 3.22% of the price discovery for AMP on the ASX exchange. The first number in the second column (81.52%) shows that the information share of AMP for the ASX price shock is 81.52% on the NZX exchange. In other words the magnitude of the AMP’s informational role of the ASX price shocks conditional on being in the NZX exchange is 81.52%. Similarly, the first number in the third column is 12.38% which shows the information share that the ASX shock has on the exchange rate.

Table 5A shows the midpoint of CIS for Australian domiciled firms. It shows that for AMP and ANZ, the shocks on ASX prices have a greater influence on the home (Australian) market than on the foreign (New Zealand) market. Thus, for AMP and ANZ, we find that the ASX information share is higher in the Australian (home) market than in the New Zealand (foreign) market. This is in line with Frijns et al. (2010). However, for TLS we find that the ASX information share is lower in the home (Australian) market than in the
foreign (New Zealand) market which is not in line with Frijns et al. (2010). In addition, we find that the influence of ASX price shocks on the determination of the exchange rate is insignificant for AMP and ANZ but is moderately significant for TLS. This means the exchange rate is mostly exogenous in relation to the stock prices of AMP and ANZ on the ASX. This is in line with Frijns et al. (2010) and Grammig et al. (2005).

The information shares for the NZX are shown in the second row of the table and it is evident that information shares are higher in the home market in comparison to the foreign market albeit the difference is trivial. Once again the exchange rate seems to be exogenous to NZX price shocks. When we compare the information shares for the ASX to the NZX and the NZX to the ASX, it is clear that the ASX significantly contributes to price discovery on both the ASX and the NZX. This finding is qualitatively compatible with the conclusions we find based on IS Hasbrouck (1995). Further, these findings are in line with Frijns et al. (2010).

The information shares of the exchange rate are shown in the last row of Table 5A. The price adjustment as a result of exchange rate changes is substantial for ANZ and TLS in both the ASX and NZX exchanges; however, it is insignificant for AMP in both exchanges. This finding is not in line with Frijns et al. (2010) where they find that the price adjustment to exchange rate changes is observable on the NZX but not on the ASX.

Table 5B shows the midpoint of CIS for New Zealand domiciled firms. The first row depicts the information shares of the ASX prices, the second row shows the information shares of the NZX prices and the third row represents the information shares for the exchange rate.

It shows that for the New Zealand companies (except TEL and WHS), the shocks on NZX prices have a smaller influence on the home (New Zealand) market than on the foreign (Australian) market. Thus, for AIA, FBU and TWR, we find that the NZX information shares are higher in the Australian (foreign) market than in the New Zealand (home) market. This confirms the significance of NZX price shocks in the ASX market. However, this finding is not in line with Frijns et al. (2010) who find that ASX information shares are higher in the New Zealand (home) market than in the Australian (foreign)
market, confirming the significance of ASX price shocks in the NZX market. However, for TEL and WHS, we find that the NZX information shares are higher in the New Zealand (home) market than in the Australian (foreign) market. When we compare the information shares for the NZX to the ASX and ASX to the NZX, it is clear that the NZX significantly contributes to price discovery on both the ASX and the NZX, except for TEL. This finding is qualitatively compatible with the conclusions we find based on IS Hasbrouck (1995). Further, these findings are in line with Frijns et al. (2010).

The information shares of the exchange rate are shown in the last row of Table 5B. We find that the price adjustment to exchange rate changes mostly occurs on the NZX for New Zealand domiciled companies except TEL and WHS. In addition, the exchange rate information shares for FBU and WHS are significantly greater confirming that substantial price adjustments to exchange rate changes occur on both the ASX and NZX. These findings are in contrast to the findings in Frijns et al. (2010) where they find that the price adjustment to exchange rate changes primarily occurs on the ASX.

We also find that ASX information shares are generally greater than the NZX information shares for Australian domiciled firms whilst on average the NZX information shares are greater than the ASX information shares for New Zealand domiciled firms except TEL. This finding is qualitatively consistent with the conclusions we find based on IS Hasbrouck (1995). Figure 6A shows that ASX information shares are clearly significant for Australian firms on the ASX and NZX exchanges whilst Figure 6B shows that NZX information shares are marginally significant for New Zealand firms on the ASX and NZX exchanges. These graphs confirm the importance of the ASX (NZX) price innovations for Australian (New Zealand) firms in both exchanges.

Additionally we find that the average information share for the ASX shocks for the Australian domiciled firms (72.69%) is greater than the average information share for NZX shocks for New Zealand domiciled firms (39.87%). Similarly we find that on average the information share for the NZX shocks for Australian domiciled firms (8.71%) is less than the average information share for ASX shocks for New Zealand domiciled firms (22.56%). Despite the negative effect of TEL on NZX shocks, these findings confirm the significance of the ASX shocks on the NZX.
Table 5A: Midpoints of Grammig et al.’s (2005) conditional information share (CIS) results for the prices of Australian domiciled firms

The table below shows averages (midpoints) of Grammig et al.’s (2005) CIS.

\[
CIS_j = \left( \frac{\Psi C}{\Psi \Omega \psi} \right)_j^2
\]

It is possible to calculate the information share of the market i with respect to price series j, CIS$_j$. The first row shows each of the market in which CIS is measured. The first column shows the market on which CIS is reported.

<table>
<thead>
<tr>
<th>Midpoints of conditional information shares [CIS] per market</th>
<th>Australian domiciled firms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ASX MARKET %</td>
</tr>
<tr>
<td>AMP</td>
<td></td>
</tr>
<tr>
<td>ASX SHOCK</td>
<td>82.71%</td>
</tr>
<tr>
<td>NZX SHOCK</td>
<td>14.07%</td>
</tr>
<tr>
<td>FX SHOCK</td>
<td>3.22%</td>
</tr>
<tr>
<td>ANZ</td>
<td></td>
</tr>
<tr>
<td>ASX SHOCK</td>
<td>65.20%</td>
</tr>
<tr>
<td>NZX SHOCK</td>
<td>10.28%</td>
</tr>
<tr>
<td>FX SHOCK</td>
<td>24.52%</td>
</tr>
<tr>
<td>TLS</td>
<td></td>
</tr>
<tr>
<td>ASX SHOCK</td>
<td>71.65%</td>
</tr>
<tr>
<td>NZX SHOCK</td>
<td>0.07%</td>
</tr>
<tr>
<td>FX SHOCK</td>
<td>28.27%</td>
</tr>
</tbody>
</table>

Figures 6A and 6B: Average conditional information share (CIS)

The figures below show the average of the CIS for Australian and New Zealand domiciled firms on the ASX and the NZX.
Table 5B: Midpoints of Grammig et al.’s (2005) conditional information share (CIS) results for the prices of New Zealand domiciled firms

The table below shows averages (midpoints) of Grammig et al.’s (2005) CIS.

\[
CIS_{ji} = \frac{(\Psi C_{ji})^2}{(\Psi \Omega)_{ji}}
\]

It is possible to calculate the information share of the market i with respect to price series j, CIS\(_{ji}\). The first row shows each of the market in which CIS is measured. The first column shows the market on which CIS is reported.

<table>
<thead>
<tr>
<th>New Zealand domiciled firms</th>
<th>Midpoints of conditional information shares [CIS] per market</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ASX MARKET % NZX MARKET % EXCHANGE RATE %</td>
</tr>
<tr>
<td>AIA</td>
<td>9.39% 3.12% 0.01%</td>
</tr>
<tr>
<td>FBU</td>
<td>13.96% 9.38% 0.83%</td>
</tr>
<tr>
<td>TEL</td>
<td>81.68% 83.70% 36.42%</td>
</tr>
<tr>
<td>TWR</td>
<td>12.28% 7.10% 2.17%</td>
</tr>
<tr>
<td>WHS</td>
<td>2.65% 2.31% 0.64%</td>
</tr>
</tbody>
</table>

6. Conclusion:

Motivated by the question of whether investing strategies in stock markets should change during different trading phases this study investigates the price discovery dynamics of cross listed stocks on the Australian and New Zealand exchanges during 2008 to 2011.

Consistent with previous research, we find that price discovery mostly takes place on the home market for the Australian domiciled firms and for all but one of the New Zealand domiciled firms. This is true in terms of both Hasbrouck’s (1995) information share and Grammig et al.’s (2005) conditional information share.
In contrast to Frijns et al. (2010) conclusions, we generally find that the price adjustment to exchange rate changes occurs on both exchanges for Australian domiciled companies whilst the price adjustment to exchange rate changes mostly occurs on the NZX for New Zealand domiciled companies. We also find a growing importance of the NZX exchange for both the Australian domiciled firms and the New Zealand domiciled firms. This finding also differs from Frijns et al. (2010) who find an increasing trend in the importance of the ASX exchange over time.

The findings in our study reinforce the conclusions of Miaoxin (2012) and Hodgson et al. (2003) who find that price discovery dynamics vary when a market changes from a bull trading phase to a bear trading phase or vice versa. The differing dynamics can be attributed to differences in investor sentiments, changes in combined investor psychology and variations in the role of stock prices in bull and bear market conditions.

The growth in importance of the NZX during a bear market suggests it is not a pure satellite market. An interesting extension of this work will be to see whether New Zealand’s recent move towards a NASDAQ OMX X-stream trading platform will improve price discovery and make it an even more important independent market.
7: References:


