Journal of Banking & Finance 34 (2010) 498–508

Contents lists available at ScienceDirect

Journal of Banking & Finance

journal homepage: www.elsevier.com/locate/jbf

The dynamics of price discovery for cross-listed shares: Evidence from Australia and New Zealand

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ARTICLE INFO

Article history:
Received 3 July 2008
Accepted 17 August 2009
Available online 20 August 2009

JEL classification:
C32
G15

Keywords:
Price discovery
Cross-listings
Market microstructure

ABSTRACT

This paper studies the dynamics of price discovery for markets with bilateral cross-listings. Using a sample of four Australian stocks cross-listed in New Zealand and five New Zealand stocks cross-listed in Australia for the period January 2002 to December 2007, we assess Hasbrouck (1995) information shares and Grammig et al. (2005) conditional information shares over time. We observe that in both cases the home market is dominant in terms of price discovery. However, when studying price discovery over time, we find that the importance of the Australian market (the larger of the two markets) is increasing for both Australian and New Zealand domiciled firms. Finally, using panel regression analysis, we find that the growth in the importance of the Australian market is positively related to the growth in the size of the firm and negatively related to the size of the percentage spread in the Australian market, implying that as firms grow larger and their cost of trading in Australia declines, the Australian market becomes more informative.

1. Introduction

A considerable number of studies have focused on price discovery among internationally cross-listed stocks, and most have found that the home market remains the dominant market. However, the questions of how price discovery changes over time and what affects this change remain largely unexplored. Moreover, Coffee (2002) suggests that due to the ongoing globalization and technological advancements smaller markets will lose out to larger ones. A study of price discovery over time involving smaller markets could shed some light on these predictions.

In this paper we study the evolution of price discovery over time. In particular, we assess price discovery for cross-listed stocks in the Australian Stock Exchange (ASX), a relatively large market, and the New Zealand Stock Exchange (NZX), a relatively small market. These markets offer an excellent opportunity to examine price discovery over time for the following reasons. First, the study of price discovery relies on the implicit assumption that price differentials between markets are bounded by arbitrage opportunities and hence prices are cointegrated. Such price differentials can only be observed in each market when these markets are open and thus studies are typically conducted for short periods during which trading hours overlap (e.g., Grammig et al., 2005; Pascual et al., 2006). The overlap in trading hours between the ASX and the NZX is rather long, ranging from 4 to 6 h. Second, the ASX and the NZX markets are highly integrated. Market participants from each market can easily trade in the other market (at similar brokerage fees, etc.). In addition, as shown by Werner and Kleidon (1996), stocks listed in different markets and currencies may not be perfect substitutes.[1] However, shares listed in both Australia and New Zealand can easily be traded in either market. Third, in the case of these two markets, cross-listing occurs in both directions, i.e. Australian firms cross-list in New Zealand, and New Zealand firms cross-list in Australia. This provides an excellent opportunity to assess whether, for these bilateral cross-listings, the home market remains dominant as found by studies that consider unilateral cross-listings (e.g., Pascual et al., 2006; Su and Chong, 2007), or whether the larger market (Australia) dominates (e.g. Hupperets and Menkveld, 2002).

We study price discovery for an extended period of time, from January 2002 to December 2007. For this period we compute Hasbrouck (1995) information shares and Grammig et al. (2005) conditional information shares, which endogenizes the exchange rate. Using this long sample period, we compute information shares for each year and each stock, allowing us to assess the informational evolution of each market over time. Moreover, once annual information shares are computed we conduct a panel regression aimed at explaining the cross-sectional and time-variation in information shares.

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[1] We thank a referee for pointing this out to us.

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doi:10.1016/j.jbankfin.2009.08.014

Our price discovery analysis leads to several interesting findings. First, in line with previous research (e.g., Grammig et al., 2005; Pascual et al., 2006), we observe that the home markets are dominant in terms of price discovery, both when prices are converted into a single currency and when incorporating the exchange rate into the model. However, home market information shares for Australian domiciled firms are, on average, higher than the home market information shares for New Zealand domiciled firms. Second, when assessing price discovery over time we observe that for both Australian and New Zealand domiciled stocks the ASX information share increases. Furthermore, for Australian domiciled stocks we find that the role of the exchange rate increases in the NZX prices, while for New Zealand domiciled firms the role of the exchange rate in ASX prices decreases. These results suggest that the Australian market is becoming increasingly important from a price discovery point of view. Finally, using panel regression analysis, we notice that the growth in the importance of the Australian market is positively related to the growth in the size of the firm and negatively related to the size of the percentage spread in the Australian market, thus implying that as firms grow larger and their cost of trading in Australia declines, the Australian market becomes more informative.

These results have important implications for financial markets and institutions. First, for financial markets our results suggest a decline in the importance of the NZX, which is taking on more and more features of a pure satellite market (i.e. the information share decreases and more of the exchange rate is getting incorporated into New Zealand prices). Second, although the NZX still dominates for New Zealand domiciled firms, financial institutions should focus more and more on prices at the ASX as these prices tend to become more and more informative than the prices on the NZX.

The remainder of this paper is organized as follows. Section 2 discusses some of the relevant literature on price discovery in the context of cross-listed shares. Section 3 describes the modeling framework and introduces the Hasbrouck (1995) information share and Grammig et al.'s (2005) extension. Section 4 presents the data and reports summary statistics. Section 5 reports the empirical results. Finally, Section 6 concludes.

2. Literature review

Price discovery has been examined for various asset classes, such as stocks (Harris et al., 1995; Hasbrouck, 1995), options (Chakravarti et al., 2004), credit spreads (Forte and Pena, 2009) and futures (Mizrach and Neely, 2008), and in a variety of market settings, such as US regional markets (Hasbrouck, 1995), floor versus electronic markets (Martins, 1998) and international markets (Eun and Sabherwal, 2003). In international markets, the dramatic increase in the number of companies cross-listed on foreign exchanges in recent years has made it both necessary and important to consider where information is impounded into prices (Eun and Sabherwal, 2003).

The study of price discovery for companies listed on multiple exchanges initially focused on the informational role of the NYSE and other regional US stock markets. Harris et al. (1995), for instance, examine the price discovery of IBM on the NYSE and two other regional exchanges and observe that all three markets play an important role in the price discovery of IBM. Hasbrouck (1995) goes further and defines a measure of the relative importance of the various markets' contributions to price discovery, called the information share. Based on a sample of 30 DJIA companies, Hasbrouck shows that NYSE price changes represent 92.7% of the price discovery, with other regional exchanges making up the remainder. Harris et al. (2002) examine the importance of the NYSE in comparison to regional exchanges over time. While they show that the NYSE has remained the dominant informational market, its dominance has declined, by 1995 regional exchanges contributed nearly 40% of the price discovery, while representing only 16% of trading volume.

While the original studies of price discovery on multiple markets started with domestic firms in the US, later studies focus on firms with listings in different countries. In general, these studies find that price discovery predominantly occurs in the home market, with the prices in the foreign market adjusting to the home market. Lieberman et al. (1999), for instance, study a sample of six Israeli firms cross-listed on the NYSE and find that price discovery mostly occurs in Israel for all but one firm, with the NYSE contributing only a small amount. Su and Chong (2007) examine eight Chinese firms listed on both the Hong Kong Stock Exchange (SEHK) and the NYSE and find that the average information share was 89.4% for the SEHK. These studies reveal a limited but not negligible role for the NYSE.

Although studies have shown different reactions to cross-listings in different markets (Roosenboom and van Dijk, 2009), most studies to date predominantly focus on stocks that are cross-listed in the US. Only a few studies have considered situations where the foreign market is another exchange. One example is Ding et al. (1999), who consider the case of a Malaysian conglomerate cross-listed on the Singapore Stock Exchange. They find that nearly 70% of the price discovery occurs in the home market. Kadapakkam et al. (2003) study price discovery for Indian companies with cross-listings in the UK and find that both markets contribute equally to price discovery. Finally, and related to this study, is Lok and Kalev (2006), who consider New Zealand and Australian cross-listings. Using an error-correction model they find that prices in the foreign market error-correct mostly towards prices in the home market, while there is only a limited error-correction of home market prices to foreign prices. However, they do not compute explicit measures for price discovery. Beyond this, to the best of our knowledge, little research has considered situations outside the US.

While most studies find that the home market remains dominant in terms of price discovery, there is some variation in the relative informational roles of the home and the foreign markets. For instance, while the previously discussed studies conclude that the foreign market has an informational role, Pascual et al. (2006) find that the influence of the NYSE on a sample of five Spanish stocks is insignificant. This supports the findings of Grammig et al. (2005), who arrive at a similar conclusion when studying a sample of three German stocks cross-listed on the NYSE. On the other side of the spectrum are studies that do find important roles for the foreign market. Hupperets and Menkveld (2002), for example, find that Dutch stocks cross-listed on the NYSE have wide variations in price discovery with some stocks predominantly driven by the Amsterdam stock exchange, some by the NYSE and some by both. Likewise, Kadapakkam et al. (2003) observe that for Indian companies cross-listed on the London Stock Exchange each market contributes nearly equally to price discovery.

A further observation is that the level of price discovery is closely linked to the liquidity of a market. Eun and Sabherwal (2003), for instance, aim to explain the variation they find in their examination of the price discovery of Toronto Stock Exchange stocks cross-listed on US exchanges. They observe variation in the percentage of price discovery occurring on US exchanges ranging from 0.02% to 98.2% with an average of 38%. Using regression analysis, they observe a positive relationship between price discovery and the ratio of the proportions of information trades occurring in the US. This is consistent with the observations of Lieberman et al. (1999) and Hasbrouck (1995) that there is a negative relationship between price discovery and the ratio of bid-ask spreads, i.e., higher spreads relate to a lower degree of price discovery.

Turning to the role of exchange rates, most studies treat exchange rates as exogenous, converting all prices into a common currency before testing for price discovery. For instance, Lieberman et al. (1999) convert all prices into US dollars while Eun and Sabherwal (2003) convert all prices into Canadian dollars. However, as Grammig et al. (2005) point out, there is little prior evidence to suggest how stock prices in multiple markets adjust to exchange rate changes. They therefore examine the impact of exchange rate changes on price discovery for a selection of German companies traded on both XETRA and the NYSE using a modified measure of Hasbrouck's (1995) information share, which incorporates the exchange rate. Consistent with previous studies they observe that most of the price discovery occurs in the home market. They also find that prices in the foreign market fully adjust to incorporate the exchange rate changes with no adjustment in XETRA prices. Finally, they conclude that models that exclude the exchange rate bias the information share of the market whose price is converted.

3. Methodology

In this section we discuss the price discovery measures used in our paper. We first discuss the relationship between the error-correction model and the information share. Second, given the error-correction model we define the Hasbrouck (1995) information share and Grammig et al.'s (2005) modification of the information share. Since we study price discovery for stocks cross-listed in one other market, we explain both approaches in terms of one home market and one foreign market.

3.1. Error-correction model

The study of price discovery relies on the assumption that when a security is listed on another market the prices in both markets share a common trend, i.e., prices are cointegrated. Let p_t^h (p_t^f) be the log price of an asset in the home (foreign) market expressed in local currency and let e_t represent the log exchange rate between the two currencies. These prices are stacked in the price vector $p_t = (p_t^h, p_t^f, e_t)'$. Since prices in both markets are driven by the same underlying fundamentals, the prices in a single currency should be cointegrated, i.e. $p_t^h + e_t$ and p_t^f are cointegrated, or, similarly, p_t^h and $p_t^f - e_t$ are cointegrated with cointegrating vector $\beta' = (1, -1)$. Hence if we define the matrix

$$A' = \begin{pmatrix} 1 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix} \quad \text{or likewise } \widetilde{A}' = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & -1 \end{pmatrix},$$

then $\beta' A' p_t (\beta' \widetilde{A}' p_t)$ should be a stationary process. The new vector $\widetilde{\beta}' = \beta' A' = \beta' \widetilde{A}' = (1, -1, 1)$ is the cointegrating vector for p_t and suggests that the price vector p_t has one cointegrating relationship and two underlying random walks (one for the price process and one for the exchange rate). In terms of estimation, we can either model price discovery using the unrestricted price vector p_t (this endogenizes the exchange rate and is the approach suggested by Grammig et al. (2005) for cross-listed stocks traded in different currencies), or use the restricted price vector $A' p_t$, which first converts prices into a single currency (this approach leads to the standard definition of the Hasbrouck (1995) information share).

Cointegration implies that the dynamics of price changes can be described by an error-correction model,

$$\Delta y_t = c + \alpha \beta' y_{t-1} + \sum_{i=1}^{N} \gamma_i \Delta y_{t-i} + \varepsilon_t, \tag{1}$$

where y_t is either p_t or $A' p_t$, c is a vector of constants, α is a vector that measures the speed of adjustment to the error-correction term and γ_i are matrices of AR coefficients. A key determinant for the study of price discovery is α, the speed of adjustment. When a market dominates in terms of price discovery its value in the α-vector will be small (in absolute terms), indicating that this market does not correct in response to any differences in prices between markets. Conversely, when a market is a satellite market its element in α will be large (in absolute terms) relative to the dominant market, indicating strong adjustment to errors in prices.

To define measures of price discovery such as the Hasbrouck (1995) information share or Grammig et al.'s (2005) modification of the information share, we rewrite (1) in its Wold representation, i.e.,

$$\Delta y_t = \Psi(L) \varepsilon_t, \tag{2}$$

where $\Psi(L)$ is a matrix polynomial in the lag operator. Following Beveridge and Nelson (1981), we can decompose $\Psi(L)$ into two components and write (2) as

$$\Delta y_t = \Psi(1) \varepsilon_t + (1 - L) \Psi^*(L) \varepsilon_t, \tag{3}$$

where $\Psi(1)$ is the sum of all moving average coefficients ($\Psi(1) = I + \Psi_1 + \Psi_2 + \cdots$) and $\Psi^*(L)$ is a second matrix polynomial. Stationarity implies that $\Psi(1)$ is finite and its meaning can be derived by integrating (3) over time,

$$y_t = \Psi(1) \sum_{s=1}^{t} \varepsilon_s + \Psi^*(L) \varepsilon_t. \tag{4}$$

Since $\Psi(1)$ is finite, it measures the long-run impact of a shock to the level of prices. The value of its elements can be found by computing the impulse response functions for the integrated model of (1).

Since prices are cointegrated, $\beta' y_t$ is a stationary process, which implies that $\beta' \Psi(1) = 0$. Given this condition we can define the information share proposed by Hasbrouck (1995) and Grammig et al.'s (2005) modification of it.

3.2. Hasbrouck (1995) information share

In the case of the Hasbrouck (1995) information share the price vector y_t is given as $A' p_t$, which implies that $\beta' = (1, -1)$. Combining this with the condition that $\beta' \Psi(1) = 0$, this implies that the rows in $\Psi(1)$ are identical. Defining one row of $\Psi(1)$ as ψ, the information share for market j, that is, the proportion of variance of the price process attributable to market j, is defined as

$$IS_j = \frac{\psi_j C_{jj}}{\psi \Omega \psi'}, \tag{5}$$

where $\Omega = \mathrm{Var}(\varepsilon_t)$ and C is the lower triangular Choleski factorization of Ω (i.e., $\Omega = CC'$). The Choleski factorization needs to be applied because Ω is typically not a diagonal matrix. When taking only the elements on the diagonal of Ω in the computation of IS, we ignore the fact that part of the variance in market j may be caused by the variance in the other market, i.e., there may be a contemporaneous common component or spillover in the variance of market j. By applying the Choleski decomposition to Ω we orthogonalize the innovation terms ε_t by assigning all the common variance to, for example, market j. However, since we do not know which market is the source of this common variance, we cannot assign all the common variance to one market. Therefore, we need to permute over all possible orderings of ε_t, with the consequence that we can only obtain a range of information shares and not a unique value for each market.[2]

[2] Hasbrouck (1995) reports both upper and lower bounds obtained in the Choleski decomposition. Alternatively, Baillie et al. (2002) suggest using the midpoint of the information share as a single measure of price discovery.

3.3. Grammig et al.'s (2005) modified information share

Grammig et al. (2005) note that the effect of exchange rate changes on asset prices has not been assessed in the price discovery literature for cross-listed stocks. They extend Hasbrouck's (1995) model by including the exchange rate. Hence they estimate (1) in its unrestricted version, where $y_t = p_t$ and $\beta' = (1, -1, 1)$. However, the fact that there is one cointegrating relationship between three price series implies that the rows of $\Psi(1)$ are not identical. Stated differently, we cannot compute a single information share for each price series as before. Grammig et al. (2005) therefore suggest computing information shares per market. For instance, we can compute the information share of the exchange rate and the home and foreign markets conditional on being in the home market. We therefore obtain information shares for each market, which we refer to as conditional information shares (*CIS*). The conditional information share of market k with respect to market j is computed as

$$CIS_{jk} = \frac{([\Psi(1)C]_{jk})^2}{(\Psi(1)\Omega\Psi(1)')_{jj}}. \quad (6)$$

This measure again depends on the specific ordering of ε_t and hence we need to permute over all possible orderings to establish upper and lower bounds.

4. Data

Our study considers Australian and New Zealand domiciled companies that cross-list shares in each others' markets. Since accurate estimation of information shares can only be achieved when data are sampled at very high frequencies, we need to restrict our sample to the most liquid companies trading on the ASX and the NZX. The selected sample therefore consists of four Australian firms (Australian Mutual Provident Society (AMP), Australia and New Zealand Banking Group (ANZ), Lion Nathan (LNN), Telstra (TLS)) and five New Zealand domiciled firms (Auckland International Airport (AIA), Telecom (TEL), the Warehouse (WHS), Tower (TWR), Fletcher Building (FBU)) that are traded on both the ASX and the NZX. These stocks are selected because they offer sufficient quoting activity in both markets for any meaningful analysis.

Intraday data for these firms as well as intraday NZD/AUD exchange rate data are obtained from SIRCA.[3] We obtain both trade and quote data. The trade data include the time of trade, trade price and traded volume. The quote data contain the time a new quote is issued, the bid and ask quotes and the volumes quoted on each side of the market. The exchange rate data only contain information on quotes, i.e., the time the quote is issued, the bid and ask prices and associated volumes. We collect these data for a long time period to investigate the evolution of the information share over time. Specifically, we examine a six-year period running from 1 January 2002 to 31 December 2007, excluding those days on which there was no trading in either market.

Given the small difference in time zones (normally 2 h between New Zealand and New South Wales, where the ASX is based) there is a long period of overlap. The ASX operates normal trading each day from 10 am AEST until 4 pm while the NZX operates normal trading from 10 am NZ time until 5 pm. The overlapping period therefore runs from the start of normal trading on the ASX until the end of trading on the NZX. For most of the year this results in 5 h of overlapping operation between the two markets. However, due to differences in the start and end dates of daylight savings this overlap can range from 4 h to 6 h. The exchange rate also has to be adjusted for differences in time zones as it is based on GMT. Since the exchange rate market lists quotes 24 h a day it imposes no restriction on the overlapping period.

In Table 1, we present summary statistics for the selected stocks for the whole sample period. The summary statistics are computed considering the overlapping period only. We report trade statistics as well as quote statistics. For the Australian domiciled firms we find that the trading activity of these firms is much higher on the ASX, both in terms of trading frequency and trading volumes. The most liquid firm in terms of daily volume is TLS, which trades on average 19,346,694 shares a day on the ASX, as opposed to only 57,249 shares per day on the NZX. We observe a similar difference in trading activity in daily trades. For TLS, there are on average 1397 trades a day on the ASX compared to 8.22 trades on the NZX. The same observation can be made for the quote statistics. On average more quotes are issued on the ASX relative to the number of quotes issued on the NZX, which is reflected in the respective bid-ask spread being considerably wider on the NZX than on the ASX. All these statistics indicate that for the Australian domiciled firms, trading and quoting activity is predominantly on the ASX.

In Fig. 1 we show a representative section of the price behavior of TLS in both markets, converted to Australian dollars (only a small section is shown so that price differences can be observed). We can clearly see that prices track each other closely and do not diverge too far from each other. This provides us with a preliminary indication that prices may be cointegrated.

Table 1
Summary statistics.

	Average price	Average daily trades	Average daily volume	Average bid-ask spread	Average daily quotes
Australian domiciled firms					
AMP					
ASX	9.12	1157.67	5,582,364	0.0257	478.95
NZX	10.40	12.42	23,453	0.1250	111.20
ANZ					
ASX	22.16	1464.56	3,668,974	0.0243	906.1
NZX	25.09	4.87	11,592	0.0698	324.47
LNN					
ASX	6.97	257.78	732,240	0.0276	201.19
NZX	7.87	5.32	57,828	0.1501	71.60
TLS					
ASX	4.56	1396.88	19,346,694	0.0158	234.20
NZX	5.16	8.22	57,249	0.0536	36.03
New Zealand domiciled firms					
AIA					
ASX	3.82	7.12	193,589	0.0960	19.00
NZX	4.29	46.99	689,422	0.0187	51.37
FBU					
ASX	5.82	24.39	175,727	0.0737	48.24
NZX	6.59	49.61	563,368	0.0378	79.73
TEL					
ASX	4.60	184.74	2,299,069	0.0196	107.90
NZX	5.19	111.31	3,544,992	0.0123	111.91
TWR					
ASX	2.14	91.59	457,404	0.0184	55.30
NZX	2.44	31.40	337,348	0.0161	42.97
WHS					
ASX	4.66	4.61	19,849	0.1276	11.85
NZX	5.31	33.79	243,640	0.0279	43.92

This table reports summary statistics on the data in the sample. We report the average price level in each market in local currency; the average number of daily trades in each market; the average daily traded volume in each market; the average absolute spread in each market; and the average number of quotes issued daily.

[3] Securities Industry Research Centre of Asia-Pacific.

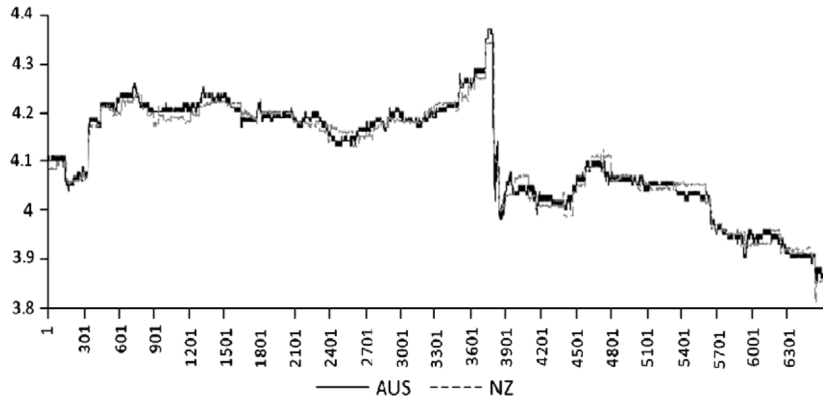

Fig. 1. Price plot for Telstra.

For the New Zealand domiciled firms the findings are similar, though less pronounced than for the Australian domiciled firms. We find that for most firms trading activity and volume are higher on the NZX, although the trading activity for TEL and TWR is higher in the ASX. When turning to the quote statistics, the findings are again similar to those for Australian domiciled firms, except for the stocks of TEL and TWR, where quoting activity is similar in both markets.

The results presented above indicate that most of the trading and quoting activity of the cross-listed shares is in the market of domicile. However, to formally analyze whether the home market is also the most important in terms of price discovery we need to assess the informational role of each market.

To study the issue of price discovery we follow Grammig et al. (2005) and consider quote midpoints instead of transaction prices. This is done for two reasons. First, using the quote midpoint mitigates the impact of microstructure noise. Since the stocks traded on the ASX and NZX are substantially less liquid than cross-listed shares normally studied in US markets, the bid-ask spread tends to be wide. The resulting large bid-ask bounce could be an issue were transaction prices to be used. Second, from Table 1 we observe that the difference in trading activity on both markets is more disperse than the difference in quoting activity. When using transaction prices our findings may be heavily affected by asynchronous prices. In our analyses we therefore use the quote midpoint and aggregate data for each market and the exchange rate at a one-minute frequency.

5. Results

In this section we present the results for the models proposed in Section 3. We first report results for the model where all prices are converted into Australian dollars. We then consider prices in their own domestic currencies and incorporate the exchange rate in the price discovery model following Grammig et al. (2005). Finally, we investigate which variables can explain the change in the information shares over time.

Before computing both types of information share we first perform ADF tests to test for unit roots and cannot reject the presence of a unit root for all cases. Also, we need to determine whether prices are cointegrated. We do this by performing Johansen's (1988) cointegration test. In this test we determine the optimal lag length using the Schwarz Information Criterion (SIC) and estimate the unrestricted and restricted VARs excluding the first n observations of each day, where n is the number of lags determined by the SIC. These observations are excluded to ensure that the coefficients on the AR components do not reflect overnight changes in prices. The Johansen tests strongly reject (at the 1% level) the hypothesis of no cointegrating relationship. The tests further show that we cannot reject the hypothesis of at least one cointegrating relationship. Cointegrating vectors are found to be close to the theoretically expected relationship.[4] The VECM coefficients are computed by Full Information Maximum Likelihood using the empirical cointegrating vectors. Given the parameter estimates of the VECM, we compute $\Psi(1)$ using impulse response functions. To ensure convergence of the long-run impact of a unit shock, we compute impulse responses for 5000 steps ahead. Using the elements of $\Psi(1)$ we can compute the information shares for the various stocks.

Table 2
Information shares for Australian and New Zealand cross-listed stocks.

	ASX (%)			NZX (%)		
	Upper bound	Lower bound	Midpoint	Upper bound	Lower bound	Midpoint
Australian domiciled firms						
AMP	97.96	88.21	93.09	11.79	2.04	6.91
ANZ	99.36	97.33	98.35	2.67	0.64	1.65
LNN	88.14	82.65	85.39	17.35	11.87	14.61
TLS	92.04	87.42	89.73	12.58	7.96	10.27
New Zealand domiciled firms						
AIA	30.17	18.06	24.12	81.94	69.83	75.88
FBU	21.54	4.56	13.05	95.44	78.46	86.95
TEL	5.52	1.50	3.51	98.51	94.48	96.49
TWR	40.03	27.50	33.76	72.50	59.97	66.24
WHS	16.69	9.26	12.97	90.74	83.31	87.03

This table reports Hasbrouck (1995) information shares for the various stocks in the sample. We report the upper and lower bounds based on the Choleski factorization of the covariance matrix. We also report the midpoint of these bounds.

5.1. Hasbrouck (1995) information shares

In Table 2 we report upper and lower bounds, and midpoints of the Hasbrouck (1995) information shares for the stocks in our sample. In line with findings of previous studies (e.g., Su and Chong, 2007; Lieberman et al., 1999) we observe that price discovery mainly takes place in the home market for each stock. For Australian domiciled firms most of the price discovery takes place on the ASX (the average midpoint of Australian domiciled stocks is 91.64%). This finding is in line with the results reported in Table 1, which show that most of the trading and quoting activity takes place on the ASX and spreads are smallest in the ASX for Australian domiciled stocks. This confirms the relationship between information shares and measures of liquidity as suggested by Eun and Sabherwal (2003).

[4] Results for the cointegration tests are not reported, but are available upon request.

Table 3
Information shares over time.

	ASX						NZX					
	2002	2003	2004	2005	2006	2007	2002	2003	2004	2005	2006	2007
Australian domiciled firms												
AMP	83.96	90.46	86.57	96.94	95.89	95.39	16.04	9.54	13.43	3.06	4.11	4.61
ANZ	94.55	98.66	98.54	96.19	99.29	99.55	5.45	1.34	1.46	3.81	0.71	0.45
LNN	71.53	78.53	86.84	71.21	61.31	83.09	28.47	21.47	13.16	28.79	38.69	16.91
TLS	77.15	87.23	93.70	82.81	84.44	96.25	22.85	12.77	6.30	17.19	15.56	3.75
New Zealand domiciled firms												
AIA	22.97	13.28	16.33	33.43	35.13	39.37	77.03	86.72	83.68	66.57	64.87	60.63
FBU	9.62	4.62	12.81	30.14	25.22	33.52	90.38	95.39	87.19	69.87	74.79	66.48
TEL	20.10	14.01	33.42	27.02	8.93	14.45	79.90	85.99	66.58	72.99	91.07	85.55
TWR	14.07	32.29	39.61	43.00	34.40	39.42	85.93	67.71	60.39	57.00	65.60	60.58
WHS	17.90	6.73	13.98	12.27	25.30	11.90	82.10	93.27	86.02	87.73	74.70	88.10

This table reports the midpoint of the Hasbrouck (1995) information share over time.

For New Zealand domiciled companies we obtain similar results although the average information share for the home market is lower (an average midpoint of 82.52). The midpoint of information shares for the home market ranges between 66.24% and 96.49%. TWR has the lowest information share, which, as observed from Table 1, has a higher trading activity (higher average of daily trades and higher daily volume) in the ASX than in the NZX. We also observe that for all stocks the range between the upper and lower bounds is relatively narrow, indicating that contemporaneous correlation does not pose a serious problem at the 1-min sampling frequency. Also, upper and lower bounds for the ASX and the NZX do not overlap, implying an unambiguous dominance of the home market.

We further investigate how the information shares have changed over time. We compute the midpoint of the information share each year by estimating the VECM annually. The results of this analysis are reported in Table 3.

Table 3 reveals an interesting trend. When considering the Australian domiciled firms, it can clearly be seen that the information shares in Australia have increased over time. This indicates a growing importance of the ASX and a diminishing importance for the NZX for Australian domiciled companies. When New Zealand based companies are examined, we find that the information shares for the ASX have been increasing considerably for three stocks and decreasing for two stocks. Combined with the observed trend for the Australian domiciled stocks this indicates that that the importance of the ASX, in terms of price discovery has been increasing over time. This trend is better observed in Fig. 2 where we plot the average midpoint of the information shares for Australian domiciled stocks (right axis) and New Zealand domiciled stocks (left axis). Given that this trend is present for stocks from both markets, it appears the ASX has grown in importance relative to the NZX over the sample period.

To summarize, the results for information shares are mostly in line with previous literature, which suggests a dominant role for a stock's home market. Further, it appears that the importance of the ASX in terms of price discovery has increased over time.

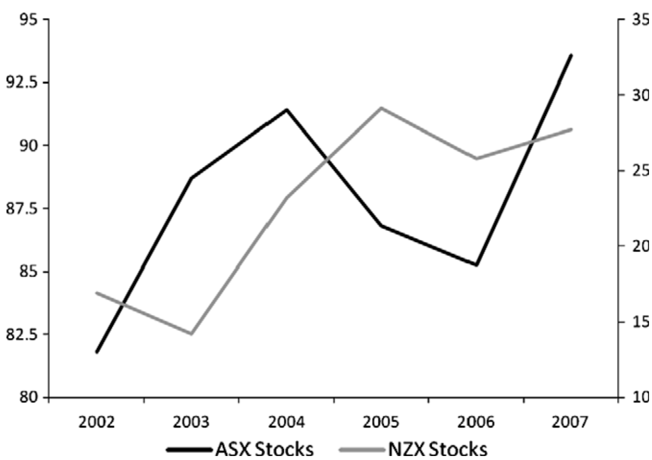

Fig. 2. Hasbrouck information shares over time.

5.2. Endogenizing the exchange rate: impulse response functions

As a second analysis we endogenize the exchange rate in the VECM and compute conditional information shares per market as suggested by Grammig et al. (2005). The Johansen tests reject the null hypothesis of no cointegrating relationship and in all cases find evidence for one cointegrating relationship among the three variables.[5] After estimating the VECM we compute impulse response functions to determine the long-run impact matrix, $\Psi(1)$ (elements in $\Psi(1)$ are estimated by computing impulse responses 5000 steps ahead). Fig. 3 shows the results for the impulse response functions for the first 2000 steps.

The first column of Panel A shows plots of the impulse response functions where a unit shock is applied to the exchange rate. For Australian based companies we find that exchange rate shocks are persistent, leveling out at about 75–80% of the initial shock. We also find that most of the exchange rate shock is incorporated into New Zealand prices. However, for three stocks there is also an adjustment in Australian prices. This contrasts with Grammig et al. (2005), who find that the adjustment to exchange rate shocks is only observed in the foreign market. When shocks to the Australian prices (second column) are considered, several results emerge. First, these shocks are persistent and lead to strong adjustments in the New Zealand prices. This is in line with previously reported results that the ASX is the dominant market for these securities. Second, in line with Grammig et al. (2005), shocks to Australian prices only have a small or no impact on the exchange rate. The last column shows the impulse response functions for shocks applied to New Zealand prices. The impact of these shocks is much less persistent than that of shocks to ASX prices. ASX prices adjust only marginally and the exchange rate remains largely unaffected.

In Panel B of Fig. 3 we present the impulse response functions for New Zealand domiciled firms. When considering shocks to the exchange rate we find that these are persistent (again leveling off at about 75% of the initial shock) and almost all of the correction for the exchange rate shock occurs in the Australian market. Combined with the findings for the Australian domiciled companies

[5] These results hold for the full period and all subperiods. Results are available on request.

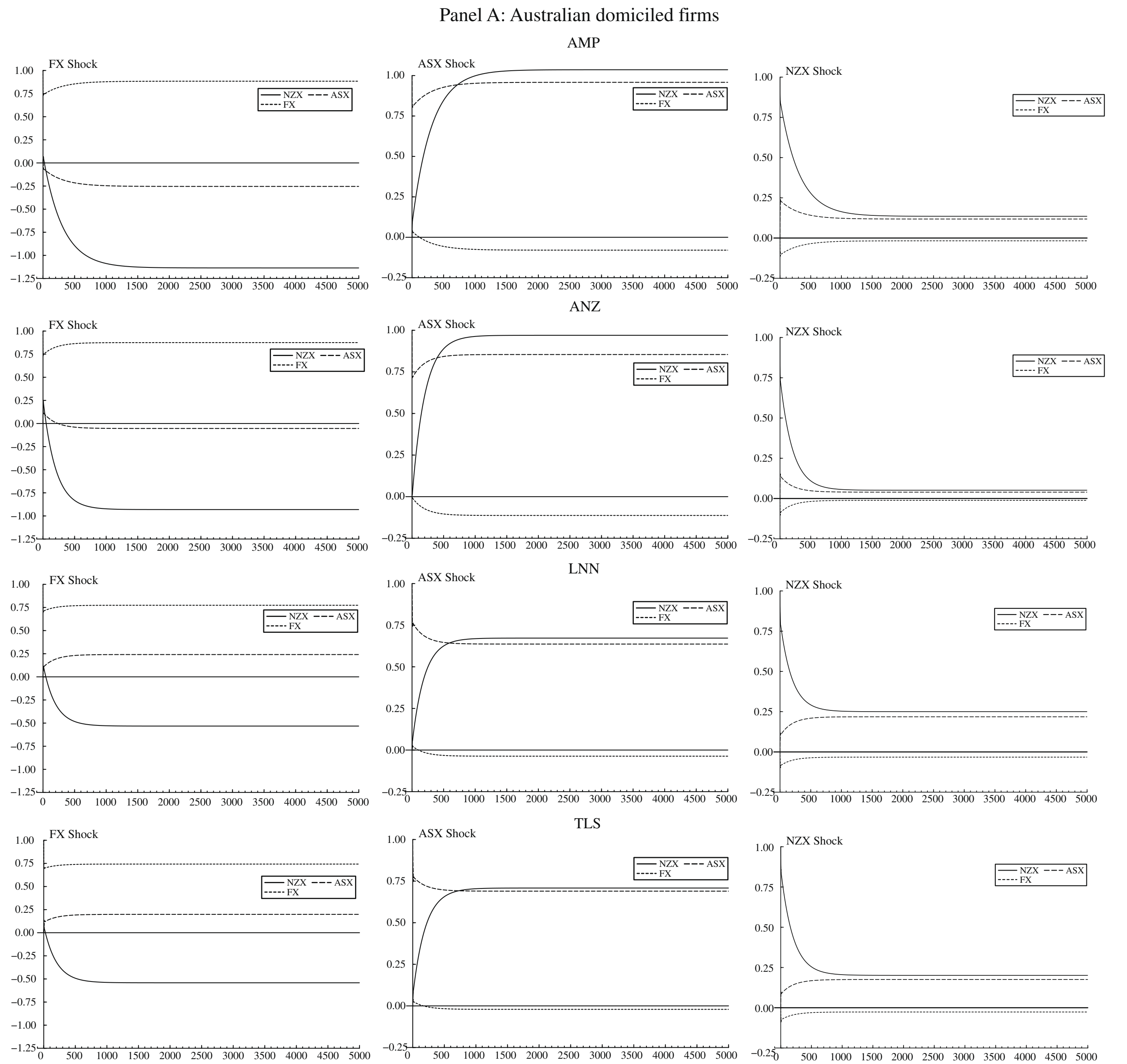

Fig. 3. Impulse response functions.

this shows that the correction for the exchange rate shocks mainly occurs in the foreign market. When applying shocks to Australian prices (column 2), we observe that these shocks have almost no impact on the levels of prices in New Zealand, expect for AIA and TWR, which were also the stocks with the lowest NZX information shares as observed in Table 1. As we observed before, the exchange rate remains unaffected by shocks to Australian prices. Finally, when shocks are applied to New Zealand prices (last column), these shocks are persistent and result in a strong adjustment in the Australian prices towards the New Zealand prices.

5.3. Conditional information shares

The next step in our analysis is to compute the conditional information shares. In Table 4, we report the midpoints of the conditional information shares. Each column represents the market on which quotes react to shocks, and each row refers to the price to which the shock has been applied. We therefore observe that information shares per market (per column) add up to one. For example, the 92.11% for AMP in the first column implies that ASX price changes contribute 92.11% of the price discovery in the ASX. In the second column we observe that the information share for the ASX is 79.84%, which implies that conditional on being in the NZX, the informational role of ASX price shocks is 79.84%. In this case we find that ASX price shocks have a greater impact in the home market than in the foreign market.

Panel A in Table 4 presents the results for the Australian domiciled firms. We find that in all cases the ASX information share is higher in its home market than in the NZX. We further observe that in all cases the ASX prices play a minor or negligible role in the

Panel B: New Zealand domiciled firms

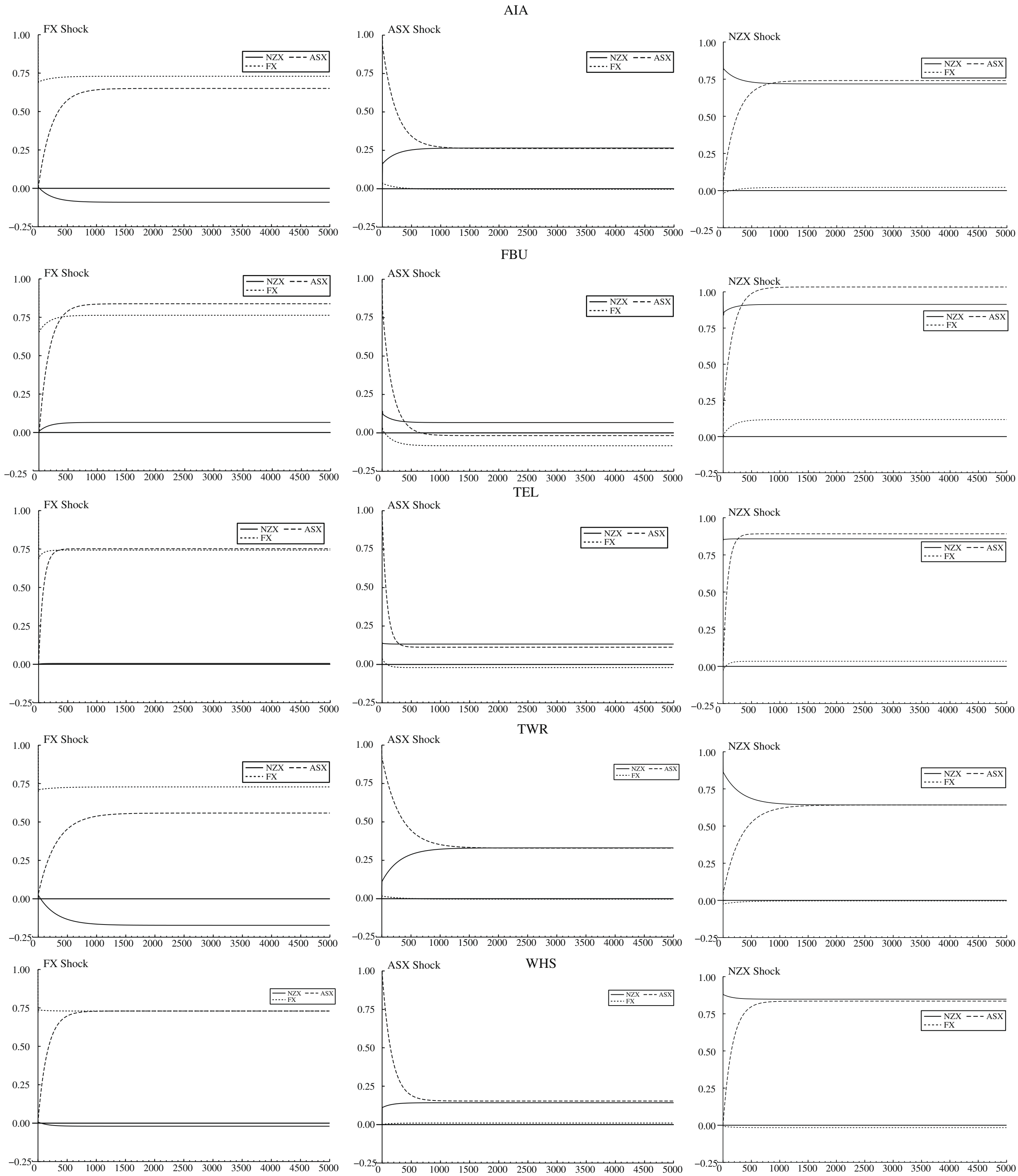

Fig. 3 *(continued)*

determination of the exchange rate. This implies that the exchange rate is largely exogenous with respect to stock prices on the ASX, which is in line with Grammig et al. (2005). The second row of this panel shows the information shares for the NZX. Similar to the ASX prices, we find that information shares are higher in the home markets, but in many cases the difference is only marginal. The exchange rate again appears to be exogenous to NZX price shocks. Comparing the information shares of the ASX to the NZX we find that the ASX dominates in terms of price discovery in both the ASX and the NZX. Hence, although the results change

Table 4
Midpoints of conditional information shares per market.

		ASX (%)	NZX (%)	FX (%)
Panel A: Australian domiciled firms				
AMP	ASX shock	92.11	79.84	4.92
	NZX shock	7.10	7.09	1.52
	FX shock	0.74	12.77	93.73
ANZ	ASX shock	98.20	85.30	8.18
	NZX shock	1.77	2.09	0.93
	FX shock	0.04	12.53	90.82
LNN	ASX shock	84.77	79.71	1.95
	NZX shock	13.89	15.55	2.47
	FX shock	1.38	4.74	95.58
TLS	ASX shock	89.15	81.36	0.63
	NZX shock	10.05	11.85	2.17
	FX shock	0.83	6.82	97.23
Panel B: New Zealand domiciled firms				
AIA	ASX shock	19.38	21.63	0.05
	NZX shock	72.34	78.17	0.39
	FX shock	8.23	0.25	99.53
FBU	ASX shock	3.03	6.90	8.62
	NZX shock	87.40	93.01	9.21
	FX shock	9.09	0.06	82.72
TEL	ASX shock	8.35	12.37	1.31
	NZX shock	80.70	87.59	0.61
	FX shock	11.00	0.05	98.03
TWR	ASX shock	33.62	34.54	0.02
	NZX shock	63.08	65.09	0.07
	FX shock	3.31	0.38	99.91
WHS	ASX shock	11.16	10.40	0.05
	NZX shock	81.80	89.59	0.04
	FX shock	7.04	0.02	99.05

This table reports the midpoints of the conditional information shares. The top row indicates the market in which the information share is measured. The first column reports the market for which the information share is reported.

Table 5
Average conditional information shares per market per year.

	2002	2003	2004	2005	2006	2007
Panel A: Australian domiciled firms						
ASX information shares in market:						
ASX (%)	81.47	89.91	90.25	86.33	81.04	93.11
NZX (%)	74.24	80.61	74.20	80.65	68.97	84.08
FX (%)	0.85	3.89	0.69	12.62	6.86	2.51
NZX information shares in market:						
ASX (%)	17.06	9.71	9.01	12.95	17.45	5.93
NZX (%)	19.94	11.30	11.43	12.24	18.15	6.54
FX (%)	1.62	3.80	4.07	2.65	1.03	0.25
FX information shares in market:						
ASX (%)	1.49	0.40	0.81	0.75	1.55	0.98
NZX (%)	5.88	8.05	14.47	5.15	13.16	9.38
FX (%)	97.60	92.35	95.30	84.71	92.17	97.24
Panel B: New Zealand domiciled firms						
ASX information shares in market:						
ASX (%)	11.51	13.27	17.55	24.50	20.97	26.39
NZX (%)	10.93	15.14	17.91	25.06	22.94	29.16
FX (%)	1.25	5.37	1.30	0.66	2.41	1.98
NZX information shares in market:						
ASX (%)	77.74	79.89	74.17	70.21	69.93	66.17
NZX (%)	88.95	84.66	81.39	74.57	76.22	70.57
FX (%)	0.96	3.87	3.31	2.59	0.91	4.22
FX information shares in market:						
ASX (%)	10.73	6.82	8.26	5.24	9.22	8.22
NZX (%)	0.12	0.21	0.73	0.45	0.95	0.34
FX (%)	97.81	90.85	95.49	96.70	96.66	94.22

This table reports the average conditional information share per market per year. The different blocks in each panel show the information shares of each price in the different markets. For example, the 74.24% in the top panel indicates that ASX prices have an average information share of 74.24% in the NZX.

quantitatively compared to traditional information shares, qualitatively the original results remain. The last row for each stock shows the information shares of the exchange rate. The results indicate that the impact of exchange rate changes on ASX prices is minimal. However, in the NZX market a price adjustment to exchange rate changes could be detected.

Panel B in Table 4 reports the results for the New Zealand domiciled firms. The first row shows the information share of the ASX prices for each stock. We find that the information shares for NZX shocks are on average quite a bit lower than the ASX information shares for the Australian domiciled stocks. Moreover, the ASX information shares are higher in the NZX, indicating the importance of ASX price shocks in the NZX market. The second row shows the NZX information share in the various markets, where we find that NZX information shares are higher in the home market. Finally, we find that all of the exchange rate adjustment occurs in the Australian market.

Overall, these findings are in line with Grammig et al. (2005), where we find that the home market remains dominant, and the foreign market adjusts to movements in the exchange rate.

5.4. Conditional information shares over time

Next we consider how the conditional information shares change over time. Table 5 reports the average conditional information shares per year for each domicile (i.e., we compute the average midpoint of the information shares for Australian and New Zealand domiciled stocks in their respective home market).

Panel A in Table 5 presents the average midpoints of the information shares for the Australian domiciled stocks. First, we consider the importance of ASX prices in the two stock markets and the foreign exchange market (first block in Panel A). The findings confirm the earlier results showing that the information share for ASX prices is higher in the domestic market than in the foreign market. Over time, we observe an upward trend in the information share for ASX prices in the ASX market, indicating the increasing importance for the ASX in the price discovery of Australian domiciled firms. For the information share of ASX prices in the NZX, we also notice an increasing importance for ASX prices. The second block in Panel A of Table 5 shows the information shares for NZX prices. For the NZX information share in both the ASX and the NZX we observe a decrease over time, going from about 17% to 6% in the Australian market and from 20% to 6.5% in the New Zealand market. This again highlights that for Australian domiciled firms the information role of the NZX is diminishing. Finally, we observe that exchange rate movements are only incorporated into the New Zealand prices and that the role of the exchange rate increases in the New Zealand market, again indicating that this market is becoming more of a satellite market for Australian domiciled firms.

Panel B of Table 5 reports the findings for the New Zealand domiciled firms. The first set of results in Panel B reports the information shares for ASX prices. Over time, we observe an increase in the information shares for the ASX in both the Australian and New Zealand market. This highlights that also for New Zealand domiciled firms the ASX is increasing in importance. The second set of results, which presents the findings for the NZX prices, confirms the previous findings, where we find a negative trend for the information shares in the Australian and the New Zealand market. The information share of the NZX decreases from about 78% to 66% in the Australian market and from about 89% to 70.5% in the New Zealand market. The trend confirms that also for New Zealand domiciled firms the importance of the New Zealand market is diminishing, however, information shares are still considerable. Finally, we observe a slight decrease in the role of the exchange rate in the Australian market, but, the Australian market is still the only market that adjusts its prices to changes in the exchange rate.

Overall, these findings show that there is an increasing importance of the Australian market for both Australian and New Zealand domiciled firms, which is at the expense of the New Zealand market. For Australian domiciled firms, the NZX is close to being a pure satellite, for New Zealand domiciled firms, the NZX still contributes most to price discovery, but the information has decreased considerably.

5.5. Explaining the increasing importance of the ASX

The overall increase in the importance of the ASX is in line with Coffee (2002), who argues that the ongoing globalization and increasing technology will lead to the diminution of certain financial markets. To investigate what drives the growing importance of the Australian market we run a panel regression of the information shares on several variables. Although the data set is rather limited (54 observations), it may provide us with some indications. We conduct these regressions by considering the Hasbrouck (1995) information share in the Australian market.

As a first analysis we consider the (logit transformation of the) Australian Hasbrouck (1995) information share and run a panel regression on various explanatory variables, where we control for firm-specific fixed effects. The regression results are presented in Panel A of Table 6. As Chan et al. (2008) suggest there is a link between cross-listing and liquidity, we perform a regression of the logit transformation of the information share on several measures of liquidity, i.e. the (log) number of trades in each market, the percentage bid-ask spread in each market (computed as the absolute spread divided by the price level) and the log of the market capitalization of the firm (measured in Australian dollars), with robust t-statistics in parentheses. The regression results show that only the size of the firm is marginally significant and positive, indicating that large firms tend to have large information shares in the Australian market. However, when we substitute number of trades with (log) volume in the second regression, we find that the significance of the size variable disappears. This can of course be explained by the high correlation between size, volume and also number of trades. In the last column we report the regression results for a model that includes the level of business activity for each firm in the Australian market. It could be that the higher information share in the Australian market is due to a higher percentage of business being conducted in the Australian market. However, this variable turns out to be insignificant.

Although the results presented above provide us with an indication that larger firms tend to have higher ASX information shares, the fit of these models is rather unsatisfactory. Although the overall R^2 is reasonably high, most of the explanatory power comes from differences between companies. In addition, it is possible that information shares contain a unit root. We therefore conduct a second analysis considering the change in the information share and regress this on various variables. These results are presented in Panel B of Table 6.

In the first column we report the results for the regression of the change in the information share on the change in (log) number of trades, the percentage bid-ask spread and the change in (log) market value (in Australian dollars) with robust t-stats in parentheses. This model reveals some interesting results. First, we find that a

Table 6
Panel regression results for ASX information shares.

	(1)	(2)	(3)
Panel A: Panel regression on levels			
Constant	−5.307	−9.503	−5.930
	(−0.92)	(−1.38)	(−1.04)
Log Trades (ASX)	−0.2762		−0.4308
	(−0.74)		(−1.07)
Log Trades (NZX)	−0.3622		−0.0128
	(−0.55)		(−0.02)
Log Volume (ASX)		0.0791	
		(0.40)	
Log Volume (NZX)		0.1420	
		(0.81)	
%BA (NZX)	33.47	36.94	51.11
	(0.83)	(1.02)	(1.13)
%BA (ASX)	−2.776	18.09	−5.225
	(−0.10)	(0.81)	(−0.17)
Log MV	0.8794*	0.7447	0.8465*
	(1.92)	(1.19)	(1.79)
Business			0.0108
			(1.02)
R^2 (within)	0.0948	0.0707	0.0948
R^2 (between)	0.5496	0.4259	0.1580
R^2 (overall)	0.4908	0.3805	0.1869
Panel B: Panel regression on first differences			
Constant	0.0357	0.0176	0.0372
	(0.87)	(0.37)	(0.90)
DLog Trades (ASX)	−0.0306		−0.0315
	(−0.73)		(−0.74)
DLog Trades (NZX)	0.1032		0.0809
	(1.24)		(0.92)
DLog Volume (ASX)		0.0133	
		(0.50)	
DLog Volume (NZX)		0.0109	
		(0.26)	
%BA (NZX)	5.000	4.695	4.931
	(1.63)	(1.29)	(1.57)
%BA (ASX)	−8.1652***	−7.290***	−8.611***
	(−4.46)	(−3.43)	(−4.49)
DLog MV	0.1600***	0.1699***	0.1830***
	(2.91)	(3.60)	(3.25)
DBusiness			0.0002
			(0.90)
R^2 (within)	0.3434	0.3270	0.3835
R^2 (between)	0.0376	0.0378	0.0234
R^2 (overall)	0.1330	0.1328	0.1367

This table report (fixed effects) panel regression results for information shares on various variables. Panel A reports results using a logit transformation of the Hasbrouck (1995) information shares in the Australian market (i.e. $\log\left(\frac{IS_{ASX}}{(100-IS_{ASX})}\right)$). Panel B reports the results using the change in the ASX information as the dependent variable. Robust *t*-statistics are presented in parentheses.
* Significance is 10% level.
** Significance is 5% level.
*** Significance is 1% level.

drop in the spread in the Australian market leads to an increase in the information share of the ASX. The percentage spread in the NZX remains insignificant. This indicates that a decrease in the trading costs in the Australian market strongly affects its informational role. Second, a change in the size of the company has a positive and significant impact on the Australian information share, indicating that as a firm grows, the importance of the Australian market increases, and vice versa. Substituting number of trades with trading volume does not alter the results, coefficients remain significant and of similar magnitude. The last column shows the results when we include changes in the level of business activity. This variable is insignificant, indicating that the change in the information shares is not due to a change in the level of business activity in Australia. When we consider the within R^2's of these regressions, we see that these R^2's are considerably larger than those reported in Panel A of Table 6, indicating that the change in the information shares over time can much better be explained rather than the level of the information shares over time.

6. Conclusion

In this paper we study price discovery for cross-listed stocks on both the Australian and the New Zealand stock exchange. Doing so, we contribute to the existing literature in several ways. First, we study price discovery for bilaterally cross-listed stocks in these markets, i.e., we consider Australian stocks cross-listed in New Zealand, and New Zealand stocks cross-listed in Australia. Second, we study price discovery in markets with a much larger overlap in trading hours than is typically considered. Third, we include the exchange rate in the price discovery model as suggested by Grammig et al. (2005). And fourth, we investigate price discovery dynamics over time.

We find several interesting results. First, in line with previous research, we find a clear dominance in terms of price discovery for the home market, in either a single currency or by following Grammig et al.'s (2005) approach. We conclude that while the ASX is much larger than the NZX, price discovery is not dominated by the ASX. Second, when considering Hasbrouck (1995) information shares over time we find that the ASX has become more important for both Australian and New Zealand domiciled firms. A further decomposition using Grammig et al.'s (2005) approach reveals that this growing importance is present in both the price discovery in the ASX and the NZX. Furthermore, we find that for Australian domiciled stocks, more and more of the exchange rate adjustment goes into the NZX prices, while for New Zealand domiciled stocks the exchange rate adjustment in the ASX prices decreases slightly. When studying the cause of the growing importance of the ASX and the demise of the NZX we note that the growth in the ASX information shares is mainly attributed to size (larger companies tend to have higher ASX information shares) and trading costs (lower spreads in the ASX tend to cause higher ASX information shares). This last finding is in line with the cross-sectional findings of Eun and Sabherwal (2003).

Overall our results suggest that while home markets still dominate in terms of price discovery, over time there is seems to be a shift in price discovery from the smaller market to the larger one. Our findings are broadly in line with Coffee (2002) who predicts the demise of smaller exchanges at the gain of larger ones. From a market perspective this suggests that the NZX is taking on more and more features of a pure satellite market.

Acknowledgements

We would like to thank the editor, Ike Mathur and two anonymous referees for their useful comments and suggestions on an earlier version of the paper that was circulated as "Price Discovery, Cross-listings and Exchange Rates: Evidence from Australia and New Zealand". We would also like to acknowledge the comments of conference participants at the European Financial Management Association meeting (Barcelona, 2007), the New Zealand Finance Colloquium (Palmerston North, 2008) and the Australian Banking and Finance Conference (2008).

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