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PRICE DISCOVERY FOR CROSS-LISTED STOCKS[1]

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We investigate price discovery for internationally traded stocks. For a sample of Canadian stocks cross-listed on the Toronto Stock Exchange (TSE) and the NYSE, we find that both markets contribute to price discovery. The US share of price discovery ranges from 0.4% to 98.1%, and averages 36%. The US contribution is directly related to the US share of trading and to the ratio of proportions of informative trades on the NYSE and the TSE, and inversely related to the ratio of bid–ask spreads on the NYSE and the TSE. In response to a positive shock to the C$/US$ exchange rate, stock prices on the TSE rise, whereas those on the NYSE decline. The NYSE bears a much greater burden of adjusting to the exchange rate changes.

With the ongoing globalization of financial markets, the number of international firms cross-listing shares on US stock exchanges has substantially increased. This reflects both the desire of foreign firms to expand their shareholder bases in the US and the conscious efforts of US exchanges to attract international listings. The popularity of international cross-listings has prompted many academic studies on the topic.[2] Most of these studies focus on the benefits of cross-listings, including the reduced cost of capital, increased investor recognition, and the enhanced liquidity of a firm's stock. Studies such as Alexander *et al.* (1987, 1988) and Henry (2000) suggest that the cost of capital declines upon cross-border listings because a more efficient risk sharing leads to lower risk premiums for equity investments. Foerster and Karolyi (1999) propose increased investor recognition as another possible explanation. Investors tend to invest in the securities they know about, and cross listing on a US exchange is an effective way of making foreign stocks familiar to US investors. Domowitz *et al.* (1998) suggest that the liquidity effect of cross-listings is complex and depends on the degree of quote transparency.

The aforementioned studies, however, have not addressed the following important question: Do

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international cross-listings of stocks contribute to the price discovery of these stocks? In view of the increasing popularity of international cross-listings, the extent to which the US stock exchange is contributing to the price discovery of non-US stocks is of considerable importance. Price discovery, i.e. the search for an equilibrium price, is a key function of stock exchanges. When a non-US stock trades on a US exchange, it is not clear what to expect regarding the relative extent of price discovery. On the one hand, the non-US stock exchange is likely to contribute substantially to price discovery, as it is the security's home market where substantial information is expected to be produced. On the other hand, the dominance of the US stock exchanges as among the largest and most liquid exchanges in the world suggests that they are also likely to contribute significantly to price discovery. The home and US exchanges thus may compete against each other for a dominant role in the price discovery for cross-listed securities. The international competition for price discovery for cross-listed stocks can be illustrated by the following quote from a report produced by the Toronto Stock Exchange (TSE) Board of Governors: "The TSE cannot afford to have the US markets become the price discovery mechanism for Canadian interlisted stocks."[3]

A key objective of this study is to examine the extent to which a US stock exchange contributes to the price discovery of US-listed international stocks. In particular, we look at the price discovery of Canadian stocks that are dually listed on the TSE and the NYSE. Another objective of our study is to analyze the factors that affect the extent of the US stock exchange's contribution to price discovery. Our focus here will be on the effects of relative trading volume, transaction costs, and the proportion of informative trading on the NYSE versus the TSE. The third main objective of this study is to examine how stock prices in the US and the home market adjust to a change in the US dollar exchange rate of the foreign currency. If the exchange rate changes such that the foreign currency depreciates (appreciates) relative to the US dollar, either the cross-listed stock's price in the US should go down (up), or the price in the non-US market should go up (down), or both. Specifically, for Canadian stocks cross-listed in the US, we examine where stock price adjustments occur in response to changes in the C$/US$ exchange rate. Whether it is the US or the Canadian stock market that bears the burden of adjusting to changes in the exchange rate is empirically an open question.

Our choice of Canadian stocks in this study is motivated by several reasons. First, the Canadian stocks represent the largest group of stocks listed in the US from a single country. Therefore, their study provides the best opportunity for a cross-sectional analysis of the determinants of relative price adjustments in the home and US markets, while holding the nationality of shares constant. Second, many of them trade actively in both the US and Canada, which is essential for conducting intraday analyses. Third, the trading time of the TSE coincides with that of the NYSE, 9:30 a.m. to 4:00 p.m. Eastern Time. Since we need prices observed at the same time in the two markets, the Canadian stocks offer a distinct advantage over cross-listed stocks from Europe or Asia for which there is little or no overlapping trading time between the home market and the US market. Finally, Canadian stocks are listed in the US as ordinary shares, whereas stocks from other countries are usually listed as American depositary receipts (ADRs). Canadian ordinaries trading in the US are more fungible with the home market securities than the ADRs.

The TSE has some institutional features similar to those of the NYSE. Like the NYSE, the TSE is an auction market where buy and sell orders are channeled into a central location and matched at the best available price. At the TSE, each stock is assigned to a registered trader who acts as the market maker in a security. This system resembles the specialist system at the NYSE.

In contrast to the NYSE where the trading occurs on the trading floor, the trading environment at TSE is floor-less and completely electronic. All trading takes place through the Computer Assisted Trading System (CATS). The order book at the TSE is open to subscribers. The Market-By-Price display offered by the TSE to subscribers shows the price and aggregate size of orders on the TSE book at the market and up to four price levels away, on both sides of the market. In contrast, at the time of this study, the contents of the order book at the NYSE were not open to traders. The TSE adopted decimal trading in 1996, much earlier than the NYSE. For most stocks trading on TSE, the tick is C$0.05 or 5 Canadian cents. The NYSE had not adopted decimal trading at the time of this study, and the tick size for most stocks was US$1/16 or 6.25 US cents. Overall, the TSE had greater transparency due to the open order book, and a smaller tick size and consequently smaller bid–ask spreads, due to decimal pricing and due to 1 US cent being almost 1.5 Canadian cents.

The rest of the paper is organized as follows. In Section 1, we discuss the sample details and perform preliminary data analysis. We discuss price discovery and the error correction model in Section 2. In Section 3, we provide details of the cross-sectional analysis. In particular, we discuss our measure of the US feedback to the TSE based on the estimates in Section 2, our hypotheses regarding the determinants of the extent of this feedback, and results of the regression analysis used to test these hypotheses. In Section 4, we analyze adjustments to exchange rate changes. Section 5 provides concluding remarks.

1 Sample details and preliminary data analysis

1.1 Sample details

We begin our sample selection with a set of 60 Canadian firms that traded on the TSE and the NYSE throughout the 6 month study period of February 2 to July 31, 1998, and had a trading history of at least 3 months preceding the study period. The markets do not seem to be particularly noteworthy during this period, and show a general upward trend consistent with the stock market performance during the 1990s. During the study period, there are 124 days for which both the TSE and the NYSE are open. We use the NYSE Trade and Quote (TAQ) database and a similar TSE database to get the intraday data for the firms for these days. To provide sufficient observations for intraday analysis and inference, we exclude 20 thinly traded stocks. We consider thinly traded stocks as those with fewer than 2000 trades during the 6 month study period on either the TSE or the NYSE. Since the stock splits in Canada and the US can differ by a few days, we exclude two stocks that split during the study period. Our final sample consists of 38 firms.

Table 1 provides the basic details of the sample firms. Our sample includes such well-known firms as Canadian Pacific, Northern Telecom, and Seagram Co. Of the 38 firms, a maximum of eight are in mining. The average market capitalization of C$6.9 billion is significantly larger than the median market capitalization of C$3.9 billion, reflecting the presence of a few very large firms such as Northern Telecom and BCE. There is a large variation in the US share of trading volume, which ranges from about 3% to 83%. Consistent with Pulatkonak and Sofianos (1999), who find that US trading in non-US stocks from the financial services sector is much lower than that of stocks from other industries, the three banks in the sample have the lowest proportion of trading in the US Collectively, the TSE faces stiff competition from the NYSE,

Table 1 Sample details.

Company	Business	MktCap (C$ mil.)	Price (C$)	SharesTraded (mil.) TSE	SharesTraded (mil.) NYSE	% trading on NYSE
Abitibi-Consolidated Inc.	Paper	3876	20.68	63.42	19.27	23.3
Agnico-Eagle Mines Ltd.	Mining	319	8.81	10.44	11.68	52.8
Agrium Inc.	Chemicals	2206	20.13	55.26	32.07	36.7
Alcan Aluminum Limited	Mining	9212	43.32	59.82	44.21	42.5
Bank of Montreal	Banking	17,762	78.18	81.12	2.58	3.1
Barrick Gold Corporation	Mining	9943	28.89	177.20	185.62	51.2
BCE Inc.	Telecommunications	31,383	59.65	210.61	29.10	12.1
Biovail Corporation International	Pharmaceuticals	1398	55.68	5.88	28.31	82.8
Canadian National Railway Co.	Transportation	5723	85.50	27.58	28.07	50.4
Canadian Pacific Limited	Transportation	13,198	41.07	78.83	63.49	44.6
Four Seasons Hotels Inc.	Lodging	1319	49.25	2.77	9.92	78.2
Gulf Canada Resources Limited	Oil & gas	3731	7.42	85.81	129.89	60.2
Inco Limited	Mining	4980	24.09	60.91	57.48	48.6
Intrawest Corporation	Lodging	917	26.99	7.52	2.76	26.9
Kinross Gold Corporation	Mining	623	5.69	127.66	10.69	7.7
Laidlaw Inc.	Environmental control	5891	18.27	255.62	50.09	16.4
Loewen Group Inc. (The)	Funeral services	2975	35.53	21.19	39.26	64.9
Magna International Inc.	Motor vehicles	6407	98.68	19.16	43.41	69.4
Meridian Gold Inc.	Mining	294	5.54	22.40	5.10	18.5
Mitel Corporation	Electronics	1240	19.67	70.96	8.69	10.9
Moore Corporation Limited	Business supplies	1902	21.69	35.42	20.36	36.5
Newbridge Networks Corporation	Networking products	8774	35.48	119.67	143.98	54.6
Newcourt Credit Group Inc.	Financing	5389	69.09	51.74	19.31	27.2
Northern Telecom Limited	Switching equipment	33,783	84.67	108.74	163.40	60.0
Philip Services Corp.	Environmental control	2677	9.91	37.79	186.75	83.2
Placer Dome Inc.	Mining	4500	18.46	116.50	100.58	46.3
Potash Corp. of Saskatchewan Inc.	Fertilizers	6405	124.56	8.45	19.78	70.1
Precision Drilling Corporation	Oil & gas	1458	28.15	24.50	22.32	47.7
Ranger Oil Limited	Oil & gas	1222	9.48	49.42	14.43	22.6
Rogers Cantel Mobile Comm. Inc.	Telecommunications	235	14.17	6.21	3.00	32.6

Table 1 (*continued*)

Company	Business	MktCap (C$ mil.)	Price (C$)	SharesTraded (mil.) TSE	SharesTraded (mil.) NYSE	% trading on NYSE
Royal Bank of Canada	Banking	25,099	85.52	87.57	3.54	3.9
Royal Group Technologies Ltd.	Construction	1894	40.79	9.46	8.10	46.1
Seagram Company Ltd. (The)	Beverages	16,408	58.48	52.84	90.15	63.0
Toronto-Dominion Bank (The)	Banking	16,535	64.02	131.96	4.19	3.1
Trizec Hahn Corporation	Real Estate	4910	33.31	33.17	22.21	40.1
TVX Gold Inc.	Mining	792	4.74	53.58	64.15	54.5
United Dominion Industries Ltd.	Engineering equip.	1581	43.67	10.62	6.25	37.0
Westcoast Energy Inc.	Utility	3991	33.80	29.67	3.55	10.7
Average		6867	39.82	63.46	44.68	40.5
Median		3934	33.56	52.29	22.27	43.6

The variable MktCap is the market capitalization reported in the *TSE Factbook, 1997*; Price is the average (weighted by the number of shares traded) of the price paid on all trades on TSE during the 6 month study period; SharesTraded are the total shares traded during this period; and % trading on NYSE is the shares traded on the NYSE as a percentage of total shares traded on the NYSE and TSE.

with the average (median) value of the percentage of shares traded on the NYSE being 40.5% (43.6%).

1.2 *Preliminary data analysis*

An analysis of a cross-listed stock trading in two markets can be based on either transaction prices or quoted prices. We perform the analyses in this study using both transaction and quoted prices. Since the use of transaction prices is likely to suffer from an autocorrelation problem induced by infrequent trading, while quotes can be updated in the absence of trades, we focus on the results based on regularly spaced quotes. However, we also briefly discuss the results based on transaction prices at the end of the next section.

For each sample stock, we form the two price series for quotes-based analysis by selecting the midpoint of the last bid and ask quotes in each market at 10 minute intervals. So, for each stock, we have 39 prices per day in each market, or 4836 observations for the study period of 124 trading days. After forming the series of prices on the TSE in C$ and the NYSE in US$, we convert the NYSE prices to C$. This facilitates the specification of the error correction term in error correction models, and the assessment of equality of prices on the NYSE and TSE. The exchange rate dataset that we use is from *Olsen & Associates*, Switzerland. It includes all the quotes that appear on the interbank Reuters network, and has almost 60,000 valid exchange rate quotes during the study period, at an average of 1.2 quotes per minute. From these quotes, we form a series of exchange rates by selecting the midpoint of the last bid and ask quotes that appear at every 10 minute interval. During our study period, the exchange rate was fairly stable.

We expect the TSE and NYSE prices of a Canadian cross-listed stock to be non-stationary. However, we do not expect them to diverge without bound from each other, because they are the prices of the same security trading at two locations. Formally, we expect the two price series for each stock j, $P_{j,t}^{\mathrm{TSE}}$ and $P_{j,t}^{\mathrm{NYSE}}$, to be cointegrated.[4] The concept of cointegration becomes relevant when the time series being analyzed are non-stationary but are integrated of the same order. In particular, two time series x_t and y_t are both integrated of order one, denoted as I(1), if they are both non-stationary but their changes are stationary. Then, x_t and y_t are cointegrated if there exists a linear combination $z_t = y_t - Ax_t$, which is stationary, denoted as I(0). Therefore, before analyzing cointegration between prices of our sample stocks on the TSE and the NYSE, we check if the two price series for each stock are I(1). Using the augmented Dickey Fuller test, we conclude that both price series for each of the sample stocks are I(1).

Having confirmed that for each sample stock, P_t^{TSE} and P_t^{NYSE} are I(1), we test for their cointegration, that is, if there exists a vector $\beta = (\beta^{\mathrm{TSE}}, \beta^{\mathrm{NYSE}})$ such that $\beta^{\mathrm{TSE}} P_t^{\mathrm{TSE}} + \beta^{\mathrm{NYSE}} P_t^{\mathrm{NYSE}}$ is I(0). Moreover, if such a vector exists, we expect its normalized estimate to be $(1, -1)$ reflecting the equality of prices on the TSE and the NYSE, i.e. $P_t^{\mathrm{TSE}} = P_t^{\mathrm{NYSE}}$ or $P_t^{\mathrm{TSE}} - P_t^{\mathrm{NYSE}} = 0$. A reason we expect the prices of the US-listed Canadian stocks in the two markets to be very close to one another is that the Canadian cross-listed stocks in the US trade as 'ordinaries', and traders can execute trades in these stocks in both the countries. There is also a relative absence of capital controls between the two markets.

We use the Johansen (1988) method for the above analysis. For each sample stock, we find that P_t^{TSE} and P_t^{NYSE} are cointegrated, with a single cointegrating vector.[5] Thus, the TSE and NYSE prices of cross-listed stocks tend to move together. The estimates of the cointegrating vector, normalized so that β^{TSE} equals one, range from $(1, -0.9994)$ to $(1, -1.0001)$, confirming that the prices of our sample firms tend to be equal on the two exchanges. Overall, the cointegration results suggest that the TSE and NYSE prices of cross-listed Canadian

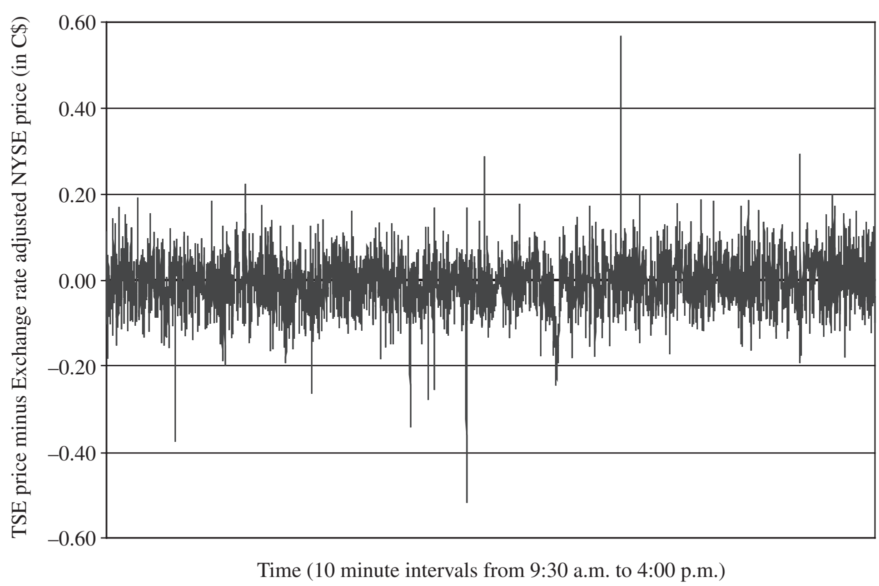

Figure 1 Difference between the TSE price and the exchange rate adjusted NYSE price: Alcan Aluminum Limited.

stocks do not diverge without bound from each other, and any difference in the two prices tends to be subsequently corrected by the two prices moving towards each other. To further investigate equality of prices, we compute the average of the absolute difference in prices on the NYSE and TSE for each firm as a percentage of the firm's stock price on the TSE. Across all 38 firms in the sample, the average (median) absolute difference in prices is only 0.24% (0.18%) of the stock price on the TSE. We also examine the equality of prices visually in Figure 1 by plotting the difference between the TSE price and the exchange rate adjusted price on the NYSE for one of the sample firms, Alcan Aluminum Limited.[6] The absolute difference is mostly less than C$ 0.20, and averages to only 0.11% of the stock price on the TSE.

2 Error correction and price discovery

The results in the previous section indicate that any difference between the TSE and NYSE prices of sample stocks tends to be subsequently corrected. Accordingly, for each sample stock, we now estimate the following generalized error correction model, which includes the lagged changes of prices, and the error correction term (ECT) specified as the difference between the two prices, $P_{t-1}^{\text{TSE}} - P_{t-1}^{\text{NYSE}}$. Multivariate Schwarz Bayesian criterion to determine the number of lags p reveals optimal lags to be one or two for the sample firms.

$$\Delta P_t^{\text{TSE}} = a_0^{\text{TSE}} + \alpha^{\text{TSE}}(P_{t-1}^{\text{TSE}} - P_{t-1}^{\text{NYSE}}) + \sum_{i=1}^{p} \gamma_i \Delta P_{t-i}^{\text{TSE}} + \sum_{i=1}^{p} \delta_i \Delta P_{t-i}^{\text{NYSE}} + \varepsilon_t^{\text{TSE}} \quad (1)$$

$$\Delta P_t^{\text{NYSE}} = a_0^{\text{NYSE}} + \alpha^{\text{NYSE}}(P_{t-1}^{\text{TSE}} - P_{t-1}^{\text{NYSE}}) + \sum_{i=1}^{p} \phi_i \Delta P_{t-i}^{\text{TSE}} + \sum_{i=1}^{p} \theta_i \Delta P_{t-i}^{\text{NYSE}} + \varepsilon_t^{\text{NYSE}} \quad (2)$$

In the above model, the changes in prices on the TSE and the NYSE (i.e. ΔP_t^{TSE} and ΔP_t^{NYSE}) depend not only on the changes in prices on the two exchanges in the previous periods (i.e. $\Delta P_{t-i}^{\text{TSE}}$ and $\Delta P_{t-i}^{\text{NYSE}}$) but also on the difference between the prices in the two markets in the preceding period (i.e. the error correction term, $P_{t-1}^{\text{TSE}} - P_{t-1}^{\text{NYSE}}$). The estimates of α^{TSE} and α^{NYSE} indicate the extent to which the price series respond to a deviation from the equality of the two price series. Either or both P_t^{TSE} and P_t^{NYSE} must respond to the magnitude of the departure. On the one hand, as the TSE is the home-market of the sample stocks, we expect the NYSE prices to respond to the TSE prices, and adjust to some extent to the departure. On the other hand, as the US is a leading financial center in the world and an important business venue for the Canadian firms, we expect some feedback from the NYSE to the TSE.

As per the above discussion, the coefficients of main interest are α^{TSE} and α^{NYSE}. Consider the situation in which $P_{t-1}^{\text{TSE}} > P_{t-1}^{\text{NYSE}}$. One likely way in which the gap between the two prices could reduce is that, at time t, P^{TSE} declines and P^{NYSE} increases.[7] Accordingly, α^{TSE} should be negative and α^{NYSE} should be positive. The same signs would be expected in the situation in which $P_{t-1}^{\text{TSE}} < P_{t-1}^{\text{NYSE}}$. Table 2 provides the estimates of the coefficients for the error correction term.

All coefficients have the expected signs: α^{TSE} values are negative and α^{NYSE} values are positive. For 37 of the 38 sample firms, α^{NYSE} is statistically significant. Thus, the NYSE prices of all the firms except one respond to deviations from the TSE prices. The sole exception is Biovail Corporation, for which 83% of the total trading takes place on the NYSE. For all but four of the sample firms, α^{TSE} is statistically significant. Thus, the TSE prices of 34 of the 38 sample firms respond to deviations from the NYSE prices. The four firms whose TSE prices are not affected by the NYSE prices include BCE Inc.

Table 2 Error correction models.

	α^{TSE}		α^{NYSE}	
Company	Coefficient	t-stat	Coefficient	t-stat
Abitibi-Consolidated Inc.	−0.077	−4.06	0.366	18.72
Agnico-Eagle Mines Ltd.	−0.144	−10.46	0.170	11.96
Agrium Inc.	−0.091	−5.46	0.293	16.45
Alcan Aluminum Limited	−0.228	−7.87	0.427	14.42
Bank of Montreal	−0.002	−0.08	0.623	24.14
Barrick Gold Corporation	−0.237	−5.93	0.520	12.81
BCE Inc.	−0.027	−0.64	0.845	20.60
Biovail Corporation International	−0.450	−18.31	0.009	0.36
Canadian National Railway Co.	−0.159	−6.15	0.458	18.02
Canadian Pacific Limited	−0.216	−6.95	0.493	15.95
Four Seasons Hotels Inc.	−0.343	−19.80	0.126	7.85
Gulf Canada Resources Limited	−0.171	−10.27	0.278	15.34
Inco Limited	−0.206	−9.30	0.326	14.41
Intrawest Corporation	−0.145	−13.68	0.075	8.96
Kinross Gold Corporation	−0.049	−3.92	0.200	14.34
Laidlaw Inc.	−0.110	−4.67	0.494	20.52
Loewen Group Inc. (The)	−0.222	−9.05	0.189	7.30
Magna International Inc.	−0.133	−7.69	0.126	7.81
Meridian Gold Inc.	−0.071	−7.18	0.084	9.24
Mitel Corporation	−0.037	−1.97	0.351	18.80
Moore Corporation Limited	−0.121	−6.04	0.416	22.32
Newbridge Networks Corporation	−0.300	−8.80	0.718	26.44
Newcourt Credit Group Inc.	−0.136	−3.91	0.553	16.71
Northern Telecom Limited	−0.273	−5.13	0.487	8.96
Philip Services Corp.	−0.232	−8.37	0.239	8.81
Placer Dome Inc.	−0.177	−5.05	0.513	14.23
Potash Corp. of Saskatchewan Inc.	−0.421	−19.72	0.157	9.21
Precision Drilling Corporation	−0.173	−7.03	0.352	14.42
Ranger Oil Limited	−0.126	−9.40	0.227	15.47
Rogers Cantel Mobile Comm. Inc.	−0.171	−12.59	0.114	11.45
Royal Bank of Canada	−0.016	−0.49	0.710	24.30
Royal Group Technologies Ltd.	−0.210	−14.61	0.174	12.72
Seagram Company Ltd. (The)	−0.132	−4.47	0.154	5.64
Toronto-Dominion Bank (The)	−0.035	−1.00	0.826	24.88
Trizec Hahn Corporation	−0.132	−9.49	0.177	12.05
TVX Gold Inc.	−0.089	−6.93	0.281	17.87

Table 2 (*continued*)

Company	α^{TSE} Coefficient	α^{TSE} t-stat	α^{NYSE} Coefficient	α^{NYSE} t-stat
United Dominion Industries Ltd.	−0.124	−7.54	0.194	14.56
Westcoast Energy Inc.	−0.222	−13.48	0.259	19.54
Average	−0.163		0.342	
Median	−0.145		0.287	

We estimate the error correction model in Eqs. (1) and (2) for each firm. The multivariate Schwarz Bayesian criterion is used to determine the number of lags p.

and the three banks in the sample, namely, the Bank of Montreal, the Royal Bank of Canada, and The Toronto Dominion Bank. On average, only 5.5% of the total trading in these four firms takes place on the NYSE. Overall, the results imply that, in general, both prices respond to a departure from equality. Thus, both the TSE and the NYSE contribute to price discovery. As expected, the average (median) value of α^{NYSE} of 0.342 (0.287) is greater than the average (median) value of $|\alpha^{TSE}|$ of 0.163 (0.145). For a majority of the firms (30 out of 38), α^{NYSE} is greater than $|\alpha^{TSE}|$.

In contrast to the purely domestic studies on price discovery, which find that the NYSE consistently dominates the regional exchanges, the above results are mixed. The TSE is dominant for a majority of the firms, but there are many firms (eight) for which the NYSE is dominant. As reflected in the average and median values of α^{NYSE} and $|\alpha^{TSE}|$ for the sample, the extent to which the TSE prices respond to the NYSE prices is substantial. Overall, there is strong evidence that considerable price discovery for the US-listed Canadian stocks takes place not only in their home market but in the US as well.

2.1 *Analysis based on transaction prices*

The use of transaction prices is likely to suffer from the problem of infrequent or non-synchronous trading. To minimize this problem, we use the minimal span procedure detailed in Harris *et al.* (1995). In this procedure, synchronous pairs of data are formed for each stock by selecting those trades on the NYSE and TSE, which chronologically follow one another. Span refers to the time between the two trades (one on each exchange) forming the pair. By applying the minimal span procedure, we are able to get an adequate number of pairs for each firm, and the span between the two trades in a pair is low. On average, each firm has 10,013 pairs of prices. The average span is 124 seconds while the median span is quite low at 41 seconds.

After forming the pairs of transaction prices on the NYSE and TSE, we convert the NYSE prices to C$ by using the intraday exchange rate dataset to select the exchange rate closest to the transaction time. We then confirm that the NYSE and TSE transaction prices in C$ are cointegrated, with a single cointegrating vector. The estimates of the normalized cointegrating vector range from $(1, -0.999)$ to $(1, -1.000)$, reflecting the equality of prices on the two exchanges. In fact, the average (median) of the absolute difference in the NYSE and TSE prices across all pairs of trades for the sample firms is only 0.16% (0.08%). Based on these results and similar results earlier using quoted prices, there is no evidence of arbitrage opportunities between the two markets.

We also estimate the error correction model in Eqs. (1) and (2) using the series of transaction prices. As with the quoted prices, all coefficients have the expected signs; α^{TSE} values are negative and α^{NYSE} values are positive. The coefficient α^{NYSE} is statistically significant for all sample firms. The coefficient α^{TSE} is statistically significant for all firms except The Toronto Dominion Bank, for which only 3.1% of the total trading takes place on the NYSE. The average (median) value of α^{NYSE} of 0.242 (0.233) is greater than the average (median) value of $|\alpha^{\text{TSE}}|$ of 0.169 (0.154). For 28 out of 38 firms, α^{NYSE} is greater than $|\alpha^{\text{TSE}}|$. Overall, the transaction prices based results are consistent with the quoted prices based results, and provide further support to the conclusion that the NYSE substantially contributes to the price discovery of the sample stocks.

3 Determinants of price discovery: cross-sectional analysis

We have seen that the extent of feedback provided by the NYSE to the TSE varies considerably across firms. In this section, we analyze the determinants of the variation. We first discuss our measure of the NYSE feedback to the TSE, which is later used as the dependent variable in the cross-sectional regressions. We then discuss our explanatory variables and the associated hypotheses, followed by the statistics of explanatory variables and the regression results.

3.1 Dependent variable

The coefficients $|\alpha^{\text{TSE}}|$ and α^{NYSE} of the error correction terms, estimated in the previous section, can be interpreted as the average adjustment of each series towards the other in order to restore the equality of the two prices. As an example, consider Alcan Aluminum Limited. The coefficient α^{TSE} is -0.228 and α^{NYSE} is 0.427, both of which are significant at the 1% level. So, if P_t^{TSE} is greater than P_t^{NYSE} by 1%, price adjustments take place such that P_t^{TSE} declines by 0.228% and P_t^{NYSE} increases by 0.427%. Though a majority of the total adjustment occurs on the NYSE, there is a significant error correction that takes place on the TSE as a result of the feedback provided by the NYSE prices.

The proportion of the total adjustment that occurs at the TSE can be considered as a measure of the price adjustment that takes place due to the trading of the security on the NYSE. We define this variable as $\text{TseAdj} = |\alpha^{\text{TSE}}|/(|\alpha^{\text{TSE}}| + \alpha^{\text{NYSE}})$. A higher value of this ratio reflects a greater feedback or contribution from the NYSE. If there is no feedback from the NYSE, then α^{TSE} is zero, and TseAdj is zero. In this case, the NYSE is not contributing to price discovery; it is a "pure satellite" of the TSE, as only the NYSE prices move toward the TSE prices. Values of TseAdj greater than zero imply feedback from the NYSE to the TSE. We use TseAdj as our dependent variable. Table 3 provides the firm-wise values of this variable, computed based on the values of α^{TSE} and α^{NYSE} reported in Table 2. The average TseAdj across our 38 sample firms is 36% and the median is 35.3%.[8] Thus, the NYSE contributes substantially to the price discovery of these stocks.

3.2 Explanatory variables

3.2.1 NYSE share of trading volume

In a study of the NYSE contribution to price discovery relative to the regional exchanges for the 30 Dow stocks, Hasbrouck (1995) finds a positive correlation between the NYSE contribution to price discovery and its market share by trading volume. Similarly, we expect TseAdj, the TSE share of total adjustment in prices in response to deviations from equality between the TSE and NYSE prices, to be

Table 3 Cross-sectional regression related variables.

Company	TseAdj (%)	NyVol (%)	NySp (%)	TseSp (%)	Spread-Ratio	Medium-Trade	Years-Listed	MktCap (C$ mil.)
Abitibi-Consolidated Inc.	17.4	23.3	0.8	0.4	1.88	1.21	10.6	3876
Agnico-Eagle Mines Ltd.	45.9	52.8	1.7	1.3	1.23	1.69	3.2	319
Agrium Inc.	23.6	36.7	0.8	0.5	1.60	1.37	1.3	2206
Alcan Aluminum Limited	34.8	42.5	0.4	0.3	1.40	1.25	47.7	9212
Bank of Montreal	0.4	3.1	0.4	0.2	2.52	0.88	3.3	17,762
Barrick Gold Corporation	31.3	51.2	0.4	0.3	1.45	0.96	10.9	9943
BCE Inc.	3.1	12.1	0.3	0.1	2.43	1.33	21.5	31,383
Biovail Corporation International	98.1	82.8	0.4	0.9	0.48	3.20	1.1	1398
Canadian National Railway Co.	25.8	50.4	0.3	0.3	0.98	1.64	2.2	5723
Canadian Pacific Limited	30.5	44.6	0.4	0.2	1.56	0.90	115.1	13,198
Four Seasons Hotels Inc.	73.2	78.2	0.6	0.9	0.70	1.14	1.0	1319
Gulf Canada Resources Limited	38.0	60.2	1.6	0.9	1.88	0.64	2.0	3731
Inco Limited	38.6	48.5	0.6	0.4	1.58	1.28	69.2	4980
Intrawest Corporation	65.8	26.9	1.2	1.2	1.03	2.75	0.9	917
Kinross Gold Corporation	19.7	7.7	2.6	1.0	2.62	1.98	3.3	623
Laidlaw Inc.	18.3	16.4	0.7	0.4	1.69	1.95	7.1	5891
Loewen Group Inc. (The)	54.1	64.9	0.5	0.5	1.00	1.74	1.3	2975
Magna International Inc.	51.5	69.4	0.3	0.4	0.71	1.66	5.3	6407
Meridian Gold Inc.	45.6	18.5	4.1	3.5	1.17	2.04	1.5	294
Mitel Corporation	9.6	10.9	0.9	0.5	1.74	1.38	16.7	1240
Moore Corporation Limited	22.5	36.5	0.7	0.5	1.33	1.93	17.2	1902
Newbridge Networks Corporation	29.4	54.6	0.5	0.3	1.67	1.57	3.4	8774
Newcourt Credit Group Inc.	19.8	27.2	0.5	0.3	1.44	2.21	0.8	5389
Northern Telecom Limited	35.9	60.0	0.2	0.2	1.02	1.59	22.2	33,783
Philip Services Corp.	49.3	83.2	1.4	1.0	1.34	0.78	1.8	2677
Placer Dome Inc.	25.7	46.3	0.6	0.4	1.57	1.02	10.5	4500
Potash Corp. of Saskatchewan Inc.	72.8	70.1	0.2	0.5	0.42	1.81	8.3	6405
Precision Drilling Corporation	32.9	47.7	0.7	0.5	1.54	2.07	1.2	1458
Ranger Oil Limited	35.7	22.6	1.5	0.9	1.63	1.83	15.0	1222
Rogers Cantel Mobile Comm. Inc.	60.1	32.6	1.6	1.8	0.93	1.60	2.1	235
Royal Bank of Canada	2.2	3.9	0.3	0.2	2.15	0.59	2.3	25,099
Royal Group Technologies Ltd.	54.8	46.1	0.6	0.6	1.04	0.98	1.8	1894
Seagram Company Ltd. (The)	46.0	63.0	0.3	0.3	1.02	1.33	62.2	16,408
Toronto-Dominion Bank (The)	4.1	3.1	0.5	0.2	2.80	1.22	1.4	16,535
Trizec Hahn Corporation	42.8	40.1	0.5	0.4	1.27	1.44	8.1	4910
TVX Gold Inc.	24.1	54.5	2.4	1.1	2.15	0.87	3.5	792

Table 3 (*continued*)

Company	TseAdj (%)	NyVol (%)	NySp (%)	TseSp (%)	Spread-Ratio	Medium-Trade	Years-Listed	MktCap (C$ mil.)
United Dominion Industries Ltd.	38.9	37.0	0.5	0.5	1.00	1.45	14.2	1581
Westcoast Energy Inc.	46.2	10.7	0.7	0.3	2.10	1.97	33.5	3991
Average	36.0	40.5	0.9	0.6	1.48	1.51	14.07	6867
Median	35.3	43.6	0.6	0.5	1.45	1.45	3.43	3934

The variable TseAdj is the TSE share of total adjustment in prices in response to deviations from equality with the NYSE prices; NyVol is the NYSE share of total number of shares traded on the NYSE and TSE; NySp and TseSp are the percentage spreads on the NYSE and TSE, respectively; SpreadRatio is the ratio of NySp and TseSp; MediumTrade is the ratio of the proportion of number of shares traded on the NYSE in medium-sized lots (2501–10,000 shares) and the proportion of number of shares traded on the TSE in medium-sized lots; YearsListed is the number of years for which a firm has been listed on the NYSE; and MktCap is the market capitalization.

directly related to the NYSE proportion of total trading. The TSE market makers for stocks with a greater fraction of trading on the NYSE would be more concerned about the NYSE prices. Moreover, the higher the NYSE share of trading in a stock, the more informative the NYSE trading is likely to be relative to the TSE.

3.2.2 Relative trading cost on the NYSE

We expect TseAdj to be inversely related to the relative trading cost on the NYSE. Since the bid–ask spread represents a major portion of the trading cost, our testable hypothesis is that there is an inverse relation between TseAdj and the ratio of spreads on the NYSE and the TSE. We expect the inverse relation because the lower the ratio of spreads on the NYSE and the TSE, the greater the competitive threat faced by the TSE market makers from the NYSE market makers. The TSE market makers who face more competition from the NYSE market makers are likely to be more responsive to the NYSE prices. Our hypothesis is consistent with earlier studies such as that of Harris *et al.* (2002), who find that the NYSE contribution to price discovery of the 30 Dow stocks relative to the regional exchanges increases when its spreads relative to the regionals decline.

3.2.3 Ratio of proportions of shares traded on the NYSE and on the TSE in medium-sized lots

Barclay and Warner (1993) provide evidence consistent with the argument that informed trades are concentrated in the medium-sized category. Hasbrouck (1995) finds that the information share of NYSE (relative to regional exchanges) is significantly positively correlated with NYSE's share of trading activity in medium-sized trades. He suggests that the lack of a relationship between NYSE's information share and small size trades reflects the low information content of these trades, and the lack of a relationship between NYSE's information share and large size trades is consistent with the argument that the block trade market supports uninformed trading. Therefore, we expect the price discovery on the NYSE relative to the TSE to be directly related to the ratio of proportions of shares traded on the NYSE and on the TSE in medium-sized lots.

3.2.4 Other variables

We examine the duration for which a firm has been listed on the NYSE. Seasoning of the issue in the

US could affect factors such as analyst coverage, media attention, and the interest from US investors, which could explain the extent to which the US contributes to price discovery. To ensure that our results are not driven by any possible effect of firm size, we also control for firm size, as proxied by the firm's market capitalization. It is possible that the home market may have superior access to information for firms in a particular industry. Therefore, we also control for the industry effects through dummy variables.

3.3 *Statistics of the explanatory variables*

We provide firm-wise details of the explanatory variables in Table 3. The NYSE share of total trading in a stock, NyVol, is measured as the number of shares traded on the NYSE as a percentage of the total number of shares traded in that stock on the NYSE and TSE during the study period. We measure transaction costs on the TSE and on the NYSE as quoted bid–ask spread:

$$\text{Spread} = \frac{\text{Ask} - \text{Bid}}{(\text{Ask} + \text{Bid})/2}.$$

The variables NySp and TseSp are percentage quoted spreads on the NYSE and the TSE, respectively, and SpreadRatio is the ratio of NySp and TseSp. The variable MediumTrade is the ratio of the proportion of NYSE shares traded in medium-sized lots and the proportion of TSE shares traded in medium-sized lots. It is measured as

$$\text{MediumTrade} = \frac{\left\{\begin{array}{c}\text{Number of shares}\\ \text{traded on NYSE in}\\ \text{medium-sized lots}\end{array}\right\} \Big/ \left\{\begin{array}{c}\text{Total number of}\\ \text{shares traded on}\\ \text{NYSE}\end{array}\right\}}{\left\{\begin{array}{c}\text{Number of shares}\\ \text{traded on TSE in}\\ \text{medium-sized lots}\end{array}\right\} \Big/ \left\{\begin{array}{c}\text{Total number of}\\ \text{shares traded on}\\ \text{TSE}\end{array}\right\}}$$

where medium size refers to 2501–10,000 shares.[9] The variable YearsListed is the number of years for which a firm has been listed on the NYSE through February 1, 1998; and MktCap is the market capitalization on December 31, 1997.

As we had seen earlier in Table 1, the NYSE share of trading is quite substantial, with an average (median) of 40.5% (43.6%). The TSE spreads are lower than the NYSE spread; the average (median) spread on the NYSE is 0.9% (0.6%) as compared to 0.6% (0.5%) on the TSE. The average and median values of MediumTrade are more than one, implying that a greater proportion of the NYSE trading is in medium-sized lots than the proportion of the TSE trading. For our sample, the median duration of listing on the NYSE at the beginning of the study period is 3.4 years.

3.4 *Regression analysis*

Before conducting a formal analysis to test our hypotheses, we plot the dependent variable, TseAdj, the TSE share of total adjustment in prices in response to deviations from equality with the NYSE prices, versus the three main explanatory variables. These plots in Figure 2 are generally consistent with our hypotheses. In the regression analysis, since the dependent variable, TseAdj, is a bounded fraction ranging from 0 to 1, we use the logistic transformation, $\ln[x/(1-x)]$, where x is TseAdj, as the dependent variable. This logistic transformation ensures that the predicted regression values lie between 0 and 1.

3.4.1 *Regression results*

We present the estimates of alternative regression models in Table 4. The values of adjusted R^2 are quite high, implying that the explanatory variables

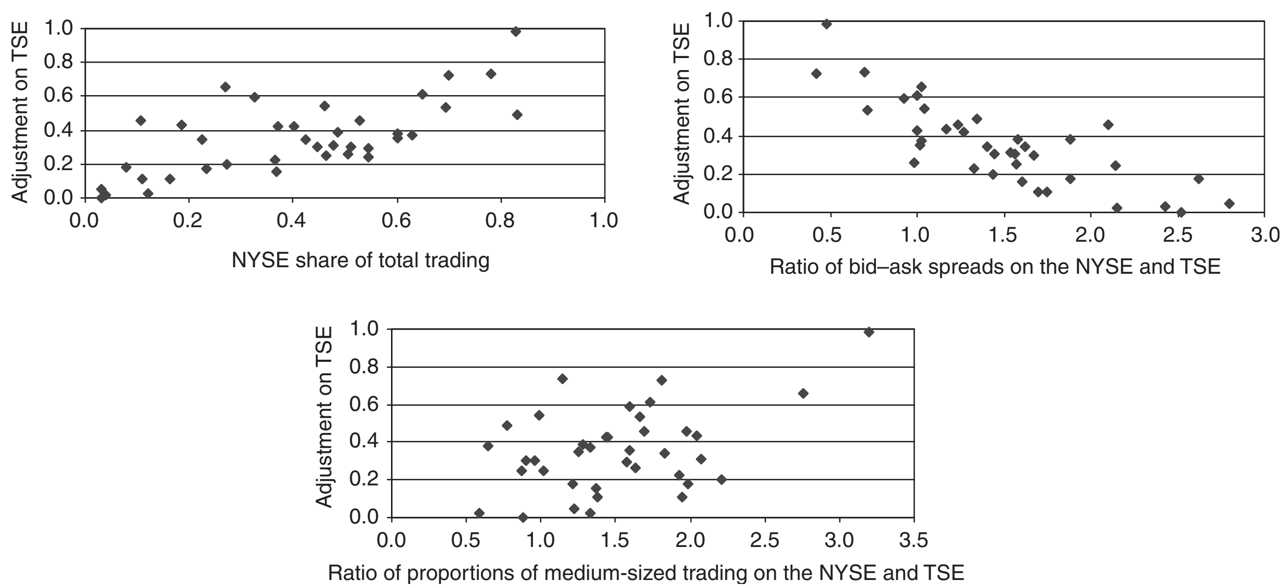

Figure 2 Effect of the NYSE share of total trading, relative NYSE bid–ask spreads, and relative NYSE proportion of medium-sized trades on TSE share of total adjustment.

Note: Adjustment on TSE is the TSE share of total adjustment in prices in response to deviations from equality between TSE and NYSE prices.

Table 4 Regression results.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Intercept	−2.70***	2.31***	−2.90***	−2.07***	−0.29	−0.34
	(−5.44)	(−4.09)	(−3.47)	(−2.76)	(−0.31)	(−0.32)
NyVol	4.73***			3.36***	3.52***	3.72***
	(4.51)			(4.91)	(6.08)	(5.87)
SpreadRatio		−2.10***		−0.75**	−0.61**	−0.53**
		(−5.26)		(−2.27)	(−2.56)	(−2.03)
MediumTrade			1.40***	1.10***	0.90***	0.97***
			(2.76)	(4.26)	(3.59)	(3.59)
LMktCap					−0.29***	−0.36***
					(−4.30)	(−4.19)
YearsListed						0.16*
						(1.86)
Adjusted R^2 (%)	48.79	60.91	23.59	75.98	80.80	82.17

The dependent variable is the logistic transformation of TseAdj, the TSE share of total adjustment in prices in response to deviations from equality between the TSE and NYSE prices. The variable NyVol is the NYSE share of total trading in a stock; SpreadRatio is the ratio of quoted spreads on the NYSE and TSE; LMktCap is the natural log of market capitalization; MediumTrade is the ratio of proportions of shares traded on the NYSE and on the TSE in medium-sized lots of 2501–10,000 shares; and YearsListed is the number of years for which a firm has been listed on the NYSE. Adjusted t-statistics based on the heteroskedasticity-consistent covariance matrix as per White (1980) are in parentheses below the coefficients. Two-tailed significance at the 1%, 5%, and 10% levels is indicated by ***, **, and *, respectively.

collectively explain most of the variation in the NYSE contribution to price discovery. In general, the regression results support our hypotheses. The coefficient of NyVol is positive and statistically significant, implying that the greater the NYSE proportion of total trading, the greater the price discovery on the NYSE. The coefficient of SpreadRatio is negative and significant, which is consistent with the argument that lower transaction costs on the NYSE imply a greater competitive threat to the TSE, resulting in a greater adjustment by the TSE prices in response to the NYSE prices. Also, as the transaction costs on the NYSE decline *vis-à-vis* the TSE, there is more informed trading in the US, and consequently more price discovery. Finally, the coefficient of MediumTrade is positive and significant, implying that the greater the proportion of NYSE shares traded in medium-sized lots relative to the TSE, the greater is the NYSE contribution to price discovery. If we use a broader definition of medium-sized lots as 501–10,000 shares, the positive relationship continues to be statistically significant; however, the relationship is not statistically significant if we define medium-sized lots as just 501–2,500 shares.

Of the other variables, the coefficient for firm size is negative and significant, suggesting that *ceteris paribus*, the NYSE contribution to price discovery relative to the TSE is greater for smaller firms.[10] As expected, the coefficient for the duration of listing on the NYSE is positive, and significant at the 10% level. So, there is some evidence that the NYSE contributes more to the price discovery of longer listed firms. To examine any industry effects, we classify sample firms into five industry groups: Mining, Manufacturing, Finance, Utility, and a fifth group consisting of service firms and the only trading firm in the sample. We then include one dummy variable at a time for each of these groups in the regressions. There is no qualitative change in results, and the coefficients on the industry dummies are not significant.[11]

3.4.2 *Effects of the explanatory variables on the NYSE contribution*

As we have used a logistic transformation of the dependent variable, it is difficult to directly interpret the magnitude of the estimated coefficients. To get an idea of the impact of the variables of interest on the relative contribution of the NYSE to price discovery, we focus on specification (6), which has all the variables. First, we estimate the NYSE contribution for the benchmark case, in which we set the value of each explanatory variable to its sample median. For this case, in which NyVol is 43.6%, SpreadRatio is 1.45, MediumTrade is 1.45, MktCap is C$3,934 million, and YearsListed is 3.43, the NYSE contribution to price discovery is 30.3%. Then, we increase one variable at a time by a quarter of its respective median value, holding the other three constant. We find that a 25% increase in NyVol (from 43.6% to 54.5%) leads to a 9.2% increase in the NYSE contribution to price discovery (from 30.3% to 39.5%). Similarly, a 25% increase in SpreadRatio, MediumTrade, MktCap, and YearsListed leads to a 3.9% decrease, a 7.9% increase, a 1.7% decrease, and a 0.8% increase, respectively, in the NYSE contribution. Clearly, the NYSE share of trading volume is the most important determinant of the NYSE contribution to price discovery.

3.4.3 *Robustness of the results of cross-sectional analysis*

We examine if the results of cross-sectional analysis are robust. We do not find any change in results when we exclude the three banks with a very low NYSE share of trading volume. In Figure 2, we notice two firms with very high values of MediumTrade. We do not find any change in results when we exclude these two firms. When we exclude one firm that has been listed on the NYSE the longest of all sample firms, we find that the duration of listing is no longer significant at the 10% level (p-value is 0.12). As indicated earlier, we include in the sample only those firms with at least 2000 trades during the 6 month study period. We examine if our results are robust to stricter criteria for inclusion. First, we raise the cutoff to 2500 trades, and consequently exclude one more firm that does not meet this stricter criterion. We do not find any qualitative change in results for this sample of 37 firms. There is also no change in results when we impose a yet stricter criterion, raising the cutoff point to 3250 trades, and excluding one more firm. Finally, we examine if our regression results are robust to the use of TseAdj values estimated using transaction prices instead of quoted prices. There is no change in results for the three main variables of interest. However, the size of the firm and the duration of listing are no longer statistically significant.

4 Stock price adjustments to exchange rate movements

In this section, we explore the role of exchange rate in more detail. We use variance decomposition and impulse response functions to examine how the TSE and NYSE prices respond to a change in the C$/US$ exchange rate. Due to the impracticality of presenting impulse response charts for each of the 38 sample stocks, we construct an equally weighted portfolio of these stocks. We perform the analysis for the mid-point of bid and ask quotes observed at 10 minute intervals for this portfolio. Since the focus is on exchange rate, we use a three-variable model, including TSE prices in C$, NYSE prices in US$, and C$/US$ exchange rates.

We first confirm that the three variables are cointegrated. Accordingly, we include an error correction term (ECT) in the vector autoregression (VAR). The number of lags used in the VAR is two, based on the multivariate Schwarz Bayesian criterion. Since log transformations of all variables are used, the law of one price in Canada and the US suggests that $P_{t-1}^{\text{TSE}} = P_{t-1}^{\text{NYSE}} + E_{t-1}^{\text{C\$/US\$}}$, where P_{t-1}^{TSE} and P_{t-1}^{NYSE} are natural logs of prices on TSE (in C$) and NYSE (in US$), respectively, at $t-1$ and $E_{t-1}^{\text{C\$/US\$}}$ is the C$/US$ exchange rate at $t-1$. Therefore, the error correction term in the model is specified as $P_{t-1}^{\text{TSE}} - P_{t-1}^{\text{NYSE}} - E_{t-1}^{\text{C\$/US\$}}$.

$$\Delta P_t^{\text{TSE}} = a_0^{\text{TSE}} + \alpha^{\text{TSE}}(P_{t-1}^{\text{TSE}} - P_{t-1}^{\text{NYSE}} - E_{t-1}^{\text{C\$/US\$}}) + \sum_{i=1}^{2} \gamma_i \Delta P_{t-1}^{\text{TSE}} + \sum_{i=1}^{2} \delta_i \Delta P_{t-i}^{\text{NYSE}} + \sum_{i=1}^{2} \lambda_i \Delta E_{t-i}^{\text{C\$/US\$}} + \varepsilon_t^{\text{TSE}} \quad (3)$$

$$\Delta P_t^{\text{NYSE}} = a_0^{\text{NYSE}} + \alpha^{\text{NYSE}}(P_{t-1}^{\text{TSE}} - P_{t-1}^{\text{NYSE}} - E_{t-1}^{\text{C\$/US\$}}) + \sum_{i=1}^{2} \phi_i \Delta P_{t-i}^{\text{TSE}} + \sum_{i=1}^{2} \theta_i \Delta P_{t-i}^{\text{NYSE}} + \sum_{i=1}^{2} \varphi_i \Delta E_{t-i}^{\text{C\$/US\$}} + \varepsilon_t^{\text{NYSE}} \quad (4)$$

$$\Delta E_t^{\text{C\$/US\$}} = a_0^{E} + \alpha^{E}(P_{t-1}^{\text{TSE}} - P_{t-1}^{\text{NYSE}} - E_{t-1}^{\text{C\$/US\$}}) + \sum_{i=1}^{2} \mu_i \Delta P_{t-i}^{\text{TSE}} + \sum_{i=1}^{2} \nu_i \Delta P_{t-i}^{\text{NYSE}} + \sum_{i=1}^{2} o_i \Delta E_{t-i}^{\text{C\$/US\$}} + \varepsilon_t^{E} \quad (5)$$

In the above model, the changes in the price on the TSE, the price on the NYSE, and the exchange rate (i.e. ΔP_t^{TSE}, ΔP_t^{NYSE}, and $\Delta E_t^{\text{C\$/US\$}}$) depend not only on the changes in the price on the TSE, the price on the NYSE, and the exchange rate in the previous periods (i.e. $\Delta P_{t-i}^{\text{TSE}}, \Delta P_{t-i}^{\text{NYSE}}$, and

Table 5 Three-variable error correction model.

Equation/Dependent variable	(1)/ΔP_t^{TSE}	(2)/ΔP_t^{NYSE}	(3)/$\Delta E_t^{C\$/US\$}$
Intercept	−0.000 (−2.19)**	0.000 (0.68)	0.000 (1.78)*
ECT	−0.103 (−3.17)***	0.171 (5.51)***	0.018 (1.55)
ΔP_{t-1}^{TSE}	−0.048 (−1.18)	0.222 (4.97)***	0.008 (0.51)
ΔP_{t-2}^{TSE}	−0.024 (−0.68)	0.075 (2.09)**	−0.000 (−0.02)
ΔP_{t-1}^{NYSE}	0.130 (3.46)***	−0.109 (−2.65)***	−0.016 (−1.08)
ΔP_{t-2}^{NYSE}	0.041 (1.28)	−0.069 (−2.09)**	−0.007 (−0.61)
$\Delta E_{t-1}^{CS/US\$}$	0.010 (0.21)	−0.125 (−2.82)***	−0.143 (−6.22)***
$\Delta E_{t-2}^{CS/US\$}$	−0.053 (−1.51)	−0.161 (−4.38)***	−0.015 (−0.94)

This table provides the three-variable error correction model, which includes the TSE prices in C$, the NYSE prices in US$, and the C$/US$ exchange rate. Since log transformations of the variables are used, the error correction term in the model is specified as $P_{t-1}^{TSE} - P_{t-1}^{NYSE} - E_{t-1}^{C\$/US\$}$. The model is estimated for an equally weighted portfolio of 38 sample stocks. Adjusted t-statistics based on the heteroskedasticity-consistent covariance matrix as per White (1980) are in parentheses below the coefficients. ***, **, and * indicate two-tailed significance at the 1%, 5%, and 10% levels, respectively.

$\Delta E_{t-i}^{C\$/US\$}$) but also on the difference between the prices in the two markets in the preceding period (i.e. the error correction term, $P_{t-1}^{TSE} - P_{t-1}^{NYSE} - E_{t-1}^{C\$/US\$}$). The estimates of this model are provided in Table 5. The coefficients of main interest are the coefficients of the ECTs, i.e. $\alpha^{TSE}, \alpha^{NYSE}$, and α^E. Their signs are consistent with our expectations. Both α^{TSE} and α^{NYSE} are significant at the 1% level, which is consistent with the earlier findings that both the NYSE and TSE prices adjust to a deviation from equality. The absolute value of α^{TSE} of 0.103 is less than α^{NYSE} of 0.171, which is also consistent with the earlier finding that the NYSE prices generally adjust more than TSE prices do. As expected, the C$/US$ exchange rate does not respond to a deviation from equality as α^E of 0.018 is insignificant at the conventional levels of significance.

In the estimates of the above model, the coefficients on $\Delta E_{t-i}^{C\$/US\$}$ in the equation with ΔP_t^{TSE} as the dependent variable are not significant. However, the coefficients on $\Delta E_{t-i}^{C\$/US\$}$ in the equation with ΔP_t^{NYSE} as the dependent variable are negative and significant, reflecting that an increase in the C$/US$ exchange rate results in a decline in the US$ prices. Overall the results in Table 5 suggest that the NYSE prices respond more than the TSE prices, in general, to a deviation from equality, and in particular, to a change in the C$/US$ exchange rate.

We further investigate where the adjustment to a change in the C$/US$ exchange rate occurs. Table 6 provides the forecast error decomposition for the TSE prices, NYSE prices, and C$/US$ exchange rate.[12] The table includes 10-minute ahead forecast error variance followed by half-, one-, two-, and three hour ahead forecast error variances. Innovations in exchange rate have a higher effect on the NYSE than on the TSE. Specifically, at the one-hour ahead forecast horizon, innovations in exchange rate account for 8.7% of the variance in the NYSE as compared to only 0.5% for the TSE. Thus, the forecast error variance decomposition also seems to suggest that it is the NYSE which mainly adjusts to a change in the C$/US$ exchange rate. As expected,

Table 6 Forecast error variance decomposition.

Variance explained in	Period	By innovations in TSE	NYSE	Exchange rate
Exchange rate	1	0.0	0.0	100.0
	3	0.1	0.1	99.8
	6	0.1	0.2	99.7
	12	0.1	0.3	99.6
	18	0.1	0.3	99.5
TSE	1	59.3	40.3	0.4
	3	56.5	43.0	0.5
	6	55.5	43.9	0.5
	12	54.8	44.7	0.5
	18	54.5	45.0	0.5
NYSE	1	38.4	56.5	5.1
	3	42.4	50.2	7.4
	6	43.7	47.6	8.7
	12	45.0	45.2	9.8
	18	45.6	44.1	10.4

This table provides the forecast error variance decomposition (%) for changes in C$/US$ exchange rate, the TSE prices in C$, and the NYSE prices in US$ of an equally weighted portfolio of the 38 sample stocks. A period consists of a 10 minute time interval.

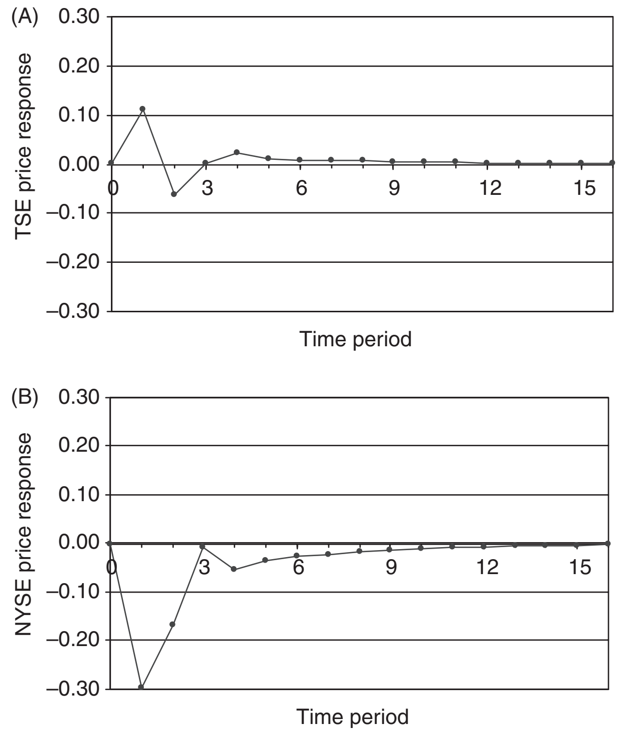

Figure 3 Stock price reactions to an exchange rate shock.

Note: This figure presents the impulse response functions for the TSE and NYSE prices of an equally weighted portfolio of 38 sample stocks to a positive one standard deviation innovation in the C$ to US$ exchange rate. One time period consists of a 10 minute interval.

innovations in exchange rate explain almost all of its own forecast error variance at all forecast horizons.

To further investigate the effect of exchange rate movements, we trace out the responses of the TSE and NYSE prices to a one-time shock in the C$/US$ exchange rate. The responses are provided in Figure 3. Panels A and B of the figure present impulse responses of the TSE and NYSE prices, respectively, to a positive shock of one standard deviation of residuals in the C$/US$ exchange rate, i.e. a depreciation of the C$ against the US$. As expected, to maintain pricing parity between the two markets, the TSE responds positively and the NYSE responds negatively. The response of the NYSE is substantially greater, suggesting that the NYSE bears a greater burden of responding to changes in the exchange rate than the TSE, which is consistent with the earlier evidence in this section. It is also interesting to note from Figure 3 that stock price adjustments to an exchange rate shock are completed within 30 minutes.

5 Conclusions

In this study, we examine cross-market adjustments to price and exchange rate movements for non-US stocks cross-listed in the US. Using a sample of 38 Canadian stocks listed on the TSE that are also listed on the NYSE, we find that price adjustments due to cross-market information flows take place not only on the NYSE but also on the TSE. Thus, the NYSE also contributes to price discovery. For a majority of the stocks, the NYSE prices adjust more to the TSE prices than vice versa. The NYSE bears a greater burden of adjusting to changes in the C$ to US$ exchange rate.

We find that the average US share of price discovery during the time period analyzed in this study is 36%. This contribution is clearly substantial. Further, there are changes that have occurred on the NYSE subsequent to the period analyzed in this study, which make it likely that its contribution to price discovery has further increased. The NYSE has adopted decimal trading, and the tick size on the NYSE is now smaller than the pre-decimalization period. Because of the reduction in tick size, the bid–ask spreads on the NYSE have declined. In a study examining the effects of the US decimalization on the Canadian stocks cross-listed in the US, Oppenheimer and Sabherwal (2003) find that the ratio of spreads on the NYSE to the TSE has declined from an average of 1.34 prior to the NYSE decimalization to 1.09 after decimalization. Accordingly, in view of the result in this study that the NYSE contribution to price discovery is inversely related to the ratio of spreads, the NYSE contribution to price discovery is likely to have increased after decimalization. Another change that has occurred is that, in 2002, the NYSE has launched a product called *OpenBook*. It provides subscribers a comprehensive view of NYSE limit-order books for all NYSE-traded securities, enabling them to see aggregate limit-order volume at every bid and offer price outside the displayed NYSE quote. This has resulted in an increased transparency of the NYSE market.

The evidence in this study of a considerable price discovery for the US-listed Canadian stocks not only in their home market but in the US as well has an interesting implication for order execution. In a letter to the US Securities and Exchange Commission (SEC) on March 9, 1999, the TSE suggested that the SEC refine the interpretation of a US broker's best execution obligation for foreign stocks listed in the US. In particular, the TSE suggested that for the US-listed Canadian firms, the US brokers should be obligated to check the Canadian prices also. Our finding that the TSE is the main price discovery mechanism for a majority of the US-listed Canadian stocks provides support for the suggested change. However, the finding that the NYSE serves as the primary price discovery mechanism for some Canadian stocks, while making a significant contribution to the price discovery of other stocks, suggests that the Canadian brokers should also be required to check the US prices of the Canadian stocks cross-listed in the US.

In this study, we also examine the factors that affect the extent to which the NYSE contributes to price determination. Our regression results are consistent with the argument that the greater the competition offered by the NYSE, the greater is its contribution to price discovery. First, a larger NYSE share of trading suggests greater competition from it as well as greater informativeness of the NYSE trading relative to the TSE trading, and we find that the adjustment by the TSE prices to the NYSE prices is more for stocks with a higher NYSE share of total trading. Second, a smaller ratio of bid–ask spreads on the NYSE and the TSE implies a larger competitive threat from the NYSE, as well as more informed trading in the US, and we find that the TSE share of total adjustment in prices is inversely related to the ratio of spreads on the NYSE and the TSE. Third, consistent with the argument that the medium-sized trades have a higher information content than small- and large-sized trades, we find that the NYSE contribution to price discovery increases as the proportion of medium-sized trades on the NYSE relative to the TSE increases.

Notes

1 This is a practitioner version of the paper Eun and Sabherwal (2003). In the current paper, we use a simplified model of price discovery and provide more firm-specific results. We also provide new results concerning the relative stock price adjustments in the home and foreign exchanges to exchange rate shocks.

2 Karolyi (1998) provides an extensive survey of international cross-listings.

3 The source of the quotation is *: The Toronto Stock Exchange: A Blueprint for Success*, TSE, October 1998.

4 We now drop the subscript "*j*" for ease of reading.

5 Detailed cointegration related results are not included for the sake of space. They are available on request.

6 We plot the differences for this firm, as its NYSE share of trading volume is fairly close to the sample average and median NYSE share of trading volume.

7 Other less likely possibilities include (i) P^{TSE} increases but P^{NYSE} increases more, and (ii) P^{TSE} decreases but P^{NYSE} decreases less.

8 When transaction prices are used in the analysis, the average (median) TseAdj is 40.4% (40.7%).

9 Barclay and Warner (1993) consider medium-size trades as 500–9900 shares. Hasbrouck (1995) includes two separate medium-sized categories, 501–2500 shares and 2501–10,000 shares. As discussed later, we consider various specifications of medium-sized trades but report results for the 2501–10,000 specification.

10 We checked for the existence of any clientele patterns that could explain this result. However, an analysis of transaction size data and informal conversations with traders on Wall Street did not suggest any clientele patterns that could explain this puzzling result.

11 For the sake of space and greater clarity of the table, we do not include the results of the five regressions with industry dummies in Table 4. The results are available from the authors.

12 The main issue of interest in this analysis—the variance in the TSE and NYSE prices explained by the innovations in C$/US$ exchange rate—is not sensitive to the stacking order of the variables (that is, to whether the TSE or the NYSE prices come before the other in the Cholesky factorization used for the decomposition). However, the variance in the TSE and NYSE prices explained by innovations in each other is sensitive to the stacking order. As we have seen that both the TSE and the NYSE contribute to the price discovery of the sample stocks, we report the averages of decomposition for two orderings, one with the TSE prices before the NYSE prices and the other with the TSE prices after the NYSE prices.

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