A Trans-Niagara Tale *of* Informed Traders[§]

"Paul" Moon Sub Choi[†]

This version: November 15, 2009

Abstract

This research documents the impact of differential private information on relative asset pricing across borders by studying the probability of informed trading (PIN) for Canadian shares traded on exchanges separated by Niagara Falls. Relative to the New York Stock Exchange (NYSE), the Toronto Stock Exchange (TSX) has more informed trades and accounts for a larger information share, indicating that informed traders contribute to cross-border price discovery. The information imbalance across the two markets is associated with small but positive price premiums for New York trades. The dynamics of these premiums depends on trade informedness. Lastly, the PIN of a TSX-listed share typically rises upon cross-listing on the NYSE, which is consistent with negative event-study returns of the original listing.

Keywords: Cross-listing, Probability of Informed Trading, Information Share, Convergence Speed, Bid-ask Spread

JEL Classifications: G15, G14, D82

[§]I thank Warren B. Bailey, Andrew Karolyi, Maureen O'Hara, Amber Anand, Arturo Bris, Charles Chang, Haigiang Chen, Bhagwan Chowdhry, Craig Doidge, David Easley, Cheol Eun, Stephen Foerster, Louis Gagnon, Yaniv Grinstein, Jungsuk Han, Yongmiao Hong, Petri Jilhä, Arzé Karam, Michael King, Lawrence Kryzanowski, Andreas Park, Sanjiv Sabherwal, Stephen Sapp, Sophie Shive, Andriy Shkilko, Ashish Tiwari, Kumar Venkataraman, Daniel Weaver, and participants at European Finance Association 2008 (Athens, Greece), Southwestern Finance Association 2009 (Oklahoma City, Oklahoma), Midwest Finance Association 2009 (Chicago, Illinois), Eastern Finance Association 2009 (Washington, D.C.), INFINITI 2009 (Dublin, Ireland), Northern Finance Association 2009 (Niagara-on-the-Lake, Ontario), and Financial Management Association 2009 (Reno, Nevada) for invaluable discussion and feedback. I also appreciate technical help from Prasun Agarwal, Jiyoun An, and Mancang Dong. This paper has been awarded the Best Paper Prize in Microstructure at Eastern Finance Association 2009 and the "NFA 2009 *&* Ivey School" Best Paper Prize at Northern Finance Association 2009. Standard disclaimer rules apply and all errors are of my own.

[†]Department of Economics, Cornell University, Ithaca, New York 14853; and the School of Management, State University of New York, P.O. Box 6000, Binghamton, New York 13902. E-mail: `mc369@cornell.edu`. I have been supported by Kwanjeong Educational Foundation grants 03112BUS044 and 0422USD012.

1 Introduction

Canada and the United States are among the most integrated economies in the world and share comparable accounting standards and institutions. Can information asymmetry explain cross-border pricing effects for Canadian shares listed in both Canadian and U.S. equity markets? This research begins by showing how dominance in private information in one market can yield a positive relative premium, referred to hereafter as the "cross-listing premium," in the other market.[1] Empirical tests relate information asymmetry to the level and dynamics of these premiums, and to cross-listing announcement effects. The probability of informed trading (PIN) proves itself to be an effective tool for revealing "how information is priced" in stock trading fragmented[2] across the border, across time, and beyond the initial cross-listing event.

Over the past several decades, many firms have listed their common shares on exchanges outside their home country. According to the World Federation of Exchanges, as of 2005, the global market capitalization of stocks listed outside their home country by 2,636 foreign companies amounted to U.S. $5.76 trillion, an increase of 16.3% from 2004. In the U.S. alone, almost 2,000 cross-listings[3] were recorded. By September 2005, the total value of American Depositary Receipts (ADRs) reached U.S.$657 billion, an increase of 36% over the preceding twelve months.[4] The popularity of international cross-listings has prompted many publications on this subject, most of which focus on

[1]The cross-listing premium is defined as the relative premium of a cross-listed stock traded on a foreign exchange against the home market share, adjusted by the exchange rate. From January 1998 through December 2000, the daily closing cross-listing premium for 55 Canadian stocks traded on both the New York Stock Exchange (NYSE) and the Toronto Stock Exchange (TSX) has arithmetic mean, median, and standard deviation of 0.00864, 0.00023, and 0.21614 respectively (Table 2).

[2]Fragmentation refers to the dispersal of trading in a security to multiple sites.

[3]This includes Levels I *&* II Depositary Receipts (DRs), Level I over-the-Counter (OTC) DRs, Rule 144a private placement DRs, ordinary shares, and Global Registered Shares (GRSs). See Bank of New York's (2006) *The Depositary Receipt Markets*.

[4]This is despite the Sarbanes-Oxley (SOX) Act of 2002 which decelerated cross-listings in the U.S. according to Doidge, Karolyi, and Stulz (2009).

the benefits of cross-border listings. See Karolyi (2006) for an excellent survey.

Cross-listings are a cross-border version of fragmentation. Consequently, the same questions asked of domestically fragmented trading also arise with international cross-listing.[5] If a stock lists on both home and foreign exchanges, where does price information originate and where does price discovery take place? What is the dynamic relationship between the two? Do both markets reflect the same fundamental values? Does the trading of identical stocks in two distinct markets reveal the same information?

Hasbrouck (1995) confirms that the New York Stock Exchange (NYSE) dominates other regional exchanges in contributing to price discovery: order purchase agreements may seek to divert small retail trades to regional locations but leave the larger and potentially more information-based trades to the NYSE. When a non-U.S. stock lists on the NYSE, the host exchange may no longer be the overwhelming source of new information being collected about the cross-listed pair. On the other hand, trades on the non-U.S. home exchange can be more influential if more information (either private or public) is traded in the home market.

In this paper, I study the trading of Canadian shares listed on the NYSE, along with their original listings on the Toronto Stock Exchange (TSX). The Canadian shares traded in the U.S. are identical to those traded at home in terms of dividends, voting rights, and other characteristics, and can be bought and sold on either market. Furthermore, the U.S. and Canadian economies are highly integrated, implying identical costs of capital and identical stock prices in both markets. While a less-than-one percent average daily relative premium in New York trading (Table 2) is not likely to yield consistent arbitrage profits after considering bid-ask spreads and other trading costs, it

[5]Previous studies on "intra-border" fragmentation include Hasbrouck (1995) and Easley, Kiefer, and O'Hara (1996).

may, as we shall see, reveal the impact of private information in interesting and useful ways.

Eun and Sabherwal (2003), Foerster and Karolyi (1998, 1999), and Jorion and Schwartz (1986) document cross-listing premiums for Canadian shares listed in the U.S. and discuss their relationship with international asset pricing concepts. By extension, my theoretical arguments and empirical results show that information asymmetry that varies across the border, firms, and time manifests itself in relative pricing of Canadian shares on the NYSE against their original listings on the TSX. The PIN on a stock proxies for the proportion of informed transactions among all trades in a particular market. Following Easley, Kiefer, O'Hara, and Paperman (1996), I individually estimate PIN for both the TSX and NYSE trading of each cross-listed share.

Easley, Hvidkjaer, and O'Hara (2002) note that, in equilibrium, a high-PIN stock carries an adverse-selection discount. Similarly, I reason that a non-zero price gap arises between New York and Toronto trades if one market features relatively more private information. Building on the noisy rational expectations model of Grossman and Stiglitz (1980), I show that a higher-PIN TSX-listed stock must trade at a lower price than on the NYSE in a no-arbitrage equilibrium given a sufficient condition of "home market liquidity dominance." Put another way, a price discount is needed to induce buyers to trade in the market which is more likely to be plagued by informed traders.

Hasbrouck's (1995) "information share" is a relative measure of the contribution made by a particular stock exchange to price discovery when trade in an asset is fragmented across multiple domestic sites. This idea is also valid beyond the border. The exchange with a higher proportion of informed traders (PIN) is expected to lead the other market in cross-border price discovery, reflected in a higher information share.

Given a "Trans-Niagara" imbalance in asymmetric information, a slightly higher NYSE price is sensible. The volatility of the price premium in New York (Table 2) can attract arbitrageurs. In turn, the degree to which arbitrage pushes NYSE and TSX prices to converge to parity can be measured by the convergence speed parameter of Gagnon and Karolyi (2009). The estimated convergence speed can then be related to trade informedness.

Cross-listing appear to affect the home exchange in a number of dimensions. Foerster and Karolyi (1998) report that, on average, the bid-ask spread narrows on the TSX upon a cross-listing in New York. The original listings also experience negative event study returns (Foerster and Karolyi (1999)). Given that fewer noise trades occur in the market with lower trading costs (Eun and Sabherwal (2003)), a higher proportion of informed traders on the TSX is likely after a cross-listing on the NYSE.

Following Eun and Sabherwal (2003), I choose to study Canadian stocks listed in the U.S. for several reasons. First, Canadian equities are the largest group of stocks cross-listed in the U.S. from a single country. Thus, a large cross-section that holds the nationality of the shares constant is available for study. Second, many of these Canadian stocks trade actively on both the NYSE and the TSX which is essential for conducting intraday tests. Third, the trading hours of the TSX coincides with that of the NYSE (9:30AM—4:00PM, EST), a distinct advantage for studying Canadian stocks relative to those from Europe and Asia with little or no overlap in trading times between home and U.S. markets. Since the potential noise and bias from trading-time differences are eliminated, analysis based on information asymmetry are more reliable. Finally, Canadian stocks trade in the U.S. as ordinary shares due to compatible accounting standards, whereas most other cross-listed shares are ADRs issued by U.S. custodian banks. This implies that arbitrage between the U.S. and Canada is particularly simple as it is not necessary to create or destroy depositary receipts (DRs).

The main empirical findings of my study are as follows. First, relative to the NYSE, the TSX has more informed trades and typically accounts for more of the measured information share. This is explicit evidence of the informed traders' contribution to cross-border price discovery. A higher PIN on one exchange reflects a larger proportion of informed traders who have a better understanding of the firm. However, this is likely to be the result of institutional background of the TSX where insider trading was more feasible due to delayed prosecution by the authority (King and Segal (2004)). The exchange with relatively more informed traders is more likely to generate relevant information that stokes price discovery in both markets.

Second, the tendency of pairs of prices to converge appears to be fostered by discretionary liquidity traders. Relating the dynamics of premiums and discounts on pairs of cross-listed shares to information asymmetry is novel in the literature. In turns out that lower-PIN pairs converge more rapidly to parity, perhaps because arbitrageurs avoid informed traders, trading with "non-discretionary" liquidity traders instead. Thus, a low PIN on a pair with a quickly vanishing premium reflects active participation of discretionary liquidity traders. Pairs trades can be done without private information on the issuers of diverged stocks as timely execution and unwinding of positions suffice.[6]

Finally, the PIN on a TSX-listed stock, on average, rises upon cross-listing on the NYSE. In other words, the information asymmetry surrounding the issuer on its home exchange intensifies once it cross-lists away from home. This increase in adverse selection is consistent with finding of negative cross listing announcement event study returns on the TSX (Foerster and Karolyi (1999)). The managers of Canadian firms may have been led to trade on inside information upon cross-listings that resulted in

[6]Statistical arbitrage, or pairs trade, is a risk-taking trading strategy on a pair of assets whose price difference is expected to diminish over a relatively short holding period. It contrasts with a true risk-free, pure arbitrage in which one simultaneously submits and settles buy and sell orders on both exchanges .

undermining their existing shareholder values. This is contrary to the case of emerging market cross-listing firms in which managerial incentives are posited to be aligned with those of shareholders' (Coffee (1999)).

These three key results effectively address "how information asymmetry is priced" in stock trading that is fragmented across a border, over time, and around cross-listings. The remainder of this paper is organized as follows. First, Section 2 shows the existence of a positive cross-listing premium with an extended version of Grossman and Stiglitz's (1980) model. Section 3 presents key hypotheses based on the existing literature. Section 4 describes the data and exhibits preliminary results. Section 5 provides my main empirical results. I conclude in Section 6.

2 Extended Grossman and Stiglitz (1980) model

Easley, Hvidkjaer, and O'Hara (2002) note that, in equilibrium, a high-probability of informed trading (PIN) stock carries an adverse-selection discount since it requires an additional return.[7] Similarly, I reason that a cross-listed pair yields either a positive or negative cross-listing premium[8] if one side carries denser private information. For a Canadian company that trades it at $p_{\mathrm{T}} > 0$ on the Toronto Stock Exchange (TSX), its cross-listing on the New York Stock Exchange (NYSE) creates a replica that trades at $p_{\mathrm{N}} > 0$ with the same underlying fair value, adjusted for the exchange rate.

Formally, a cross-listing event gives rise to a cross-listing premium, $\kappa \equiv p_{\mathrm{N}}/p_{\mathrm{T}} - 1 \gtreqless 0$, then $p_{\mathrm{N}} = p_{\mathrm{T}} + \alpha\left(\pi_{\mathrm{T}} - \pi_{\mathrm{N}}\right)$ for some $\alpha > 0$, where π_{T} and π_{N} are the respective proportions of informed traders on the TSX and the NYSE whose proxies are the exchange-specific PINs. Thus, the cross-listing premium is determined as follows:

[7] See Appendix A1 for derivation of the PIN.

[8] The relative premium of a cross-listed stock on a foreign exchange against its home market share, adjusted by the exchange rate.

$\kappa = \left(\frac{\alpha}{p_{\text{T}}}\right)(\pi_{\text{T}} - \pi_{\text{N}}) \gtrless 0$ for $\pi_{\text{T}} \gtrless \pi_{\text{N}}$.

Following the noisy rational expectations model introduced by Grossman and Stiglitz (1980), informed traders and uninformed traders have respective proportions on their own exchanges of π_i and $(1 - \pi_i)$, where $i = \text{T(SX)}, \text{N(YSE)}$. Arbitrageurs do not have an *a priori* proportion on either exchange in a "no-arbitrage" equilibrium. Informed traders and uninformed traders share the same constant relative risk aversion (CARA) utility function with a risk aversion coefficient (ρ) or a risk tolerance parameter ($\eta \equiv 1/\rho$). Arbitrageurs are risk-neutral.

The future earnings (υ) of the cross-lister is uncertain, $\upsilon \sim N(\overline{\upsilon}, \sigma_\upsilon^2)$. Informed traders recognize a signal S about υ with random noise $\epsilon_s \sim N(0, \sigma_s^2)$, such that $S = \upsilon + \epsilon_s$. The exchange-specific aggregate supply of shares is $Y_i \sim N(\overline{y}_i, \sigma_i^2)$ and is proportionately driven by uninformed (noise) traders. For convenience, all variances are expressed in precision terms in the following discussion: $\tau_\upsilon \equiv 1/\sigma_\upsilon^2, \tau_i \equiv 1/\sigma_i^2$, and $\tau_s \equiv 1/\sigma_s^2$.

Neither informed nor uninformed traders cross the Niagara Falls, and they trade on their own exchanges. Informed traders on both exchanges receive the same earnings signal, and they trade based on their updated expectations of future earnings of the firm. Uninformed traders extract information from historical price data only from their respective exchange. Their bias is reasonable since uninformed investors cannot tell informativeness of prices so they only refer to familiar listings. The two markets share the same risk-free asset with a guaranteed net return of r which serves as the common opportunity cost of capital.

Arbitrageurs can buy and sell in both markets, and their demand only depends on the cross-listing premium, or discount. Specifically, their demand for one side of the cross-listed pair (in order to shortsell) is given by x_i^A on each exchange, and it satisfies

$x^A_{\text{T}} + x^A_{\text{N}} = 0$ since "pure" arbitrageurs use a perfect hedged strategy. Thus, their short position on the TSX equals their long position on the NYSE,s $\mu \equiv x^A_{\text{T}} = -x^A_{\text{N}}$.

Denote the surprises in the earnings signal and the exchange-specific supply of shares as $\Delta S \equiv S - \overline{S}$, and $\Delta Y_i \equiv Y_i - \overline{y}_i$, respectively. The prices of the cross-listed pair are bullish on a positive earnings shock ($\Delta S > 0$), and bearish on positive liquidity excesses ($\Delta Y_i > 0$) and shortsells ($x^A_i > 0$) on respective exchanges. Thus, the prices on the TSX and the NYSE are conjectured to be:

$$p_{\text{T}} = \beta^0_{\text{T}} + \beta^S_{\text{T}} \Delta S - \beta^Y_{\text{T}} \Delta Y_{\text{T}} - \beta^A_{\text{T}} x^A_{\text{T}},$$

$$p_{\text{N}} = \beta^0_{\text{N}} + \beta^S_{\text{N}} \Delta S - \beta^Y_{\text{N}} \Delta Y_{\text{N}} - \beta^A_{\text{N}} x^A_{\text{N}}.$$

Informed traders in the two markets observe the same private signal S and use it to update their beliefs. Upon receiving a new earnings signal, their updated (posterior) earnings forecast ($\mathbb{E}(v|S)$) and updated earnings forecast precision ($\tau(v|S)$) are given by

$$\begin{aligned} \mathbb{E}(v|S) &= \overline{v} + \left(\frac{\tau_s}{\tau_s + \tau_v} \right) \Delta S, \\ \tau(v|S) &\equiv \frac{1}{\text{Var}(v|S)} = \tau_s + \tau_v. \end{aligned}$$

Under the CARA utility function assumption, exchange-specific informed traders' demand for shares is

$$\begin{aligned} x^I_i(p_i, S) &= \frac{\mathbb{E}(v|S) - p_i(1+r)}{\rho \text{Var}(v|S)} \\ &= \eta(\tau_s + \tau_v) \left\{ \overline{v} + \left(\frac{\tau_s}{\tau_s + \tau_v} \right) \Delta S - p_i(1+r) \right\}. \end{aligned}$$

Uninformed traders observe prices on their respective exchanges and form their expectations of future earnings. Their price-contingent updated (posterior) earnings forecast ($\mathbb{E}(\upsilon|p_i)$), updated earnings precision ($\tau(\upsilon|p_i)$) and demand function are, respectively, given by

$$\mathbb{E}(\upsilon|p_i) = \overline{\upsilon} + \left(\frac{1}{\beta_i^S}\right)\left(\frac{\phi_i\tau_s}{\phi_i\tau_s+\tau_\upsilon}\right)\Delta p_i,$$

$$\tau(\upsilon|p_i) \equiv \frac{1}{\mathrm{Var}(\upsilon|p_i)} = \left(\frac{\tau_i}{\tau_i+h_i^2\tau_s}\right)\tau_s + \tau_\upsilon,$$

$$\begin{aligned} x_i^U(p_i) &= \frac{\mathbb{E}(\upsilon|p_i) - p_i(1+r)}{\rho\mathrm{Var}(\upsilon|p_i)} \\ &= \eta(\phi_i\tau_s+\tau_\upsilon)\left\{\overline{\upsilon} + \left(\frac{1}{\beta_i^S}\right)\left(\frac{\tau_s}{\tau_s+\tau_\upsilon}\right)\Delta p_i - p_i(1+r)\right\}, \end{aligned}$$

where $h_i \equiv \beta_i^Y/\beta_i^S$ and $\phi_i \equiv \tau_i/(\tau_i+h_i^2\tau_s)$.

The market clearing condition on each exchange prescribes

$$\pi_i\, x_i^I(p_i, S) + (1-\pi_i)\, x_i^U(p_i, S) = Y_i - x_i^A.$$

Consequently, for a given arbitrageurs' position (μ), solving the market-clearing condition for the coefficients ($\beta_i^0, \beta_i^S, \beta_i^Y$, and β_i^A) of conjectured prices yields

$$\beta_i^0 = \frac{\overline{\upsilon}}{1+r} - \frac{\overline{y}_i}{(1+r)(\omega_i^I+\omega_i^U)},$$

$$\beta_i^S = \frac{1}{(1+r)(\omega_i^I+\omega_i^U)}\left\{\omega_i^I\left(\frac{\tau_s}{\tau_s+\tau_\upsilon}\right) + \omega_i^U\left(\frac{\phi_i\tau_s}{\phi_i\tau_s+\tau_\upsilon}\right)\right\},$$

$$\beta_i^Y = \frac{\omega_i^I\{\tau_s/(\tau_\epsilon+\tau_\upsilon)\}}{(1+r)(\omega_i^I+\omega_i^U)}\left\{\omega_i^I\left(\frac{\tau_s}{\tau_s+\tau_\upsilon}\right) + \omega_i^U\left(\frac{\phi_i\tau_s}{\phi_i\tau_s+\tau_\upsilon}\right)\right\},$$

$$\beta_i^A = \frac{1}{(1+r)\,(\omega_i^I + \omega_i^U)},$$

where $\phi_i \equiv \frac{\pi_i^2\,\eta^2\,\tau_s\,\tau_i}{1+\pi_i^2\,\eta^2\,\tau_s\,\tau_i}$, $\omega_i^I \equiv \pi_i\,\eta\,(\tau_s + \tau_v)$, and $\omega_i^U \equiv (1-\pi_i)\,\eta\,(\phi_i\tau_s + \tau_v)$.[9]

In a no-arbitrage equilibrium ($\mu = \Delta S = \Delta Y_{\text{T}} = \Delta Y_{\text{N}} = 0$), the cross-listing dollar premium is as follows.

$$\begin{aligned}
p_{\text{N}} - p_{\text{T}} &= \beta_{\text{N}}^0 - \beta_{\text{T}}^0 \\
&= \frac{\overline{y}_{\text{T}}}{(1+r)\,(\omega_{\text{T}}^I + \omega_{\text{T}}^U)} - \frac{\overline{y}_{\text{N}}}{(1+r)\,(\omega_{\text{N}}^I + \omega_{\text{N}}^U)} \\
&= \frac{\overline{y}_{\text{T}}}{(1+r)\,\omega_{\text{T}}} - \frac{\overline{y}_{\text{N}}}{(1+r)\,\omega_{\text{N}}} = \frac{\omega_{\text{N}}\,\overline{y}_{\text{T}} - \omega_{\text{T}}\,\overline{y}_{\text{N}}}{(1+r)\,\omega_{\text{T}}\,\omega_{\text{N}}} \\
&= \frac{\omega_{\text{N}}\,\{\overline{y}_{\text{T}} - (\omega_{\text{T}}/\omega_{\text{N}})\overline{y}_{\text{N}}\}}{(1+r)\,\omega_{\text{T}}\,\omega_{\text{N}}}.
\end{aligned}$$

If $\pi_{\text{T}} > \pi_{\text{N}}$, then $\omega_{\text{T}} \equiv \left(\omega_{\text{T}}^I + \omega_{\text{T}}^U\right) > \omega_{\text{N}} \equiv \left(\omega_{\text{N}}^I + \omega_{\text{N}}^U\right)$, thus $\omega_{\text{T}}/\omega_{\text{N}} > 1$. With a sufficient "home market liquidity dominance" condition that $\overline{y}_{\text{T}}/\overline{y}_{\text{N}} > \omega_{\text{T}}/\omega_{\text{N}} > 1$,[10] the stock is dearer on the NYSE than on the TSX such that $p_{\text{N}} > p_{\text{T}}$. In other words, as long as liquidity on the home exchange is relatively "better" than on the host exchange, a higher proportion of informed traders on the home-listed stock must give rise to a strictly positive cross-listing premium in the cross-listed stock. A price discount on the original listing is needed to induce buyers to trade in the market which is more likely to be plagued by informed traders. This premium on the cross-listing does not attract arbitrageurs and, thus, neither side of the pair is mispriced.

[9]It can be shown that *1.* $\partial\beta_i^0(\pi_i)/\partial\pi_i > 0$ for all $\pi_i \in [0,1]$; *2.* $\partial\beta_i^S(\pi_i)/\partial\pi_i > 0$ for all $\pi_i \in [0,1]$; *3.* $\partial\beta_i^Y(\pi_i)/\partial\pi_i < 0$ for some large π_i; and *4.* $\partial\beta_i^A(\pi_i)/\partial\pi_i < 0$ for all $\pi_i \in [0,1]$. $\partial\beta_i^S(\pi_i)/\partial\pi_i > 0$ is an intuitive result since the price is expected to reflect more information shocks with an increase in the proportion of informed traders. See proofs in Appendix A3.

[10]This sufficient condition is reasonable since the higher adverse-selection risk side of a cross-listed pair is offering better liquidity, or facilitating easier exit, in addition to a commensurate discount to attract investors.

If $\overline{y}_{\text{T}} = \overline{y}_{\text{N}}$, $\pi_{\text{T}} > \pi_{\text{N}}$ implies $p_{\text{T}} > p_{\text{N}}$, which is consistent with Chan, Menkveld, and Yang's (2008) application to the Chinese A and B share markets. The no-arbitrage condition in an equilibrium ($\Delta S = \Delta Y_{\text{T}} = \Delta Y_{\text{N}} = 0$) is $p_{\text{N}} - p_{\text{T}} = \beta^0_{\text{N}} - \beta^0_{\text{T}}$ (see proof in Appendix A3).

3 Hypotheses

Theoretically speaking, cross-border differential in private information can explain relative pricing of Canadian shares concurrently traded on the TSX and the NYSE. I subsequently raise testable hypotheses of empirical support for the institutional background of information asymmetry, the dynamics of cross-listing premiums, and the informational and economic consequences of cross-listings on the home exchange.

3.1 Informed trading and cross-border price discovery

Unlike articles that focus on the joint distribution of trades and prices,[11] Easley, Kiefer and O'Hara (1997a, 1997b) and Easley, Kiefer, O'Hara, and Paperman (1996) make parametric assumptions to estimate a relative measure of adverse selection using buy and sell order indicators instead of price data. In their theoretical setting, there are risk-averse and competitive market makers, informed traders, and uninformed liquidity traders.

The four parameters of the maximum likelihood model are: the probability that an information event occurs on a given day (α); the probability that the information event is pessimistic (δ); and the respective (Poisson) order arrival rates of informed and uninformed traders (μ and η). As a result, the probability of informed trading[12]

[11] Bagehot (1971), Grossman and Stiglitz (1980), Kyle (1985), and Glosten and Milgrom (1985).

[12] $\text{PIN} \equiv \frac{\alpha\,\mu}{\alpha\,\mu + 2\,\eta}$. See Appendix A1.

(PIN) measures the relative degree of private information-based trades among all trades. Easley, Kiefer and O'Hara (1997b) argue that, as informed traders gain weight in the market, adverse selection is aggravated and the trading volume increases.

Fragmentation is the dispersal of trading in a security to multiple exchanges or markets. As an early bridge between fragmentation and informed trading, Chowdhry and Nanda (1991) note that information lags between distinct trading locations yield transitory disparities in the prices of an identical security. Blume and Goldstein (1991) and Lee (1993) report that price discovery (convergence towards an equilibrium price) on U.S. exchanges occurs primarily on the NYSE. Similar results are drawn by Harris, Mclnish, Shoesmith, and Wood (1995) and Gardner and Subrahmanyam (1994).[13]

When a NYSE-listed stock trades not only on the NYSE but also on the regional exchanges, the fragmented security prices may not be identical but they also cannot differ too much in the long run either. Hasbrouck's (1995) "information share"[14] is a relative measure of contribution made by a stock exchange to price discovery of shares fragmented on multiple exchanges. Hasbrouck (1995) finds that price discovery of fragmented stocks appears to be concentrated on the NYSE whose information share is shown to be the highest.

Easley, Kiefer, and O'Hara (1996) show that there is a significant difference in the information content of orders executed in New York and in Cincinnati, and that this difference is consistent with the "cream-skimming" hypothesis, instead of the competi-

[13]Extending the works of Hasbrouck (1991, 1995), Gardner and Subrahmanyam (1994) conclude that fewer informed trades are executed on the regional exchanges than on the NYSE.

[14]Information shares are estimated by the vector error correction model (ECM) provided that the dispersed security prices are "cointegrated." Security prices are cointegrated if there exists a linear combination of the non-stationary prices that can be toned stationary. A time series is strongly stationary if its probability distribution is time-invariant, and weakly stationary up to its second moments: mean, variance, and covariance. This property renders Sims's (1980) original vector autoregressive (VAR) model unwieldy. That is why Hasbrouck (1995) takes an ECM (Engle and Granger (1987), and Engle and Yoo (1987)) approach to propose "information shares." See Appendix A2.

tion hypothesis. The notion that trades in distinct U.S. locations carry different levels of information is also relevant to cross-border fragmentation.

Extending the fragmentation idea to the international finance literature, based on U.S.-listed Canadian stocks, Eun and Sabherwal (2003) find that prices on the Toronto Stock Exchange (TSX) and U.S. exchanges are mutually convergent, following Harris, McInish, Shoesmith, and Wood (1995). They report that the U.S. share of price discovery ranges from 0.2 percent to 98.2 percent, with an average of 38.1 percent.

Across the global equity markets, Bailey, Mao, and Sirodom (2006) and Chan, Menkveld, and Yang (2008) describe intriguing multi-board trading structures in Thailand and China, respectively, and explain how information asymmetry affects fragmented trading. Also, foreigners are disadvantaged in Korea (Choe, Kho, and Stulz (2005)) while they wield superior information processing capability in Thailand and Singapore (Bailey, Mao, and Sirodom (2007)).

If a stock listed on an exchange has a higher PIN than its cross-listing traded on the other cross-border exchange, this reflects a greater proportion of informed traders who have private information of the issuer. Since informed traders are believed to contribute to price discovery, it is also likely that the exchange with heavier intensity of informed trades generates more relevant information which fuels price discovery.[15]

By definition, an exchange is said to *lead* the other exchange if it accounts for more price discovery (reflected in its higher information share). However, unlike domestically dispersed stocks, trades in TSX-NYSE co-listed shares are exposed to aggregate shocks hitting the two exchanges and the foreign exchange market. In other words, cross-border fragmentation is a more intricate mechanism of price discovery than the

[15] Hasbrouck (2007) notes that a vector ECM analysis assigns quote changes to the influx of trades. Asymmetric information is then reflected in a wide price change. In this sense, the information share is expected to be directionally equivalent to the PIN.

domestic case. My first hypothesis attempts to verify the role of informed traders in determining cross-border price discovery. Specifically,

> *H1: compared to the other exchange, the lead market (with a higher average information share) has relatively more informed trades (with a higher average PIN).*

3.2 Dynamics of cross-listing premiums

Easley, Hvidkjaer, and O'Hara (2002) note that, in equilibrium, a high-PIN stock carries an adverse-selection discount since it requires an additional return. Similarly, as discussed in Section 2, I reason that a cross-listed pair yields either a positive or negative cross-listing premium[16] if one side carries relatively more private information.[17] Unless that relative price spread is believed to persist due to severe liquidity constraints, shortsale restrictions, or other frictions, an arbitrageur will buy the discounted stock and short the other side with favorable assumptions on the exchange rate.

The international finance literature has accumulated articles on arbitrage opportunities created by cross-listed shares. The early studies (Maldonado and Saunders (1983), Kato, Linn, and Schallheim (1991), Park and Tavakkol (1994), Miller and Morey (1996), and Karolyi and Stulz (1996)) conclude that arbitrage profits for cross-listed shares do not exist and thus they are priced at parity. Wahab, Lashgari, and Cohn (1992) show that there are arbitrage opportunities in cross-listed pairs. Froot and Dabora (1999) study pricing of a couple of dual-listed corporations (Royal Dutch

[16] This as defined as the relative premium of a cross-listed stock on a U.S. exchange against its home market basis share, adjusted by the exchange rate.

[17] In Section 2, based on an extended version of the noisy rational expectations model (Grossman and Stiglitz (1980)), I provide a sufficient condition ("home market liquidity dominance") under which a higher-PIN TSX-listed stock must be priced lower than its NYSE-listed replica in a "no-arbitrage" equilibrium.

and Shell, and Unilever N.V. and Unilever PLC) and find a sizable and significant price deviation from parity.[18]

Gagnon and Karolyi (2009) record significant price deviations in 581 ADR-underlying pairs under their study: they report discounts of up to 90% and premiums of up to 70%. The speed at which a cross-listing premium converges to parity is measured by a parameter proposed by Gagnon and Karolyi (2009). According to their empirical model each firm's cross-listing premium can be explained by its first-lag term, and its time-distributed risk exposure to the respective returns on the home and host market indices and the foreign exchange rate.

In a rational expectations equilibrium, informed investors impound information in prices (Grossman and Stiglitz (1980)) and, thus, catalyze price discovery. Cross-sectionally, a higher PIN implies enhanced price discovery. Hence, for the "synchronous" cross-listing premium of a Canada-U.S. cross-listed pair, its dynamics (convergence speed) is expected to depend on the informedness of trades, after controlling for market friction, liquidity constraint, and firm characteristics. Parity-convergence can, therefore, be accelerated by the degree of private information on the cross-lister. In this regard, my second conjecture states that

> *H2: the higher the PIN on a cross-listed pair, the faster the parity-convergence of cross-listing premiums.*[19]

[18] See Kim, Szakmary, and Mathur (2000) for vector autoregressive (VAR) and seemingly unrelated estimation (SURE) methods that analyze adjustments in ADR-implied prices.

[19] By specification, a lower absolute value of parameter below one is equivalent to a higher convergence speed.

3.3 Cross-listing effects on the home exchange

De Long, Shleifer, Summers, and Waldman (1990) argue that, since noise traders do not reflect information on the fundamentals their trades dislocate prices from their intrinsic values, reducing price informativeness while increasing volatility (noise trader risk). Eun and Sabherwal (2003), Fleming, Ostdiek, and Whaley (1996), and Jones and Seguin (1997) suggest that less noise trades occur in the markets with lower trading costs.

Foerster and Karolyi (1998) document that post-cross-listing spreads in Canada decrease. The augmented liquidity gives rise to TSX market makers' competitive reaction by setting bid-ask spreads lower.[20] The bid-ask spread represents a significant portion in transaction costs, thus cross-listings can reduce noise trader risk on the home exchange. This, in turn, may enhance price discovery, since less noisy fluctuation contributes to setting a more precise and stable process towards the fair price of a security.

A subsequent question will be: "whether less *volatility* entails a higher *proportion* of informed trades?" Further, "does cross-listing exacerbate the home market information environment with relatively more perverse adverse selection?" My last hypothesis is that

> *H3: after cross-listing on the NYSE, on average, information asymmetry on a TSX-listed stock intensifies (the PIN rises).*

Cross-listings can be a good source of additional liquidity to the existing home-listed stocks. Intensifying adverse selection captured by the PIN and increasing trading volume are positively correlated (Easley, Kiefer and O'Hara (1997b)) and this further

[20] The decrease in spreads on the TSX is heavily weighed on the stocks whose trading volume contribution by the U.S. exchanges is relatively large.

leverages my hypothesis. The additional liquidity on the TSX forces market makers to set spreads narrower. See Admati and Pfleiderer (1988) for a similar discussion.

4 Data and preliminary results

4.1 Data

55 TSX-NYSE pairs are identified through the sample period: January 1, 1998, through December 31, 2000.[21] In order to conduct microstructure analyses, high-frequency data are required for the shares co-listed on the TSX and the NYSE, and the U.S.-Canada exchange rate. Accordingly, the tick-by-tick trade and quote data for the TSX-listed Canadian stocks and the Trade-And-Quote (TAQ) data of their cross-listings on the NYSE through the period are used. The exchange rate intraday data is purchased from Olson & Associates.

Unlike a specialist-based auction exchange NYSE, electronic exchange TSX uses a Central Limit Order Book (CLOB) system, thus orders are required to be in the book to have standing.[22] By studying decrements in the inside depth on one side of the quote that correspond to uncommon trade sizes (like a trade of 1,300 shares), matching trades with prevailing quotes of five-second lead (Lee and Ready (1991)) is reasonable: a trade is considered buyer-initiated if it is higher than the five-second earlier mid-quote, and seller-initiated if lower.[23]

[21] Following Eun and Sabherwal (2003), the augmented Dickey-Fuller (1981) unit root test is conducted for each pair of daily closing price time series with appropriate lag lengths, per Akaike (1974), to verify first-order integration ($I(1)$). Applying Johansen's (1991) either the trace or eigen-value tests yielded one co-integrating equation for each TSX-NYSE co-listed pair. These results provide justification for constructing error correction models (ECMs) to estimate the information shares of each co-listed pair's exchanges.

[22] I owe this comment to Daniel Weaver. See Eun and Sabherwal (2003) for a detailed institutional comparison between the TSX and the NYSE.

[23] See Schultz and Shive (2008) for trade misclassification of the TAQ on the NYSE which becomes severe after 2000.

I construct the preliminary datasets for estimation of the PIN following Easley, Kiefer, O'Hara, and Paperman (1996), and Easley, Hvidjkaer, and O'Hara (2002). The NYSE-resident specialists are central to the theory of the PIN (Easley, O'Hara, and Saar (2001), and Duarte and Young (2008)). There are official market makers, known as registered traders, on the TSX whose function is akin to that of NYSE specialists. Thus, a comparison of trade informedness on the two exchanges by the PIN is deemed appropriate.[24]

4.2 Preliminary results

The PINs for TSX- and NYSE-listed Canadian stocks are estimated following Easley, Kiefer, O'Hara, and Paperman (1996) and Easley, Kiefer and O'Hara (1997a, 1997b).[25] The arithmetic means of monthly PIN estimates of 55 Canadian cross-listers on the TSX and the NYSE are plotted in Figure 1. It appears that the TSX, on average, dominates the NYSE in terms of the PIN in annual estimates for the cross-listed pairs through the sample period.[26]

[Insert Figure 1 about here.]

The bid-ask spreads[27] are adjusted by the mid-quotes and, thus, measure the relative discrepancy between bid and ask quotes free from the exchange rate. Following Eun and Sabherwal (2003), the mid-points of U.S.-Canada exchange rate bid and ask

[24] I owe this comment to Lawrence Kryzanowski. See Fuller, Van Ness, and Van Ness (2008) for difficulties in estimation of the PIN for NASDAQ trades.

[25] I adopt Easley, Engle, O'Hara, and Wu's (2008) log-likelihood function specification for improved numerical stability in computing the the PIN. See Appendix A1.

[26] The annual estimates for the PIN on the TSX are {0.242, 0.213, 0.206} in 1998, 1999, and 2000, respectively, while the corresponding estimates for the NYSE are {0.204, 0.212, 0.196}, over the same period. The spikes in PIN are seen in the post-decimalization period between November and December 1999, a finding consistent with Zhao and Chung (2006).

[27] $\text{SPREAD}_{\text{NYSE}} \equiv \frac{\text{ask}_{\text{NYSE}} - \text{bid}_{\text{NYSE}}}{(\text{ask}_{\text{NYSE}} + \text{bid}_{\text{NYSE}})/2}$; and $\text{SPREAD}_{\text{TSX}} \equiv \frac{\text{ask}_{\text{TSX}} - \text{bid}_{\text{TSX}}}{(\text{ask}_{\text{TSX}} + \text{bid}_{\text{TSX}})/2}$.

quotes are updated every minute. The bid and ask quotes of the NYSE-listed Canadian stocks are matched with their previous minutes' exchange rate quote mid-points. Based on mutual interaction (orthogonalized impulse responses) of bid and ask quotes on the TSX and the NYSE, the information shares[28] of the TSX and the NYSE for each cross-listed pair are estimated.

The averages across monthly estimates of PINs, spreads, and information shares of each pair over the entire sample period are listed in Table 1.[29] About twenty firms in the sample exhibit higher PINs on the NYSE than on the TSX. For some cross-listers, like Manulife Financial Corp. and Suncor Energy Inc., there is no significant difference between the PINs on the two exchanges. Only nine firms in the sample show higher spreads on the TSX, and only two firms have higher information shares on the NYSE.

[Insert Table 1 about here.]

First, on average, the PIN on the TSX (0.241) exceeds that on the NYSE (0.211). Second, the relative quoted spread on the TSX (0.016) is narrower than that on the NYSE (0.022). Third, the information share of the TSX (0.542) is higher than that of the NYSE (0.458). For a Canadian cross-lister, on average, it appears that more price discovery takes place on the TSX (the lead market) where the intensity of informed trades tends to be heavier (a higher PIN) and yet with lower spreads (competitive market making).

[Insert Figure 2 about here.]

[28]Since there are four quote prices (bid_{TSX}, ask_{TSX}, bid_{NYSE}, and ask_{NYSE}), there are 24 (= 4!) orderings in terms of Cholesky exogeneity. For each TSX-NYSE co-listed pair, thus, there are 24 pairs of TSX-NYSE information shares. Averaging across varying exogeneity reduces them to a single pair of information shares for each co-listed pair. See Appendix A2.

[29]For brevity, in Table 1, I do not present the monthly estimates (January 1998 through December 2000) of the PIN and the spreads for the cross-listed pairs. They are, however, available upon request.

The impulse response function plots of bid and ask quotes for Abitibi Consolidated, Inc. are shown in Figure 2. Each of the four consecutive charts specifies the source of innovation by two standard deviations. The quotes on the NYSE rarely affect the quotes on the TSX. To the contrary, positive increases in ask and bid prices on the TSX are followed by changes in ask and bid prices on the NYSE, respectively. This pattern does not hold for all cross-listed stocks, and the degree to which an exchange responds to the other side is reflected in the magnitude of information share.

[Insert Table 2 about here.]

Based on the daily cross-listing premiums of 55 cross-listed pairs traded through the sample period, the arithmetic mean, the median, and the standard deviation are 0.00864, 0.00023, and 0.21614, respectively (Table 2). The average daily cross-listing premium of 86.4 basis points with a 21.6 percent volatility is a statistically insignificant deviation from parity. This suggests the extent to which Toronto and New York are integrated.[30] By the close of an average trading day, it appears that there is no further room to exploit cross-border arbitrages on the cross-listed pairs. However, as the high standard deviation suggests, it is evident that the dynamics of cross-listing premiums reflects active pairs trades.

A regression analysis of cross-listing premiums against cross-border differences in the proportions of informed traders is conducted in Table 3. It shows that a higher PIN on a stock listed on the TSX, on average, is associated with a positive premium on the cross-listed stock traded on the NYSE. This strongly supports the extended Grossman and Stiglitz (1980) model presented in Section 2. The seemingly unarbitrageable and negligibly positive average daily cross-listing premium is a result of cross-border imbalance in private information.

[30]See Kryzanowski and Zhang (2002) for intraday analyses of price differences of Canadian cross-listed pairs traded in Toronto and New York.

[Insert Table 3 about here.]

5 Results

5.1 Informed trading and cross-border price discovery

Based on monthly estimates, the statistical significance of the TSX's dominance over the NYSE in terms of the PIN can be verified by the Wilcoxon signed-rank test.[31] In the first column of Table 4, the Wilcoxon-test statistic, under the null hypothesis is very strongly rejected at a 1% right-tail significance level. Thus, the traders on the TSX posses relatively more private information on Canadian cross-listed stocks than their counterparts on the NYSE. However, this is likely to be the result of institutional background of the TSX where insider trading was more feasible due to delayed prosecution by the authority (King and Segal (2004)).[32]

[Insert Table 4 about here.]

Harris, McInish, and Wood (2002) report that the influence of the NYSE on price discovery against its regional counterparts increases as its spreads compared to those of the regionals' decrease. In the cross-border context, competitive market making by the TSX versus the NYSE can be inferred from, similarly, comparing the bid-ask spreads on the TSX and on the NYSE.[33] The test result overwhelmingly agrees with the alternative hypothesis as seen in the second column of Table 4. As a result, the market makers on the TSX are more competitive in setting quote spreads than their competitors on the NYSE are.

[31] H_0 : $\text{PIN}_{\text{TSX}} = \text{PIN}_{\text{NYSE}}$ versus H_1 : $\text{PIN}_{\text{TSX}} > \text{PIN}_{\text{NYSE}}$.

[32] Canadian insider trading was no less egregious than that of the U.S. until 2003 when the anti-white collar crime act was legislated under the Criminal Code. See King and Segal (2004) for an excellent survey on this issue.

[33] H_0 : $\text{SPREAD}_{\text{TSX}} = \text{SPREAD}_{\text{NYSE}}$ versus H_1 : $\text{SPREAD}_{\text{TSX}} < \text{SPREAD}_{\text{NYSE}}$.

Relative dominance of the TSX over the NYSE in terms of information share can be empirically checked[34] and the test confirms that the information share of the TSX, on average, far exceeds that of the NYSE as seen in the third column of Table 4. Thus, the TSX contributes more to price discovery than the NYSE does.

[Insert Tables 5, 6, and 7 about here.]

In order to check for robustness of the Wilcoxon test results shown in Table 4, I construct a monthly panel dataset of the PIN, spread, the information share, volume,[35] and the TSX indicator.[36] In Tables 5, 6, and 7, the PIN, spread, and the information share are, respectively, regressed against the others controlled for volume and the TSX dummy variable. The signs of the binary TSX variable in Models 2 and 3 confirm the results shown in Table 4. Trade informedness (PIN) is graver on the exchange with a higher information share (vice versa) as shown by Models 1 and 2 in Table 5 (Table 7).

In summary, I find that the *lead* market (TSX), on average, shows a higher PIN than the *lag* exchange (NYSE).[37] In other words, the trading venue with heavier intensity of informed trades contributes more to the price discovery of cross-listed pairs. This is explicit empirical evidence that informed traders contribute to cross-border price discovery.

Eun and Sabherwal (2003) conclude that informed traders prefer to trade in a market where more original information can be found. By extension, I use direct relative measures of informed trades (PIN) and contribution to price discovery (information share). The trades executed on the lead exchange, the TSX, are more likely to be

[34] $H_0 : \text{IS}_{\text{TSX}} = \text{IS}_{\text{NYSE}}$ versus $H_1 : \text{IS}_{\text{TSX}} > \text{IS}_{\text{NYSE}}$.

[35] It is the per-trade average shares of the cross-listed pairs on the TSX and the NYSE.

[36] It equals one if the estimated numerical value is of the TSX, or zero if the NYSE.

[37] Hasbrouck (1995) defines that an exchange is said to *lead* the other exchanges if it accounts for more price discovery (reflected in its higher information share).

information-based than the trades executed on the lag exchange, the NYSE. The PINs of a cross-listed pair represent the proportions of exchange-specific informed traders.

5.2 Dynamics of cross-listing premiums

The Canadian listings on the NYSE, on average, carry slightly positive and highly volatile cross-listing premiums relative to their home listing on the TSX through the sample period (Table 2). At close of an average trading day, the pairs appear to be fairly priced and the small premium an average NYSE-cross-listing carries against its original TSX-listing is not surprising given the implication of the extended Grossman and Stiglitz (1980) model presented in Section 2.[38]

As the high standard deviation suggests, there evidently are more-than-profitable, but short-lived, cross-listing premiums which subsequently attract pairs traders. It is natural to ask how quickly *and* by whom a temporarily profitable cross-listing premium is pushed back towards parity. Following Gagnon and Karolyi (2009),[39] I estimate the convergence speed parameter in a daily frequency for each firm. The PIN effect on the convergence speed can be inferred from regressing the convergence speed parameter ($\text{SPEED}_{\text{CONV}}$) onto the average PIN on both exchanges, since convergence speed is a mutual concept, and average spread (on both exchanges), controlling for firm size,[40]

[38] In Section 2, based on an extended version of the noisy rational expectations model of Grossman and Stiglitz (1980), I derive an implication of "home market liquidity dominance": higher-PIN TSX-listed stock must be priced lower than its NYSE-listed share in a "no-arbitrage" equilibrium.

[39] $DR_i(t) = \alpha_i + \theta_i DR_i(t-1) + \sum_{j=-1}^{1} \beta_j^{US} R_M^{US}(t+j) + \sum_{j=-1}^{1} \beta_j^{C} R_M^{C}(t+j) + \sum_{j=-1}^{1} \beta_j^{FX} R_{FX}(t+j) + \varepsilon_i(t),$
where θ_i ($\equiv \text{SPEED}_{\text{CONV}}$) captures the reciprocal speed of convergence of cross-listing premiums to parity.

[40] Normalized average market capitalization on the TSX and the NYSE.

industry dummy,[41] volume, [42] and governance index[43] as follows

$$\text{SPEED}_{\text{CONV}} = \gamma_1 \text{PIN}_{\text{AVG}} + \gamma_2 \text{SPREAD}_{\text{AVG}} + \gamma_3 \text{SIZE} + \gamma_4 \text{INDUSTRY} + \gamma_5 \text{VOLUME} + \gamma_6 \text{GOVERNANCE} + \eta.$$

According to the regression model, the dynamics of synchronous cross-listing premiums is explained by the asymmetric information component (PIN) and market friction (spread) while holding idiosyncracies (size and industry), liquidity constraint (volume), and the level of corporate governance constant.

[Insert Table 8 about here.]

It turns out that, in Table 8, a higher PIN on either exchange very significantly impedes the convergence to parity in all specifications, since the convergence speed parameter is reciprocal to actual speed. This is against the second hypothesis raised in Section 3. The uninformed traders appear to deplete cross-listing premiums faster than their informed cohort. The PIN effect appears robust controlling for liquidity of cross-listed pairs in Models 2, 3, and 4. The higher the spread on either exchange (the higher the average spread as a result) the slower the convergence speed in Models 1, 2, and 4.

Practitioners executing statistical arbitrages (pairs trades) and profiting from cross-listing premiums need not be informed of the issuer's fundamental value. Timely execution and unwinding of their positions will suffice. Thus, statistical arbitrageurs are believed to be discretionary liquidity traders who are responsible for quickly converging

[41] Equals one if the cross-lister is a manufacturing firm, and zero otherwise.

[42] Normalized average per-trade volume on the TSX and the NYSE.

[43] The Report on Business governance index of Canadian firms is published by *Globe and Mail* (McFarland (2002)). Full scores in the four following criteria total up to 100 points: board composition (40), compensation (23), shareholder rights (22), and disclosure (15). The higher the index score, the better the firm is governed.

and low-PIN cross-listed pairs.[44] Relating the dynamics of synchronous cross-listing premiums to asymmetric information is novel in the cross-listed shares literature.

I further explore the cross-sectional relationship between the average spread across the exchanges against the average PIN on both exchanges, and convergence speed, controlled for firm size and industry dummy. In Table 9, the average PIN is very significantly positively associated with the average spread which is consistent with the finding of Easley, Kiefer, O'Hara, and Paperman (1996).

$$\text{SPREAD}_{\text{AVG}} = \delta_1 \, \text{PIN}_{\text{AVG}} \, + \, \delta_2 \, \text{SPEED}_{\text{CONV}} \, + \, \delta_3 \, \text{SIZE} \, + \, \delta_4 \, \text{INDUSTRY} \, + \, \epsilon.$$

[Insert Table 9 about here.]

Table 3 shows that a higher PIN of a stock listed on the TSX gives rise to a positive premium in the stock cross-listed on the NYSE. This relation is robust to controlling for convergence speed and governance index as shown in Table 10. This provides further support for the extended Grossman and Stiglitz (1980) model presented in Section 2.

$$\left(p_{\text{NYSE}} - p_{\text{TSX}}\right)/p_{\text{TSX}} \; = \; \beta_1 \left(\text{PIN}_{\text{TSX}} \; - \; \text{PIN}_{\text{NYSE}}\right) \, + \, \beta_2 \, \text{SPEED}_{\text{CONV}} \, + \, \beta_3 \, \text{GOVERNANCE} \, + \, \epsilon.$$

[Insert Table 10 about here.]

One arbitrageur may prefer to short-sell on the NYSE and to long on the TSX, while another to short-sell on the TSX and to long on the NYSE for liquidity reasons. This may render using the quote mid-points of U.S.-Canada exchange rate problematic.[45] For

[44] Admati and Pfleiderer (1988) distinguish discretionary liquidity traders who can skillfully and strategically time their executions, in contrast to non-discretionary liquidity (or noise) traders.

[45] I owe this point to Bhagwan Chowdhry. In other words, dynamics in the foreign exchange market are another source of innovation to the cointegrated system of co-listed stock pairs.

example, it may be easier to short-sell on the TSX than on the NYSE. The *cross-border relative quoted spreads* are defined as follows

$$\widetilde{\text{SPREAD}}_{\text{NT}} \equiv \{\text{ask}_{\text{NYSE}} - \text{bid}_{\text{TSX}} \cdot (\text{US\$/CAN\$})_{\text{ask}}\} / \{\text{bid}_{\text{TSX}} \cdot (\text{US\$/CAN\$})_{\text{ask}}\},$$

$$\widetilde{\text{SPREAD}}_{\text{TN}} \equiv \{\text{ask}_{\text{TSX}} \cdot (\text{US\$/CAN\$})_{\text{bid}} - \text{bid}_{\text{NYSE}}\} / \text{bid}_{\text{NYSE}}.$$

$\widetilde{\text{SPREAD}}_{\text{NT}}$ is the percentage cross-border arbitrage profit from buying on the TSX and selling on the NYSE, and $\widetilde{\text{SPREAD}}_{\text{TN}}$ is from buying on the NYSE and selling on the TSX. The first strategy narrows down $\widetilde{\text{SPREAD}}_{\text{NT}}$, while the second pairs trade squeezes $\widetilde{\text{SPREAD}}_{\text{TN}}$. Either strategy may turn out more lucrative than the other due to the existence of bid-ask spread in the exchange rate.

In Table 11, monthly averages of cross-border relative quoted spreads (updated every minute) of 55 cross-listed pairs are tested for differences using the Wilcoxon test. It turns out that the two spread measures are empirically equivalent. In other words, arbitrageurs' positions are not skewed towards either trans-Niagara trading venue due to exchange rate market friction. Thus, using exchange rate mid-quotes appears reasonable.

[Insert Table 11 about here.]

5.3 Cross-listing effects on the home exchange

Table 12 shows fifteen Canadian firms that cross-listed on the NYSE during the sample period. Thirteen firms had been listed on the TSX before they cross-listed on the NYSE. The firms without the PIN either have cross-listing dates too near the end of the sample period or are insufficiently liquid. For the PIN estimates before and after cross-listing events, there are eight pairs with a six-month window, six pairs with a twelve-month window, and nine pairs with an exhaustive window.

[Insert Table 12 about here.]

The arithmetic means of the columns of the PIN show that they rise around the cross-listing events. The pre- versus post-cross-listing scatter plots are provided for respective event windows in Figures 3, 4, and 5. The PIN on the TSX, on average, rises upon cross-listing on the NYSE within all event windows. The significance of the PIN increase (rise in the relative degree of adverse selection) around cross-listings can be verified by the Wilcoxon test with the difference in PINs before and after cross-listings.[46]

[Insert Table 13 about here.]

In Table 13, each of the null hypotheses against the alternative hypotheses are rejected at a 10% right-tail significance level. This result that the PIN rises (or that the intensity of private information increases) on the home exchange upon cross-listing unifies and extends the existing claims in the cross-border finance literature.

Cross-listing lowers transaction costs and narrows the spreads on the TSX and, resultantly, reduces noise trader risk (Eun and Sabherwal (2003), Fleming, Ostdiek, Whaley (1996), and Jones and Seguin (1997)), or subdues excessive volatility borne by liquidity trades. The more perverse degree of adverse selection in the home market shown in Table 13 is the first documentation of *relative* cross-listing effects on the home exchange information environment.[47] The aforementioned articles only mention the decrease in *absolute* magnitude of noise trades.

---

[46] $H_0 : \text{PIN}_{+3\text{M}} = \text{PIN}_{-3\text{M}}$ versus $H_1 : \text{PIN}_{+3\text{M}} > \text{PIN}_{-3\text{M}}$,
$H_0 : \text{PIN}_{+6\text{M}} = \text{PIN}_{-6\text{M}}$ versus $H_1 : \text{PIN}_{+6\text{M}} > \text{PIN}_{-6\text{M}}$,
$H_0 : \text{PIN}_{\text{after}} = \text{PIN}_{\text{before}}$ versus $H_1 : \text{PIN}_{\text{after}} > \text{PIN}_{\text{before}}$.

[47] In a comparable case, Chan, Menkveld, and Yang (2008) report that the PIN on B shares in China (that had only been legally traded by foreign investors) rises on opening access to locals.

The TSX-listed firms, on average, post negative cumulative abnormal returns (CARs) within all event windows around cross-listings in Table 12. This result resembles that of Foerster and Karolyi (1999). It is reasonable that Canadian firms who cross-list in the U.S. do not benefit from lower costs of capital. Unlike those in the emerging market economies, Canadian managers can easily diversify their financing risk across the border.

There appears to be no discernable cross-listing premium due to diminished market incompleteness (Merton (1987)) for Canadian cross-listers in the U.S. The higher post-cross-listing PIN intuitively explains the negative event study returns on the home-listed stocks. As the original TSX listings become more concentrated with private information, they must reflect relative discounts in equilibrium, as in Easley, Hvidkjaer, and O'Hara (2002).

[Insert Table 14 about here.]

$$\begin{aligned} \text{RETURN}_{\text{AB}} &= \beta_0 + \beta_1\,\text{PIN} + \beta_2\,\text{CROSS-LIST} + \beta_3\,\text{SPREAD} + \beta_4\,\text{VOLUME} + \beta_5\,\text{VOLATILITY} \\ &\quad + \beta_6\,\text{PIN} \times \text{CROSS-LIST} + \beta_7\,\text{SPREAD} \times \text{CROSS-LIST} \\ &\quad + \beta_8\,\text{VOLUME} \times \text{CROSS-LIST} + \beta_9\,\text{VOLATILITY} \times \text{CROSS-LIST} + \epsilon. \end{aligned}$$

Accordingly, the negative abnormal returns on the TSX-listed stocks upon cross-listing on the NYSE are associated with heavier trade informedness in Table 14. In the fixed-effect panel regression analyses, the abnormal returns[48] ($\text{RETURN}_{\text{AB}}$) on the original listings on the TSX are regressed, on a monthly basis, onto the PIN, cross-

[48]The monthly cumulative return on the stock minus the monthly cumulative return on the market index.

listing dummy,[49] spread,[50] volume,[51] return volatility,[52] and cross-listing interaction terms. Once cross-listed, the home-listed stock returns, on average, with the intensity of informed trades (PIN×CROSS-LIST). This relation is robust to controlling for other variables. Spread, volume, and volatility measures do not appear as economically and statistically significant as the PIN after cross-listings on the NYSE.

[Insert Table 15 about here.]

Table 15 shows that the bid-ask spreads evidently narrow after cross-listing events over the exhaustive threshold window (before and after cross-listing through the sample period), a finding consistent with Foerster and Karolyi (1998). Whether Canadian firms' cross-listings on the NYSE facilitate enhanced volume[53] on the home exchange is shown in Table 16. Statistically, the incremental effect of cross-listing on home market liquidity is not strong, perhaps due to the limited sample size. This may also reflect Karolyi's (2006) summarizing comment that "... Price discovery does not necessarily originate in the markets with the highest relative turnover, but rather where the informed traders are going with limited market impact."

[Insert Table 16 about here.]

The above findings suggest that, at least within integrated economies, cross-listings boost the intensity of private information-based trades in home-listed stocks. A higher proportion of informed traders is a double-edged sword: it fosters price discovery *and* exacerbates adverse selection. This shift in information ambience lends support to the

[49] A dummy variable which equals one in the month of cross-listing event, or zero otherwise.
[50] The monthly average relative quoted spread.
[51] The monthly average per-trade number of shares.
[52] The standard deviation of daily returns multiplied by 250/12.
[53] The per-trade number of TSX-listed shares of NYSE-cross-listed Canadian firms.

claim of Bailey, Karolyi, and Salva (2006) that cross-listings may not reduce information asymmetry. The managers of Canadian firms may have been led to trading on inside information upon cross-listings that resulted in undermining their existing shareholder values given the comparatively lax insider trading environment on the TSX (King and Segal (2004)) during the sample period. The result herein may contradict the bonding hypothesis (Coffee (1999)) which states that insiders have "less" incentive to trade after cross-listings.

6 Conclusion

In this paper, I address how information asymmetry determines relative pricing of Canadian stocks that trade across the Niagara Falls. The theoretical prediction is empirically supported with evidence on Canadian shares listed on both the Toronto and New York stock exchanges, from January 1998 through December 2000. The three key results reveal "information asymmetry" explains across the border, across time, and around cross-listing events. Overall, the PIN proves to be a useful for understanding the effect of asymmetric information on stock trading fragmented across an international border.

My first empirical finding reveals that, on average, the TSX leads the NYSE in price discovery (measured by information share) and shows a higher PIN. In other words, the exchange with greater intensity of informed trading contributes more to price discovery. This is explicit *cross-border* evidence that informed traders stoke price discovery. However, the higher proportion of informed traders on the TSX is, likely to be, due to the comparatively lax regulatory environment therein by then.

Second, I find that New York and Toronto prices of lower-PIN stocks converge more rapidly. Specifically, a preponderance of discretionary liquidity traders yields a low PIN, and some of them attempt to arbitrage the cross-listing premium when there are fewer informed traders around. This is the first notable documentation that relates the dynamics of premiums and discounts on home versus foreign listings to asymmetric information.

Finally, on average, the PIN on a TSX-listed stock rises upon cross-listing on the NYSE. This finding of *relative* cross-listing effects on the home market information environment not only explains negative cross-listing announcement event study returns but also unifies and extends existing findings in the literature. Previous articles mention a reduced noise trader risk as a result of decreased transaction costs on the home exchange following cross-listings.

There are numerous unresolved issues for cross-listings between integrated markets. The consequences of cross-listings by Canadian firms I have shown imply that insiders may trade more on hidden corporate information in their home market as their companies cross-list overseas. This is likely to be a downside of cross-listing. As this contradicts the bonding hypothesis, I leave a testable hypothesis for future research. Cross-listing emerging market firms may warrant higher event study returns on their home exchanges than for developed country firms. This is possible since the former group's bonding effect is dominant while the latter group's adverse selection aggravates like I have shown in the paper.

References

[1] Admati, A. and P. Pfleiderer. 1988. “A Theory of Intraday Patterns: Volume and Price Variability.” *Review of Financial Studies* 1: 3-40.

[2] Akaike, Hirotugu. 1974. “A New Look at the Statistical Model Identification.” *IEEE Transactions on Automatic Control* 19(6): 716-723.

[3] Bagehot, W. 1971. “The Only Game in Town.” *Financial Analysts Journal* 22: 12-14.

[4] Bailey, Warren B., G. Andrew Karolyi, and C. Salva. 2006. “The Economic Consequences of Increased Disclosure: Evidence from International Cross-Listings.” *Journal of Financial Economics* 81(1):175-213.

[5] Bailey, Warren B., Connie X. Mao, and Kulpatra Sirodon. 2006. “Locals, Foreigners, and Multi-Market Trading of Equities: Some Intraday Evidence.” Working Paper, Cornell University, Temple University and Thammasat University.

[6] Bailey, Warren B., Connie X. Mao, and Kulpatra Sirodom. 2007. “Investment Restrictions and the Cross-Border Flow of Information: Some Empirical Evidence.” *Journal of International Money and Finance* 26: 1-25.

[7] Bank of New York. 2006. *The Depositary Receipt Markets.* New York: Bank of New York.

[8] Blume, M. E. and M. Goldstein. 1991. “Execution Costs on the NYSE, the Regionals and the NASD.” Working Paper, University of Pennsylvania.

[9] Chan, Kalok, Albert J. Menkveld, and Zhishu Yang. 2008. “Information Asymmetry and Asset Prices: Evidence from the China Foreign Share Discount.” *The Journal of Finance* 58(1): 159-196.

[10] Choe, Hyuk, Kho, Bong-Chan, and Rene M. Stulz. 2005. “Do Domestic Investors Have an Edge? The Trading Experience of Foreign Investors in Korea.” *The Review of Financial Studies* 18: 795-830.

[11] Chowdhry, Bhagwan, and Vikram Nanda. 1991. “Multimarket Trading and Market Liquidity.” *The Review of Financial Studies* 3: 483-511.

[12] Coffee, J. 1999. “The Future as History: The Prospects for Global Convergence in Corporate Governance and Its Implications.” *Northwestern University Law Review* 93: 641-708.

[13] De Long, J.B., A. Shleifer, L.H. Summers, and R.J. Waldmann. 1990. “Noise trader risk in financial markets.” *Journal of Political Economy* 98: 703-738.

[14] Dempster, Arthur, Nan Laird, and Donald Rubin. 1977. ”Maximum likelihood from incomplete data via the EM algorithm.” *Journal of the Royal Statistical Society* 39(1):1-38.

[15] Dickey, David A., and Wayne A. Fuller. 1981. “Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root.” *Econometrica* 49: 1057-1072.

[16] Doidge, Craig, G. Andrew Karolyi, and Rene M. Stulz. 2009. “Has New York Become Less Competitive in Global Markets? Evaluating Foreign Listing Choices over Time.” Forthcoming, *The Review of Financial Economics.*

[17] Duarte, Jefferson, and Lance Young. 2009. “Why is PIN Priced?” *Journal of Financial Economics* 91: 119-138.

[18] Easley, David, Robert F. Engle, Maureen O’Hara, and Liuren Wu. 2008. “Time-Varying Arrival Rates of Informed and Uninformed Trades.” *Journal of Financial Ecnometrics* 6(2):171-207.

[19] Easley, David, Soeren Hvidkjaer, and Maureen O’Hara. 2002. “Is Information Risk a Determinant of Asset Returns?” *The Journal of Finance* 57: 2185-2221.

[20] Easley, David, Nicholas M. Kiefer, and Maureen O’Hara. 1996. “Cream-Skimming or Profit-Sharing? The Curious Role of Purchased Order Flow.” *The Journal of Finance* 51(3): 811-833.

[21] Easley, David, Nicholas M. Kiefer, and Maureen O'Hara. 1997. "The Information Content of the Trading Process." *Journal of Empirical Finance* 4: 159-186.

[22] Easley, David, Nicholas M. Kiefer, and Maureen O'Hara. 1997. "One Day in the Life of a Very Common Stock." *The Review of Financial Studies* 10(3): 805-835.

[23] Easley, David, Nicholas M. Kiefer, Maureen O'Hara and Joseph B. Paperman 1996. "Liquidity, Information, and Infrequently Traded Stocks." *The Journal of Finance* 51(4): 1405-1436.

[24] Easley, David, Maureen O'Hara, and Gideon Saar. 2001. "How Stock Splits Affect Trading: A Microstructure Approach." *Journal of Financial and Quantitative Analysis* 36(1): 25-51.

[25] Engle, R. F. and C. Granger. 1987. "Co-integration and Error Correction: Representation, Estimation, and Testing." *Econometrica* 55(2): 251-276.

[26] Engle, R. F. and B. S. Yoo. 1987. "Forecasting and Testing in Co-integrated Systems." *Journal of Econometrics* 35: 143-159.

[27] Eun, C. and S. Sabherwal. 2003. "Cross-Border Listings and Price Discovery: Evidence from U.S. Listed Canadian Stocks." *Journal of Finance* 58: 549-574.

[28] Fleming, Jeff, Barbara Osdiek, and Robert E. Whaley. 1996. "Trading Costs and the Relative Rates of Price Discovery in Stock, Futures, and Option Markets." *Journal of Futures Markets* 16: 353-387.

[29] Foerster, Stephen R., and G. Andrew Karolyi. 1998. "Multimarket Trading Liquidity: A Transaction Data Analysis of Canada-U.S. Interlistings." *Journal of Internatinal Financial Markets, Institions and Money* 8: 393-412.

[30] Foerster, Stephen R., and G. Andrew Karolyi. 1999. "The Effects of Market Segmentation and Investor Recognition on Asset Prices: Evidence from foreign stocks listing in the United States." *Journal of Finance* 54: 981-1013.

[31] Froot, K. A. and E. Dabora. 1999. "How are Stock Prices Affected by the Location of Trade?" *Journal of Financial Economics* 53: 189-216.

[32] Fuller, K., B. Van Ness, and R. Van Ness. "Is Information Risk Priced for NASDAQ-listed Securities." Working Paper, University of Mississippi.

[33] Gardner, A, and A. Subrahmanyam. 1994. "Multi-Market Trading and the Informativeness of Stock Trades: An Empirical Intraday Analysis." Working Paper, Columbia University.

[34] Gagnon, L. and G. Andrew Karolyi. 2009. "Multi-Market Trading and Arbitrage." Forthcoming, *Journal of Financial Economics*.

[35] Glosten, L., and P. Milgrom. 1985. "Bid, Ask and Transaction Prices in a Specialist Market with Heterogeneously Informed Traders." *Journal of Financial Economics* 14: 71-100.

[36] Grossman, S., and J. Stiglitz. 1980. "On the Impossibility of Informationally Efficient Markets." *American Economic Review* 70: 393-408.

[37] Harris, Frederick H. deB.,Thomas H. McInish, and Robert A. Wood. 2002. "Security Price Adjustment across Exchanges: An Investigatino of Common Factor Components for Dow Stocks." *Journal of Financial Markets* 5: 277-308.

[38] Harris, Frederick H. deB.,Thomas H. McInish, Gary L. Shoesmith, and Robert A. Wood. 1995. "Cointegration, Error Correction and Price Discovery on Informationally Linked Security Markets." *Journal of Financial and Quantitative Analysis* 30: 563-579.

[39] Hasbrouck, Joel. 1991. "Measuring the Information Content of Stock Trades." *The Journal of Finance* 46: 179-208.

[40] Hasbrouck, Joel. 1995. “One Security, Many Markets: Determining the Contribution to Price Discovery.” *The Journal of Finance* 50(4): 1175-1199.

[41] Hasbrouck, Joel. 2007. *Empirical Market Microstructure: The Institutions, Economics, and Econometrics of Securities Trading*. New York: Oxford University Press.

[42] Johansen, Søren. 1991. “Estimation and Hypothesis Testing of Cointegration Vectors in Gaussian Vector Autoregressive Models.” *Econometrica* 59(6): 1551-1580.

[43] Jones, Charles M., and Paul J. Seguin. 1997. “Transaction Costs and Price Volatility: Evidence from Commission Deragulation.” *American Economic Review* 87: 728-737.

[44] Jorion, P. and E. Schwartz. 1986. “Integration vs. Segmentation in the Canadian Stock Market.” *The Journal of Finance* 41: 603-614.

[45] Karolyi, G. Andrew. 2006. “The World of Cross-Listings and Cross-Listings of the World: Challenging Conventional Wisdom.” *Review of Finance* 10(1): 73-115.

[46] Karolyi, G. Andrew, and Stulz, Rene M. 1996. “Why Do Markets Move Together? An Investigation of U.S.-Japan Stock Return Comovements.” *The Journal of Finance* 51(3): 951-86

[47] Kato, K., S. Linn, and J. Schallheim. 1991. “Are There Arbitrage Opportunities in the Market for American Depository Receipts?” *Journal of International Financial Markets, Institutions & Money* 1: 73-89.

[48] Kim, M., A. C. Szakmary, and I. Mathur. 2000. “Price Transmission Dynamics between ADRs and Their Underlying Foreign Securities.” *Journal of Banking and Finance* 24: 1359-1382.

[49] King, Michael R., and Dan Segal. 2004. “International Cross-Listing and the Bonding Hypothesis.” Working Paper, The Bank of Canada.

[50] Kryzanowski, Lawrence, and Hao Zhang. 2002. “Intraday Market Price Integration for Shares Cross-listed Internationally.” *Journal of Financial and Quantitative Analysis* 37(2): 243-269.

[51] Kyle, A. 1985. “Continuous Auctions and Insider Trading.” *Econometrica* 53: 1315-1335.

[52] Lee, Charles M. C. 1993. “Market Integration and Price Execution for NYSE-Listed Securities.” *The Journal of Finance* 48(3): 1009-1038.

[53] Lee, Charles M. C. and Mark J. Ready. 1991. “Inferring Trade Direction from Intraday Data.” *The Journal of Finance* 46(2): 733-746.

[54] Lee, Tae-Hwy, Halbert White and Clive W. J. Granger. 1993. “Testing for Neglected Nonlinearity in Time Series Models: A Comparison of Neural Network Methods and Alternative Tests.” *Journal of Econometrics* 56: 269-290.

[55] Maldonado, W. and A. Saunders. 1983. “Foreign Exchange Futures and the Law of One Price.” *Financial Management* 12: 19-23.

[56] McFarland, Janet. 2002. Report of Business. *Globe and Mail*, 7 October, B6.

[57] Merton, R. C. 1987. “Presidential Address: A Simple Model of Capital Market Equilibrium with Incomplete Information.” *The Journal of Finance* 42: 483-510.

[58] Miller, P. D., and R. M. Morey. 1996. “The Intraday Pricing Behavior of International Dually Listed Securities.” *Journal of International Financial Markets, Institutions and Money* 6: 79-89.

[59] Newey, W.K. and K.D. West. 1987. “A Simple, Positive Semi-Definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix.” *Econometrica* 55: 703-708.

[60] Newey, W.K. and K.D. West. 1994. “Automatic Lag Selection in Covariance Matrix Estimation.” *Review of Economic Studies* 61: 631-653.

[61] Park, J., and A. Tavokkol. 1994. “Are ADRs a Dollar Translation of Their Underlying Securities? The Case of Japanese ADRs.” *Journal of International Financial Markets, Institutions, and Money* 4: 77-87.

[62] Sarkissian, S. and M. Schill. 2004. “The Overseas Listing Decision: New Evidence of Proximity Preference.” *The Review of Financial Studies* 17(3): 769-809.

[63] Schultz, Paul, and Sophie Shive. 2008. “Mispricing of Dual Class Shares: Profit Opportunities, Arbitrage, and Trading.” Working Paper, University of Notre Dame.

[64] van Dyk, D. A. and X. L. Meng. 2001. ”The Art of Data Augmentation (with discussion).” *Journal of Computational and Graphical Statistics* 10: 1-111.

[65] Wahab, M., M. Lashgari, and R. Cohn. 1992. “Arbitrage in the American Depository Receipts Market Revisited.” *Journal of International Markets, Institutions and Money* 2.

[66] Wilcoxon, F. 1945. “Individual Comparisons by Ranking Methods.” *Biometrics* 1: 80-83.

[67] Zhao, Xin and Kee H. Chung. 2006. “Decimal Pricing and Information Based trading: Tick Size and Information Efficiency of Asset Pricing.” *Journal of Business Finance and Accounting* 33: 753-766.

Table 1: Sample of Canadian firms listed on both the TSX and the NYSE

Company	*PIN NYSE*	*Spread NYSE*	*IS NYSE*	*PIN TSX*	*Spread TSX*	*IS TSX*
Abitibi-Consolidated, Inc.	0.151	0.018	41.7%	0.184	0.005	58.3%
Advantage Energy Income Fund	0.372	0.117	50.0%	0.482	0.131	50.0%
Agnico-Eagle Mines Limited	0.188	0.026	50.0%	0.421	0.080	50.0%
Agrium Inc.	0.190	0.020	43.0%	0.202	0.007	57.0%
Alcan Inc.	0.147	0.006	40.7%	0.169	0.003	59.3%
Bank of Nova Scotia (The)	0.234	0.063	49.9%	0.188	0.003	50.1%
Barrick Gold Corporation	0.190	0.008	38.6%	0.215	0.003	61.4%
BCE Inc.	0.112	0.006	49.1%	0.174	0.002	50.9%
Biovail Corporation	0.181	0.008	49.5%	0.220	0.006	50.5%
BMO Financial Group	0.160	0.007	41.4%	0.204	0.002	58.6%
Brookfield Properties Corporation	0.267	0.020	45.3%	0.226	0.016	54.7%
Cameco Corporation	0.223	0.020	38.0%	0.197	0.009	62.0%
Canadian Imperial Bank of Commerce	0.308	0.017	49.9%	0.160	0.002	50.1%
Canadian National Railway Company	0.139	0.007	48.4%	0.215	0.003	51.6%
Canadian Pacific Railway Limited	0.206	0.007	43.8%	0.173	0.003	56.2%
Celestica Inc.	0.186	0.010	44.4%	0.225	0.005	55.6%
CGI Group Inc.	0.195	0.028	49.9%	0.280	0.018	50.1%
Compton Petroleum Corporation	0.110	0.010	50.0%	0.253	0.023	50.0%
Corus Entertainment, Inc.	0.311	0.016	46.0%	0.210	0.012	54.0%
Cott Corporation	0.147	0.012	50.0%	0.223	0.014	50.0%
Domtar Corporation	0.199	0.010	50.0%	0.206	0.007	50.0%
Energy Metals Corporation (Listed NYSE Arca)	0.203	0.059	50.0%	0.274	0.047	50.0%
Enerplus Resources Fund	0.261	0.020	46.2%	0.286	0.019	53.8%
Fairfax Financial Holdings Limited	0.308	0.012	50.0%	0.254	0.007	50.0%
Four Seasons Hotels Inc.	0.202	0.009	46.5%	0.214	0.009	53.5%
Gildan Activewear Inc.	0.239	0.019	83.6%	0.800	0.018	16.4%
Goldcorp Inc.	0.354	0.072	41.4%	0.178	0.011	58.6%
Intertape Polymer Group Inc.	0.246	0.020	40.8%	0.277	0.014	59.2%
IPSCO Inc.	0.301	0.027	48.7%	0.215	0.010	51.3%
Kinross Gold Corporation	0.247	0.059	44.8%	0.231	0.012	55.2%
Magna International Inc.	0.153	0.006	42.6%	0.179	0.004	57.4%
Manulife Financial Corp.	0.223	0.011	41.4%	0.222	0.031	58.6%
MDS Inc.	0.218	0.024	33.8%	0.323	0.038	66.2%
Meridian Gold Inc.	0.205	0.042	42.7%	0.267	0.019	57.3%
Nexen, Inc.	0.168	0.014	44.9%	0.160	0.004	55.1%
Nortel Networks Corporation	0.205	0.006	47.9%	0.188	0.002	52.1%
NOVA Chemicals Corporation	0.245	0.015	38.8%	0.275	0.006	61.2%
Pengrowth Energy Trust	0.247	0.025	49.2%	0.183	0.007	50.8%
Petro-Canada	0.238	0.017	42.5%	0.196	0.004	57.5%
Potash Corporation of Saskatchewan Inc.	0.128	0.007	44.2%	0.170	0.005	55.8%
Precision Drilling Trust	0.167	0.011	36.5%	0.190	0.005	63.5%
Quebecor World, Inc.	0.230	0.013	45.4%	0.183	0.004	54.6%
RBC Financial Group	0.163	0.007	46.3%	0.173	0.002	53.7%
Rogers Communications Inc.	0.179	0.017	37.4%	0.238	0.006	62.6%
Shaw Communications Inc.	0.195	0.012	49.2%	0.187	0.007	50.8%
Stantec Inc.	0.158	0.010	50.0%	0.394	0.020	50.0%
Sun Life Financial, Inc.	0.233	0.042	50.0%	0.263	0.042	50.0%
Suncor Energy Inc.	0.185	0.010	47.4%	0.184	0.004	52.6%
Talisman Energy Inc.	0.190	0.013	39.4%	0.164	0.005	60.6%
TELUS Corporation	0.199	0.014	43.0%	0.228	0.005	57.0%
The Thomson Corporation	0.290	0.034	49.6%	0.175	0.005	50.4%
Tim Hortons Inc.	0.202	0.017	50.0%	0.536	0.124	50.0%
Toronto-Dominion Bank	0.152	0.010	26.0%	0.203	0.002	74.0%
TransAlta Corporation	0.308	0.081	49.9%	0.180	0.005	50.1%
TransCanada Corporation	0.157	0.012	48.6%	0.211	0.004	51.4%
Mean	0.211	0.022	45.8%	0.241	0.016	54.2%
Median	0.202	0.014	46.2%	0.211	0.006	53.8%
Standard Deviation	0.058	0.022	7.3%	0.108	0.026	7.3%

The PIN is the probability of informed trading, following Easley, Kiefer, O'Hara, and Paperman (1996). The bid-ask spreads are defined: *1.* $\text{SPREAD}_{\text{NYSE}} \equiv \frac{\text{ask}_{\text{NYSE}} - \text{bid}_{\text{NYSE}}}{(\text{ask}_{\text{NYSE}} + \text{bid}_{\text{NYSE}})/2}$; and *2.* $\text{SPREAD}_{\text{TSX}} \equiv \frac{\text{ask}_{\text{TSX}} - \text{bid}_{\text{TSX}}}{(\text{ask}_{\text{TSX}} + \text{bid}_{\text{TSX}})/2}$. The information share (IS) is exchange-specific relative contribution to price discovery of a security traded on multiple exchanges, following Hasbrouck (1995, 2007). All values are arithmetic means of monthly estimates through the sample period: January 1, 1998, through December 31, 2000.

Table 2: Summary statistics of cross-listing premiums

	Mean	Median	Standard Deviation	*No. of Obs.*
$(p_{\text{NYSE}} - p_{\text{TSX}})/p_{\text{TSX}}$	0.00864	0.00023	0.21614	34,418

For a TSX-NYSE cross-listed pair, the cross-listing premium ($\equiv (p_{\text{NYSE}} - p_{\text{TSX}})/p_{\text{TSX}}$) is the percentage premium earned on the NYSE-listed stock against the original listing traded on the TSX, adjusted for the U.S.-Canada exchange rate. Above summary statistics are based on end-of-the-month daily closing prices and monthly PINs of 55 cross-listed pairs through the sample period: January 1, 1998, through December 31, 2000. The observations are in firm-days.

Table 3: Cross-listing premiums against cross-border difference in the PIN

$$(p_{\text{NYSE}} - p_{\text{TSX}})/p_{\text{TSX}} = \beta\,(\text{PIN}_{\text{TSX}} - \text{PIN}_{\text{NYSE}}) + \epsilon$$

	Estimate	*No. of Obs.*	*Adj.* R^2
$(\text{PIN}_{\text{TSX}} - \text{PIN}_{\text{NYSE}})$	1.087^{***}	1,591	0.176
	(3.259)		

The PIN is the probability of informed trading, following Easley, Kiefer, O'Hara, and Paperman (1996). $(p_{\text{NYSE}} - p_{\text{TSX}})/p_{\text{TSX}}$ is the cross-listing premium on a NYSE-listed stock against its TSX-listed basis share over the sample period: January 1, 1998, through December 31, 2000. $(\text{PIN}_{\text{TSX}} - \text{PIN}_{\text{NYSE}})$ is the difference in the monthly PINs on the TSX- and the NYSE-listed pairs, respectively. The numerical value in the parentheses below the estimate is a t-statistic. ***, **, and * stand for statistical significance based on two-sided student-t tests at the 1%, 5%, and 10% level, respectively. The observations are in firm-months.

Table 4: Wilcoxon signed-rank test results

	PIN	Spread	Information Share
H_0	$\text{PIN}_{\text{TSX}} = \text{PIN}_{\text{NYSE}}$	$\text{SPREAD}_{\text{TSX}} = \text{SPREAD}_{\text{NYSE}}$	$\text{IS}_{\text{TSX}} = \text{IS}_{\text{NYSE}}$
H_1	$\text{PIN}_{\text{TSX}} > \text{PIN}_{\text{NYSE}}$	$\text{SPREAD}_{\text{NYSE}} > \text{SPREAD}_{\text{TSX}}$	$\text{IS}_{\text{TSX}} > \text{IS}_{\text{NYSE}}$
d	$\text{PIN}_{\text{TSX}}(i,t) - \text{PIN}_{\text{NYSE}}(i,t)$	$\text{SPREAD}_{\text{NYSE}}(i,t) - \text{SPREAD}_{\text{TSX}}(i,t)$	$\text{IS}_{\text{TSX}}(i,t) - \text{IS}_{\text{NYSE}}(i,t)$
V_0	424250	680698	2926092
p-value	0.001458	$< 2.2 \times 10^{-16}$	$< 2.2 \times 10^{-16}$

The PIN is the probability of informed trading, following Easley, Kiefer, O'Hara, and Paperman (1996). The bid-ask spreads are defined as: *1.* $\text{SPREAD}_{\text{NYSE}} \equiv \frac{\text{ask}_{\text{NYSE}} - \text{bid}_{\text{NYSE}}}{(\text{ask}_{\text{NYSE}} + \text{bid}_{\text{NYSE}})/2}$; and *2.* $\text{SPREAD}_{\text{TSX}} \equiv \frac{\text{ask}_{\text{TSX}} - \text{bid}_{\text{TSX}}}{(\text{ask}_{\text{TSX}} + \text{bid}_{\text{TSX}})/2}$. The information share is exchange-specific relative contribution to price discovery of a security traded on multiple exchanges, following Hasbrouck (1995, 2007). The Wilcoxon signed-rank test is a non-parametric pair-wise comparison test, following Wilcoxon (1945). The coordinates (i,t) denote each firm and each month, respectively. d is a differential measure defined for the estimates of each quantity of interest. They are defined as: *1.* $d(i,t) \equiv \text{PIN}_{\text{TSX}}(i,t) - \text{PIN}_{\text{NYSE}}(i,t)$; *2.* $d(i,t) \equiv \text{SPREAD}_{\text{NYSE}}(i,t) - \text{SPREAD}_{\text{TSX}}(i,t)$; and *3.* $d(i,t) \equiv \text{IS}_{\text{TSX}}(i,t) - \text{IS}_{\text{NYSE}}(i,t)$. The Wilcoxon test-statistic is defined as: $V_0 \equiv \sum_{\{(i,t)\}} \mathbf{1}_{\{d(i,t)>0\}} \cdot \rho_{it}$, where ρ_{it} is the rank of $\{|d(i,t)|\}$.

Table 5: Robustness tests of the PIN

$$\text{PIN} = \beta_0 + \beta_1\,\text{SPREAD} + \beta_2\,\text{IS} + \beta_3\,\texttt{log}(\text{VOLUME}) + \beta_4\,\text{TSX} + \epsilon$$

	Model 1	*Model 2*	*Model 3*
(Intercept)	0.161***		0.110***
	(10.120)		(3.301)
SPREAD	1.938***	2.043***	2.003***
	(22.908)	(23.632)	(20.848)
IS	0.043***	0.017*	
	(5.550)	(1.655)	
log(VOLUME)	−0.000	0.021***	0.003
	(−0.086)	(33.774)	(1.234)
TSX Dummy		0.026***	0.083***
		(6.525)	(4.124)
Company Effect	No	No	Yes
Month Effect	No	No	Yes
Fixed Effect	Yes	Yes	Yes
No. of Obs.	3,960	3,960	3,960
Adj. R^2	0.118	0.855	0.184

The panel dataset is constructed with columns of company symbol, monthly date, TSX indicator, and monthly estimates of the PIN, spread, information share, and volume, following Dempster, Laird, and Rubin (1977), and van Dyk and Meng (2001). On the TSX and the NYSE, for each cross-lister (i) and in each month (t), January 1998 through December 2000, *1.* PIN is the probability of informed trading, following Easley, Kiefer, O'Hara, and Paperman (1996); *2.* SPREAD is the relative quoted spread; *3.* the information share (IS) is exchange-specific relative contribution to price discovery of a security traded on multiple exchanges, following Hasbrouck (1995, 2007); and *4.* VOLUME is the per-trade average volume. TSX equals one if the estimated numerical value is of the TSX, or zero if the NYSE. The numerical values in the parentheses below the estimates are t-statistics. ***, **, and * stand for statistical significance based on two-sided student-t tests at the 1%, 5%, and 10% level, respectively. The observations are in firm-months on both the TSX and the NYSE.

Table 6: Robustness tests of spread

$$\text{SPREAD} = \beta_0 + \beta_1\,\text{PIN} + \beta_2\,\text{IS} + \beta_3\,\texttt{log}(\text{VOLUME}) + \beta_4\,\text{TSX} + \epsilon$$

	Model 1	*Model 2*	*Model 3*
(Intercept)	-0.008^{***}		0.022^{***}
	(-2.723)		(4.219)
PIN	0.064^{***}	0.061^{***}	0.050^{***}
	(22.908)	(23.632)	(20.848)
IS	-0.016^{***}	-0.002	
	(-12.191)	(-1.231)	
log(VOLUME)	0.003^{***}	0.001^{***}	0.002^{***}
	(7.229)	(10.019)	(5.314)
TSX Dummy		-0.008^{***}	-0.013^{***}
		(-12.374)	(-3.983)
Company Effect	No	No	Yes
Month Effect	No	No	Yes
Fixed Effect	Yes	Yes	Yes
No. of Obs.	3,960	3,960	3,960
Adj. R^2	0.155	0.582	0.369

The panel dataset is constructed with columns of company symbol, monthly date, TSX indicator, and monthly estimates of the PIN, spread, information share, and volume, following Dempster, Laird, and Rubin (1977), and van Dyk and Meng (2001). On the TSX and the NYSE, for each cross-lister (i) and in each month (t), January 1998 through December 2000, *1.* PIN is the probability of informed trading, following Easley, Kiefer, O'Hara, and Paperman (1996); *2.* SPREAD is the relative quoted spread; *3.* the information share (IS) is exchange-specific relative contribution to price discovery of a security traded on multiple exchanges, following Hasbrouck (1995, 2007); and *4.* VOLUME is the per-trade average volume. TSX equals one if the estimated numerical value is of the TSX, or zero if the NYSE. The numerical values in the parentheses below the estimates are t-statistics. ***, **, and * stand for statistical significance based on two-sided student-t tests at the 1%, 5%, and 10% level, respectively. The observations are in firm-months on both the TSX and the NYSE.

Table 7: Robustness tests of information share

$$\text{IS} = \beta_0 + \beta_1\,\text{PIN} + \beta_2\,\text{SPREAD} + \beta_3 \log(\text{VOLUME}) + \beta_4\,\text{TSX} + \epsilon.$$

	Model 1	*Model 2*	*Model 3*
(Intercept)	0.484***		0.461***
	(15.162)		(9.696)
PIN	0.179***	0.098*	
	(5.550)	(1.655)	
SPREAD	−2.196***	−0.175	0.038
	(−12.191)	(−1.231)	(0.280)
log(VOLUME)	0.002	0.049***	−0.026***
	(0.651)	(62.986)	(−7.150)
TSX Dummy		0.260***	0.350***
		(57.344)	(12.167)
Company Effect	No	No	Yes
Month Effect	No	No	Yes
Fixed Effect	Yes	Yes	Yes
No. of Obs.	3,960	3,960	3,960
Adj. R^2	0.036	0.919	0.561

The panel dataset is constructed with columns of company symbol, monthly date, TSX indicator, and monthly estimates of the PIN, spread, information share, and volume, following Dempster, Laird, and Rubin (1977), and van Dyk and Meng (2001). On the TSX and the NYSE, for each cross-lister (i) and in each month (t), January 1998 through December 2000, *1.* PIN is the probability of informed trading, following Easley, Kiefer, O'Hara, and Paperman (1996); *2.* SPREAD is the relative quoted spread; *3.* the information share (IS) is exchange-specific relative contribution to price discovery of a security traded on multiple exchanges, following Hasbrouck (1995, 2007); and *4.* VOLUME is the per-trade average volume. TSX equals one if the estimated numerical value is of the TSX, or zero if the NYSE. The numerical values in the parentheses below the estimates are t-statistics. ***, **, and * stand for statistical significance based on two-sided student-t tests at the 1%, 5%, and 10% level, respectively. The observations are in firm-months on both the TSX and the NYSE.

Table 8: Cross-sectional determinants of the convergence speed parameter of cross-listed pairs

$$\text{SPEED}_{\text{CONV}} = \gamma_1\, \text{PIN}_{\text{AVG}} + \gamma_2\, \text{SPREAD}_{\text{AVG}} + \gamma_3\, \text{SIZE} + \gamma_4\, \text{INDUSTRY} + \gamma_5\, \text{VOLUME} + \gamma_6\, \text{GOVERNANCE} + \eta$$

	Model 1	*Model 2*	*Model 3*	*Model 4*
PIN	1.281***	0.919***	1.138***	1.147***
	(4.845)	(3.604)	(5.162)	(3.060)
SPREAD	4.606*	3.034		1.828
	(1.821)	(1.487)		(0.466)
SIZE	0.021	−0.006	−0.074	0.073
	(0.207)	(−0.049)	(−0.537)	(0.706)
INDUSTRY	−0.165***	−0.205***	−0.227***	−0.195***
	(−3.436)	(−2.952)	(−3.203)	(−3.254)
VOLUME		0.406**	0.483**	0.324
		(2.134)	(2.568)	(1.200)
GOVERNANCE				−0.001
				(−0.445)
No. of Obs.	1,591	1,591	1,591	1,591
Adj. R^2	0.606	0.635	0.629	0.557

For each cross-listed pair (i), $\text{SPEED}_{\text{CONV}}$ ($\equiv \theta_i$) measures the reciprocal speed of the parity-convergence of cross-listing premium, following Gagnon and Karolyi's (2004) empirical model:

$$DR_i(t) = \alpha_i + \theta_i\, DR_i(t-1) + \sum_{j=-1}^{1} \beta_j^{US}\, R_M^{US}(t+j) + \sum_{j=-1}^{1} \beta_j^{C}\, R_M^{C}(t+j) + \sum_{j=-1}^{1} \beta_j^{FX}\, R_{FX}(t+j) + \varepsilon_i(t).$$

The daily cross-listing premium $\left(DR_i(t) \equiv \left(P_i^{US}(t) - P_i^{C}(t)\right)/P_i^{C}(t)\right)$ can be explained by *1.* its own lag ($DR_i(t-1)$) associated with *2.* the *convergence speed parameter* (θ_i): the closer the absolute value to zero, the faster the convergence to parity; and lag-distributed (yesterday ($j = -1$), today ($j = 0$), and tomorrow ($j = +1$)) returns on *3.* the S&P 500 Index $\left(R_M^{US}(t+j)\right)$, *4.* the S&P TSX Composite Index $\left(R_M^{C}(t+j)\right)$, and *5.* the Canada-U.S. exchange rate return ($R_{FX}(t+j)$), a positive R_{FX} implies a depreciation in the Canadian dollar. The forward-lag is due to information leakages and market impact. The explanatory variables are: *1.* PIN_{AVG} is the arithmetic average of the PINs of the pair on the TSX and the NYSE; *2.* $\text{SPREAD}_{\text{AVG}}$ is the arithmetic average of the bid-ask spreads of the pair on the TSX and the NYSE; *3.* SIZE is the proxy of normalized firm size and defined as the average market capitalization on the TSX and the NYSE; *4.* INDUSTRY equals one if the cross-lister is a manufacturing firm, or zero otherwise; *5.* VOLUME is the normalized per-trade average volume of the pair on the TSX and the NYSE; and *6.* GOVERNANCE is the Report on Business governance index of Canadian firms published by *Globe and Mail* (McFarland (2002)). Standard errors are corrected for heteroskedasticity, following Newey and West (1987, 1994). The numerical values in the parentheses below the estimates are t-statistics. ***, **, and * stand for statistical significance based on two-sided student-t tests at the 1%, 5%, and 10% level, respectively. The observations are in firm-months.

Table 9: Cross-sectional determinants of cross-border average spread

$$\text{SPREAD}_{\text{AVG}} = \delta_1\, \text{PIN}_{\text{AVG}} + \delta_2\, \text{SPEED}_{\text{CONV}} + \delta_3\, \text{SIZE} + \delta_4\, \text{INDUSTRY} + \epsilon$$

	PIN_{AVG}	$\text{SPEED}_{\text{CONV}}$	SIZE	INDUSTRY
Estimate	0.074^{**}	0.018^{**}	-0.021^{*}	-0.002
	(2.359)	(2.548)	(-1.876)	(-0.289)
No. of Obs.	1,591			
Adj. R^2	0.625			

For each cross-listed pair, i, *1.* $\text{SPEED}_{\text{CONV}}$ ($\equiv \theta$) measures the reciprocal speed of the parity-convergence of cross-listing premium, following Gagnon and Karolyi (2004); *2.* PIN_{AVG} is the arithmetic average of the PINs of the pair on the TSX and the NYSE; *3.* $\text{SPREAD}_{\text{AVG}}$ is the arithmetic average of the bid-ask spreads of the pair on the TSX and the NYSE; *4.* SIZE is the proxy of firm size and defined as the average market capitalization on the TSX and the NYSE; and *5.* INDUSTRY equals one if the cross-lister is a manufacturing firm, or zero otherwise. Standard errors are corrected for heteroskedasticity and autocorrelation, following Newey and West (1987, 1994). The numerical values in the parentheses below the estimates are t-statistics. ***, **, and * stand for statistical significance based on two-sided student-t tests at the 1%, 5%, and 10% level, respectively. The observations are in firm-months.

Table 10: Cross-sectional determinants of cross-listing premiums

$$(p_{\text{NYSE}} - p_{\text{TSX}})/p_{\text{TSX}} = \beta_1 (\text{PIN}_{\text{TSX}} - \text{PIN}_{\text{NYSE}}) + \beta_2\, \text{SPEED}_{\text{CONV}} + \beta_3\, \text{GOVERNANCE} + \epsilon$$

	$\text{PIN}_{\text{TSX}} - \text{PIN}_{\text{NYSE}}$	$\text{SPEED}_{\text{CONV}}$	GOVERNANCE
Estimate	0.849^{***}	0.018^{**}	-0.0003
	(4.125)	(2.669)	(-0.980)
No. of Obs.	1,591		
Adj. R^2	0.380		

For each cross-listed pair, i, *1.* $(p_{\text{NYSE}} - p_{\text{TSX}})/p_{\text{TSX}}$ is the cross-listing premium on the NYSE-listed stock; *2.* $(\text{PIN}_{\text{TSX}} - \text{PIN}_{\text{NYSE}})$ is the difference of the PINs of the pair on the TSX and the NYSE; *3.* $\text{SPEED}_{\text{CONV}}$ measures the reciprocal speed of the parity-convergence of cross-listing premium, following Gagnon and Karolyi (2004); and *4.* GOVERNANCE is the Report on Business governance index of Canadian firms published by *Globe and Mail* (McFarland (2002)). The numerical values in the parentheses below the estimates are t-statistics. ***, **, and * stand for statistical significance based on two-sided student-t tests at the 1%, 5%, and 10% level, respectively. The observations are in firm-months.

Table 11: Test of exchange-specific liquidity skewness

H_0	H_1	d	V_0	*p-value*
$\widetilde{\text{SPREAD}}_{\text{NT}} = \widetilde{\text{SPREAD}}_{\text{TN}}$	$\widetilde{\text{SPREAD}}_{\text{NT}} \neq \widetilde{\text{SPREAD}}_{\text{TN}}$	$\widetilde{\text{SPREAD}}_{\text{NT}}(i,t) - \widetilde{\text{SPREAD}}_{\text{TN}}(i,t)$	507568	0.9407

$\widetilde{\text{SPREAD}}_{\text{NT}}$ is the percentage cross-border arbitrage profit from buying on the TSX and selling on the NYSE, and $\widetilde{\text{SPREAD}}_{\text{TN}}$ is from buying on the NYSE and selloing on the TSX. They are defined as:

- $\widetilde{\text{SPREAD}}_{\text{NT}} \equiv \{\text{ask}_{\text{NYSE}} - \text{bid}_{\text{TSX}} \cdot (\text{US\$/CAN\$})_{\text{ask}}\} / \{\text{bid}_{\text{TSX}} \cdot (\text{US\$/CAN\$})_{\text{ask}}\}$,
- $\widetilde{\text{SPREAD}}_{\text{TN}} \equiv \{\text{ask}_{\text{TSX}} \cdot (\text{US\$/CAN\$})_{\text{bid}} - \text{bid}_{\text{NYSE}}\} / \text{bid}_{\text{NYSE}}$.

The Wilcoxon signed-rank test is a non-parametric pair-wise comparison test, following Wilcoxon (1945). The coordinates (i,t) denote each firm and each month, respectively. d is a differential measure defined as: $d(i,t) \equiv \text{SPREAD}_{\text{TN}}(i,t) - \text{SPREAD}_{\text{NT}}(i,t)$. The Wilcoxon test-statistic is defined as: $V_0 \equiv \sum_{\{(i,t)\}} \mathbf{1}_{\{d(i,t)>0\}} \cdot \rho_{it}$, where ρ_{it} is the rank of $\{|d(i,t)|\}$.

Table 12: Cross-listings on the NYSE by TSX-listed firms, 1998 through 2000

Company	*Industry*	*TSX Code*	*TSX Listing*	*NYSE Code*	*NYSE Listing*	*Listing Sequence*
Celestica Inc.	Electrical and Electronic Products	CLS	7 07, 1998	CLS	6 30, 1998	NYSE → TSX
Shaw Communications Inc.	Communications & Media	SJR.B	3 25, 1983	SJR	7 01, 1998	TSX → NYSE
NOVA Chemicals Corporation	Chemicals	NCX	7 03, 1998	NCX	7 06, 1998	TSX → NYSE
CGI Group Inc.	Consulting	GIB.A	4 21, 1992	GIB	10 07, 1998	TSX → NYSE
Brookfield Properties Corporation	Property Management and Investment	BPO	6 27, 1985	BPO	6 02, 1999	TSX → NYSE
Intertape Polymer Group Inc.	Packaging and Containers	ITP	1 06, 1993	ITP	8 16, 1999	TSX → NYSE
Gildan Activewear Inc.	Household Goods	*GIL*	*6 24, 1998*	*GIL*	*9 01, 1999*	*TSX → NYSE*
Manulife Financial Corp.	Insurance	MFC	9 30, 1999	MFC	9 24, 1999	NYSE → TSX
Sun Life Financial, Inc.	Insurance	SLF	3 29, 2000	SLF	3 23, 2000	NYSE → TSX
MDS Inc.	Medical Services	MDS	6 25, 1973	MDZ	4 07, 2000	TSX → NYSE
Corus Entertainment, Inc.	Entertainment Services	CJR.B	9 03, 1999	CJR	5 10, 2000	TSX → NYSE
Canadian Natural Resources, Ltd.	Oil and Gas Producers	CNQ	5 14, 1976	CNQ	7 31, 2000	TSX → NYSE
TELUS Corporation	Telephone Utilities	T.A	2 01, 1999	TU	10 17, 2000	TSX → NYSE
Nexen, Inc.	Oil and Gas Producers	NXY	7 14, 1971	NXY	11 14, 2000	TSX → NYSE
*Enerplus Resources Fund****	Oil and Gas Producers	*ERF.UN*	*3 11, 1987*	*ERF*	*11 17, 2000*	*TSX → NYSE*

	PIN		*PIN*		*PIN**		*Spread*		*Spread*		*Spread***	
Company	*-3M*	*+3M*	*-6M*	*+6M*	*Before*	*After*	*-3M*	*+3M*	*-6M*	*+6M*	*Before*	*After*
Celestica Inc.						0.186						
Shaw Communications Inc.				0.237		0.164						
NOVA Chemicals Corporation	0.329	0.326	0.329			0.268	0.006	0.007	0.006	0.007	0.006	0.007
CGI Group Inc.	0.183	0.283	0.176	0.277	0.256	0.226	0.268	0.151	0.181	0.123	0.150	0.055
Brookfield Properties Corporation		0.223		0.206	0.068	0.194		0.020		0.017	0.069	0.016
Intertape Polymer Group Inc.	0.218	0.247	0.209	0.209	0.266	0.262	0.034	0.025	0.026	0.025	0.027	0.031
Gildan Activewear Inc.												
Manulife Financial Corp.					0.035	0.150		0.003		0.004	0.221	0.003
Sun Life Financial, Inc.												
MDS Inc.	0.156	0.192	0.156	0.154	0.102	0.238	0.008	0.009	0.008	0.008	0.097	0.008
Corus Entertainment, Inc.	0.098	0.212	0.134	0.180	0.067	0.201	0.029	0.051	0.028	0.042	0.025	0.036
Canadian Natural Resources, Ltd.	0.142	0.127	0.159	0.348	0.152	0.128	0.004	0.003	0.004	0.004	0.007	0.004
TELUS Corporation	0.120	0.338		0.559	0.047	0.336	0.004	0.005	0.006	0.005	0.006	0.005
Nexen, Inc.	0.100	0.163	0.100	0.163	0.018	0.134	0.009	0.005	0.009	0.005	0.009	0.005
*Enerplus Resources Fund****												
Average	***0.168***	***0.235***	***0.180***	***0.259***	***0.112***	***0.207***	***0.045***	***0.028***	***0.033***	***0.024***	***0.062***	***0.017***

	Cumulative Abnormal Return			
Company	*[-2,+2]*	*[-5,+5]*	*[-10,+10]*	*[-10,+250]*
Celestica Inc.				
Shaw Communications Inc.	-0.002	0.156	0.242	0.024
NOVA Chemicals Corporation				
CGI Group Inc.	-0.204	-0.269	-0.204	-0.757
Brookfield Properties Corporation	-0.045	-0.041	-0.075	-0.358
Intertape Polymer Group Inc.	0.031	0.040	0.083	-0.740
Gildan Activewear Inc.	0.046	-0.029	-0.124	-0.477
Manulife Financial Corp.				
Sun Life Financial, Inc.				
MDS Inc.	0.018	-0.006	-0.037	-0.341
Corus Entertainment, Inc.	-0.033	-0.087	-0.047	-0.684
Canadian Natural Resources, Ltd.	0.042	-0.011	-0.019	-0.287
TELUS Corporation	-0.027	0.033	-0.011	-0.615
Nexen, Inc.	-0.025	-0.012	0.001	-0.364
*Enerplus Resources Fund****	0.014	0.007	-0.027	-0.287
Average	***-0.017***	***-0.020***	***-0.020***	***-0.444***

** Arithmetic mean of monthly PIN estimates. For derivation and estimation algorithm of PIN, see Appendix A3.*

*** Arithmetic mean of monthly spread estimates*

**** Prior to June of 2001, Enerplus Resources Fund traded under ERF.G. Upon the merger with EnerMark, the symbol became ERF.UN.*

The PIN is the probability of informed trading, following Easley, Kiefer, O'Hara, and Paperman (1996). The bid-ask spreads are defined as: *1.* $\text{SPREAD}_{\text{NYSE}} \equiv \frac{\text{ask}_{\text{NYSE}} - \text{bid}_{\text{NYSE}}}{(\text{ask}_{\text{NYSE}} + \text{bid}_{\text{NYSE}})/2}$; and *2.* $\text{SPREAD}_{\text{TSX}} \equiv \frac{\text{ask}_{\text{TSX}} - \text{bid}_{\text{TSX}}}{(\text{ask}_{\text{TSX}} + \text{bid}_{\text{TSX}})/2}$. When estimating the cumulative abnormal return (CAR) around a cross-listing on the NYSE, *1.* the market model uses the S&P TSX Composite Index as the market return through the pre-run-up period ($[-250, -11]$) prior to the cross-listing; then *2.* the product of "gross" residuals within an event window is subtracted by one to yield the CAR.

Table 13: Wilcoxon signed-rank test results of cross-listing effect on the PIN on the TSX

	[-3M,+3M]	[-6M,+6M]	Threshold
H_0	$\text{PIN}_{+3\text{M}} = \text{PIN}_{-3\text{M}}$	$\text{PIN}_{+6\text{M}} = \text{PIN}_{-6\text{M}}$	$\text{PIN}_{\text{after}} = \text{PIN}_{\text{before}}$
H_1	$\text{PIN}_{+3\text{M}} > \text{PIN}_{-3\text{M}}$	$\text{PIN}_{+6\text{M}} > \text{PIN}_{-6\text{M}}$	$\text{PIN}_{\text{after}} > \text{PIN}_{\text{before}}$
d	$\text{PIN}_{+3\text{M}} - \text{PIN}_{-3\text{M}}$	$\text{PIN}_{+6\text{M}} - \text{PIN}_{-6\text{M}}$	$\text{PIN}_{\text{after}} - \text{PIN}_{\text{before}}$
V_0	33	14	30
p-value	0.01953	0.05282	0.05469

The PIN is the probability of informed trading, following Easley, Kiefer, O'Hara, and Paperman (1996). d is a differential measure defined for the estimates of each quantity of interest. The Wilcoxon signed-rank test is a non-parametric pair-wise comparison test, following Wilcoxon (1945). The Wilcoxon test-statistic is defined as: $V_0 \equiv \sum_{\{(i,t)\}} \mathbf{1}_{\{d(i,t)>0\}} \cdot \rho_{it}$, where ρ_{it} is the rank of $\{|d(i,t)|\}$, and the coordinates (i,t) denote each firm and each period, respectively.

Table 14: Fixed-effect panel regression analyses of abnormal returns of TSX-listed stocks

$$\begin{aligned}\text{RETURN}_{\text{AB}} \;=\; & \beta_0 + \beta_1\,\text{PIN} + \beta_2\,\text{CROSS-LIST} + \beta_3\,\text{SPREAD} + \beta_4\,\text{VOLUME} + \beta_5\,\text{VOLATILITY} \\ & + \beta_6\,\text{PIN} \times \text{CROSS-LIST} + \beta_7\,\text{SPREAD} \times \text{CROSS-LIST} \\ & + \beta_8\,\text{VOLUME} \times \text{CROSS-LIST} + \beta_9\,\text{VOLATILITY} \times \text{CROSS-LIST} + \epsilon\end{aligned}$$

	Model 1	*Model 2*	*Model 3*	*Model 4*	*Model 5*	*Model 6*
(Intercept)	0.024	0.025*	0.025*	0.020	0.017	0.020
	(1.636)	(1.670)	(1.652)	(1.300)	(1.148)	(1.248)
PIN	−0.050	−0.037	−0.034	−0.065	−0.020	0.005
	(−0.456)	(−0.320)	(−0.294)	(−0.566)	(−0.175)	(0.041)
CROSS-LIST Dummy	−0.035*	−0.037*	−0.037*	−0.028	−0.024	−0.025
	(−1.886)	(−1.911)	(−1.898)	(−1.447)	(−1.278)	(−1.297)
SPREAD		−0.280	−0.281	−0.296		−0.548
		(−0.356)	(−0.355)	(−0.382)		(−0.559)
VOLUME			0.000	0.000	0.000	0.000
			(0.204)	(−0.570)	(1.491)	(1.427)
VOLATILITY				−0.124***	−0.077	−0.073
				(−3.185)	(−0.969)	(−0.913)
PIN×CROSS-LIST	−0.255*	−0.264*	−0.266*	−0.251*	−0.306**	−0.336**
	(−1.716)	(−1.747)	(−1.754)	(−1.686)	(−2.056)	(−2.138)
SPREAD×CROSS-LIST						0.874
						(0.544)
VOLUME×CROSS-LIST					0.000**	0.000*
					(−2.013)	(−1.957)
VOLATILITY×CROSS-LIST					−0.073	−0.077
					(−0.805)	(−0.834)
No. of Obs.	218	218	218	218	218	218
Adj. R^2	0.039	0.035	0.031	0.071	0.086	0.079

13 TSX-listed firms cross-listed on the NYSE through the sample period: January 1, 1998 through December 31, 2000. For each firm (i) and in each month (t), *1.* the abnormal return ($\text{RETURN}_{\text{AB}}$) is the monthly cumulative return minus the monthly cumulative return on the S&P TSX Composite Index; *2.* PIN is the monthly estimate of the probability of informed trading, following Easley, Kiefer, O'Hara, and Paperman (1996); *3.* CROSS-LIST is a dummy variable which equals one in the month of cross-listing on the NYSE, or zero otherwise; *4.* SPREAD is the monthly average relative quoted spread; *5.* VOLUME is the monthly average per-trade number of shares; and *6.* VOLATILITY is the standard deviation of daily returns multiplied by 250/12. The numerical values in the parentheses below the estimates are t-statistics. ***, **, and * stand for statistical significance based on two-sided student-t tests at the 1%, 5%, and 10% level, respectively. The observations are in firm-months.

Table 15: Wilcoxon signed-rank test results of cross-listing effect on bid-ask spread on the TSX

	[-3M,+3M]	[-6M,+6M]	Threshold
H_0	$\text{SPREAD}_{+3\text{M}} = \text{SPREAD}_{-3\text{M}}$	$\text{SPREAD}_{+6\text{M}} = \text{SPREAD}_{-6\text{M}}$	$\text{SPREAD}_{\text{after}} = \text{SPREAD}_{\text{before}}$
H_1	$\text{SPREAD}_{+3\text{M}} < \text{SPREAD}_{-3\text{M}}$	$\text{SPREAD}_{+6\text{M}} < \text{SPREAD}_{-6\text{M}}$	$\text{SPREAD}_{\text{after}} < \text{SPREAD}_{\text{before}}$
d	$\text{SPREAD}_{-3\text{M}} - \text{SPREAD}_{+3\text{M}}$	$\text{SPREAD}_{-6\text{M}} - \text{SPREAD}_{+6\text{M}}$	$\text{SPREAD}_{\text{before}} - \text{SPREAD}_{\text{after}}$
V_0	45	48	72
p-value	0.34820	0.25740	0.05260

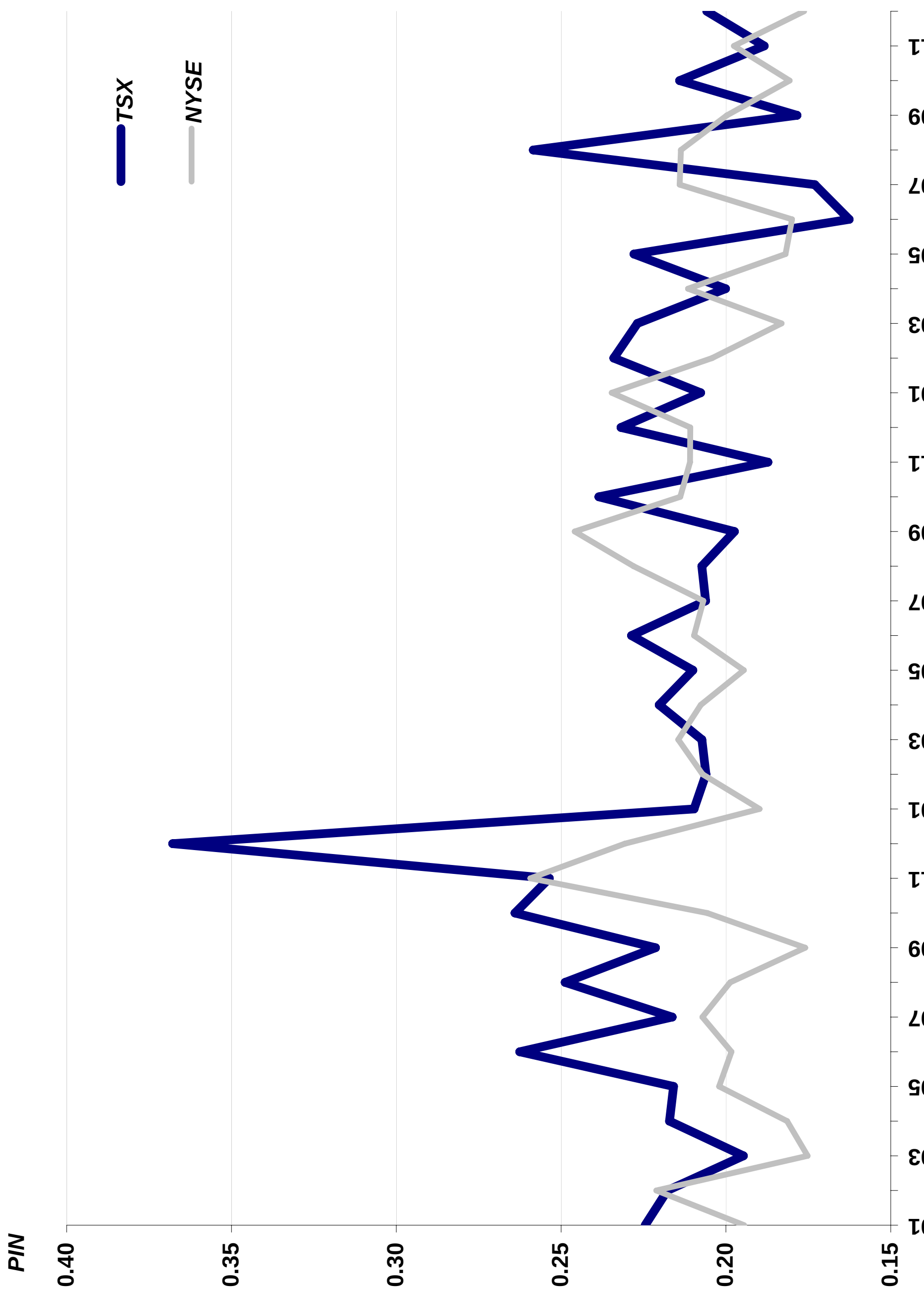
The bid-ask spreads are defined as: *1.* $\text{SPREAD}_{\text{NYSE}} \equiv \frac{\text{ask}_{\text{NYSE}} - \text{bid}_{\text{NYSE}}}{(\text{ask}_{\text{NYSE}} + \text{bid}_{\text{NYSE}})/2}$; and *2.* $\text{SPREAD}_{\text{TSX}} \equiv \frac{\text{ask}_{\text{TSX}} - \text{bid}_{\text{TSX}}}{(\text{ask}_{\text{TSX}} + \text{bid}_{\text{TSX}})/2}$. The Wilcoxon signed-rank test is a non-parametric pair-wise comparison test, following Wilcoxon (1945). d is a differential measure defined for the estimates of each quantity of interest. The Wilcoxon test-statistic is defined: $V_0 \equiv \sum_{\{(i,t)\}} \mathbf{1}_{\{d(i,t)>0\}} \cdot \rho_{it}$, where ρ_{it} is the rank of $\{|d(i,t)|\}$, and the coordinates (i,t) denote each firm and each period, respectively.

Table 16: Wilcoxon signed-rank test results of cross-listing effect on volume on the TSX

	[-3M,+3M]	[-6M,+6M]	Threshold
H_0	$\text{VOLUME}_{+3\text{M}} = \text{VOLUME}_{-3\text{M}}$	$\text{VOLUME}_{+6\text{M}} = \text{VOLUME}_{-6\text{M}}$	$\text{VOLUME}_{\text{after}} = \text{VOLUME}_{\text{before}}$
H_1	$\text{VOLUME}_{+3\text{M}} > \text{VOLUME}_{-3\text{M}}$	$\text{VOLUME}_{+6\text{M}} > \text{VOLUME}_{-6\text{M}}$	$\text{VOLUME}_{\text{after}} > \text{VOLUME}_{\text{before}}$
d	$\text{VOLUME}_{+3\text{M}} - \text{VOLUME}_{-3\text{M}}$	$\text{VOLUME}_{+6\text{M}} - \text{VOLUME}_{-6\text{M}}$	$\text{VOLUME}_{\text{after}} - \text{VOLUME}_{\text{before}}$
V_0	42	39	58
p-value	0.7293	0.6285	0.9433

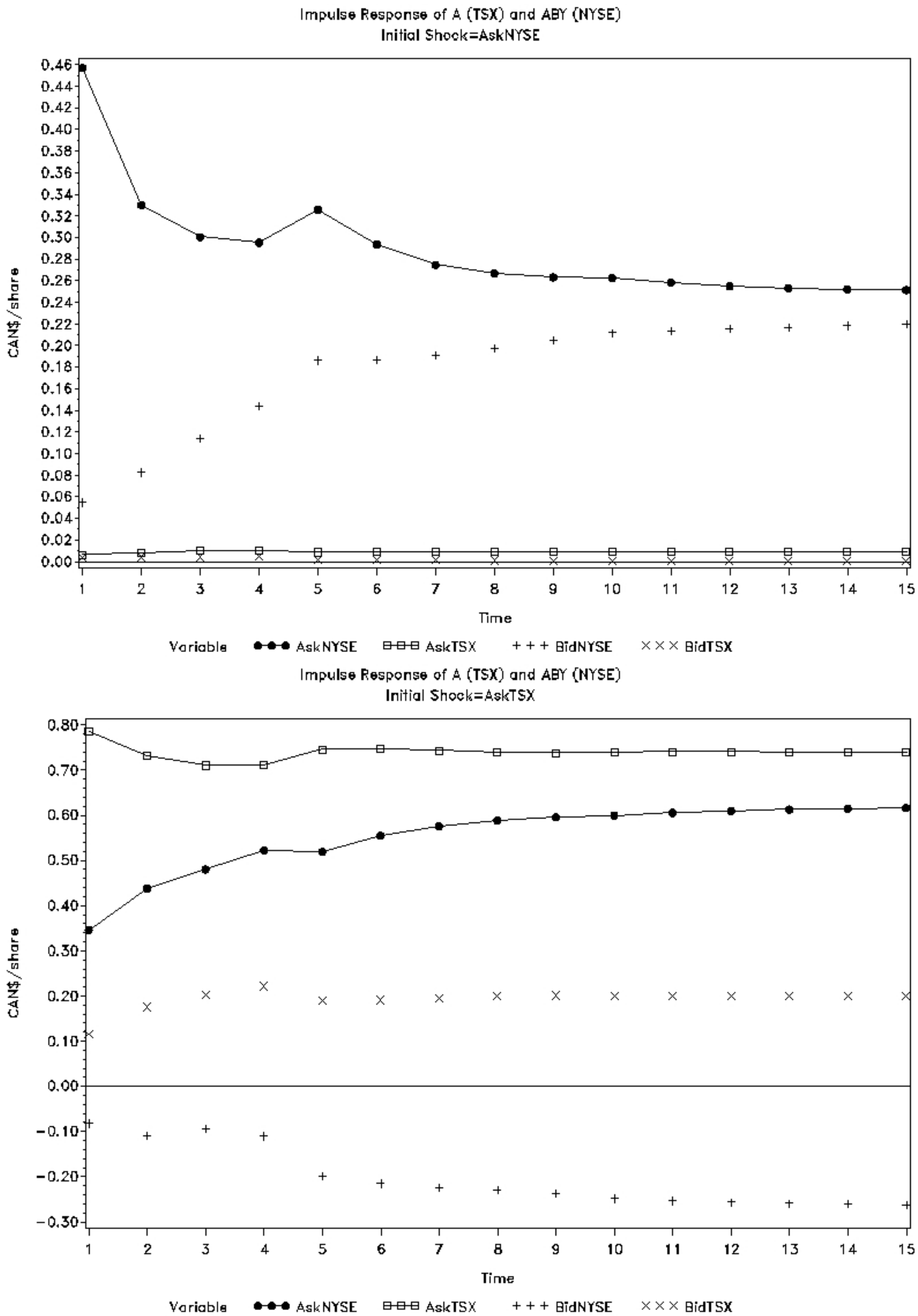
VOLUME is per-trade number of the TSX-listed stock of a NYSE-cross-listed Canadian firm. The Wilcoxon signed-rank test is a non-parametric pair-wise comparison test, following Wilcoxon (1945). d is a differential measure defined for the estimates of each quantity of interest. The Wilcoxon test-statistic is defined: $V_0 \equiv \sum_{\{(i,t)\}} \mathbf{1}_{\{d(i,t)>0\}} \cdot \rho_{it}$, where ρ_{it} is the rank of $\{|d(i,t)|\}$, and the coordinates (i,t) denote each firm and each period, respectively.

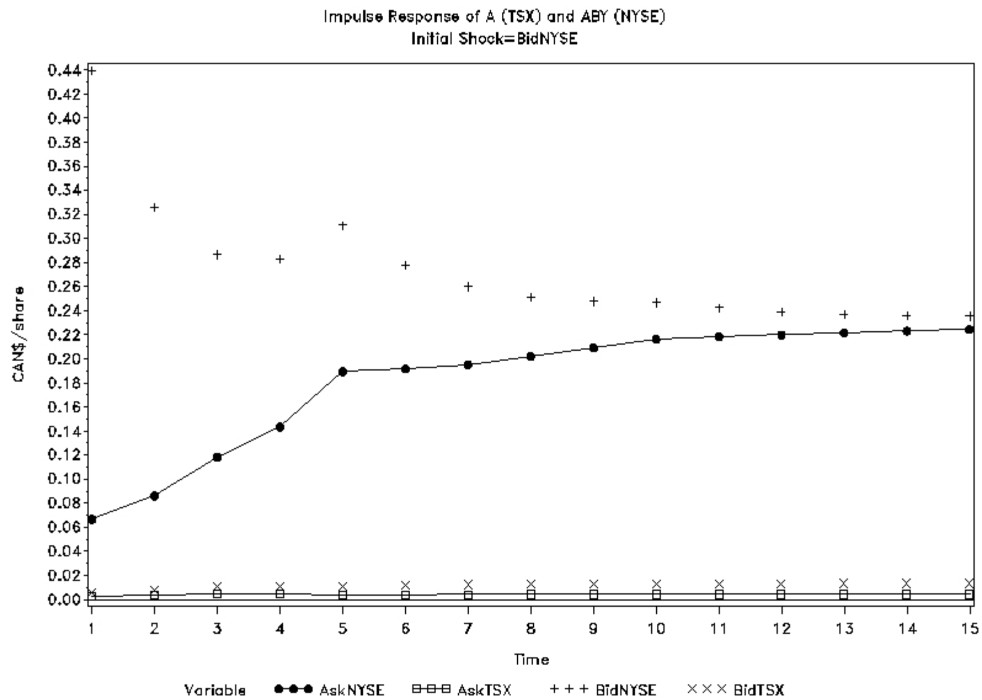
Figure 1: Monthly estimates of PIN on TSX and NYSE

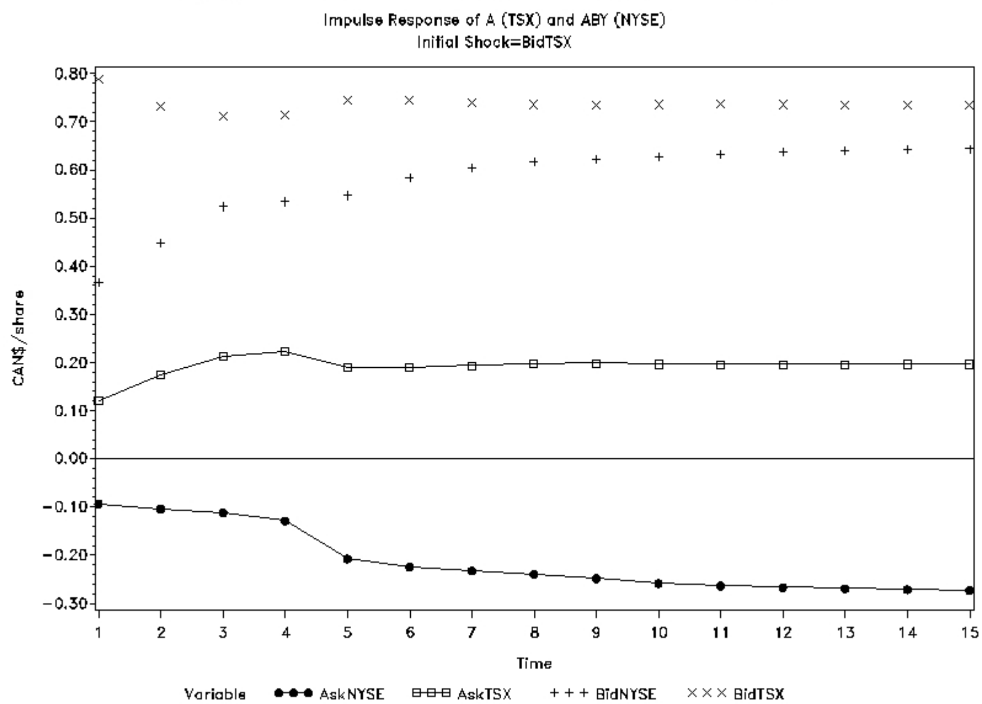


The PIN is the probability of informed trading, following Easley, Kiefer, O'Hara, and Paperman (1996). Figure 1 shows the average monthly PIN of the sample firms co-listed on the TSX and the NYSE. The annual estimates for the PIN on the TSX are {0.242, 0.213, 0.206} in 1998, 1999, and 2000, respectively, while the corresponding estimates for the NYSE are {0.204, 0.212, 0.196}, over the same period.

Figure 2: Impulse response function plots: cross-border responses of quote changes

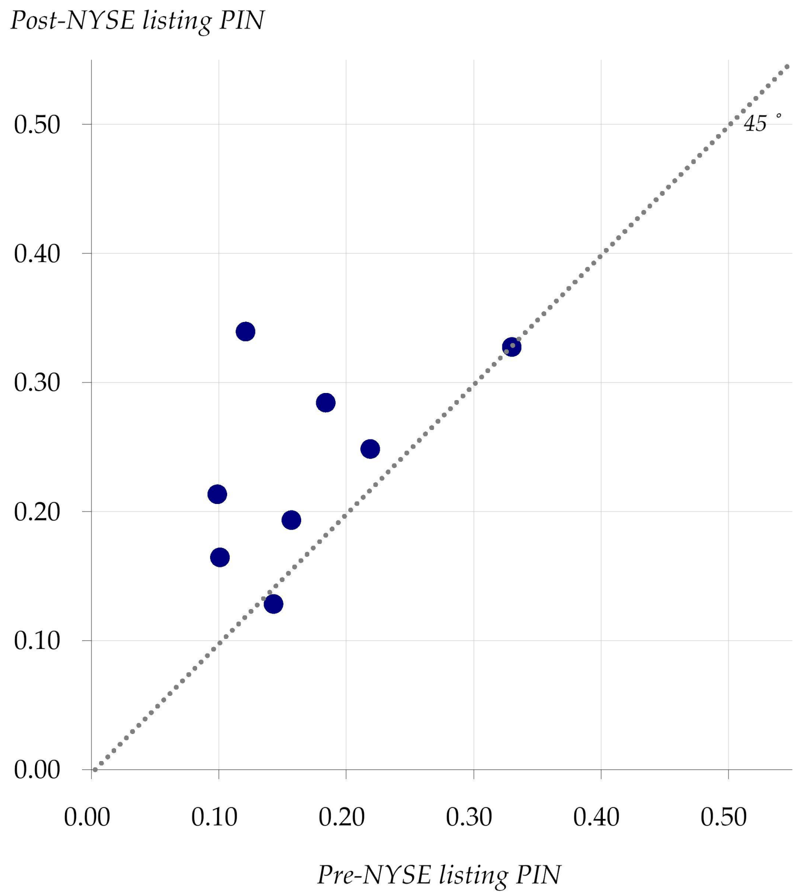






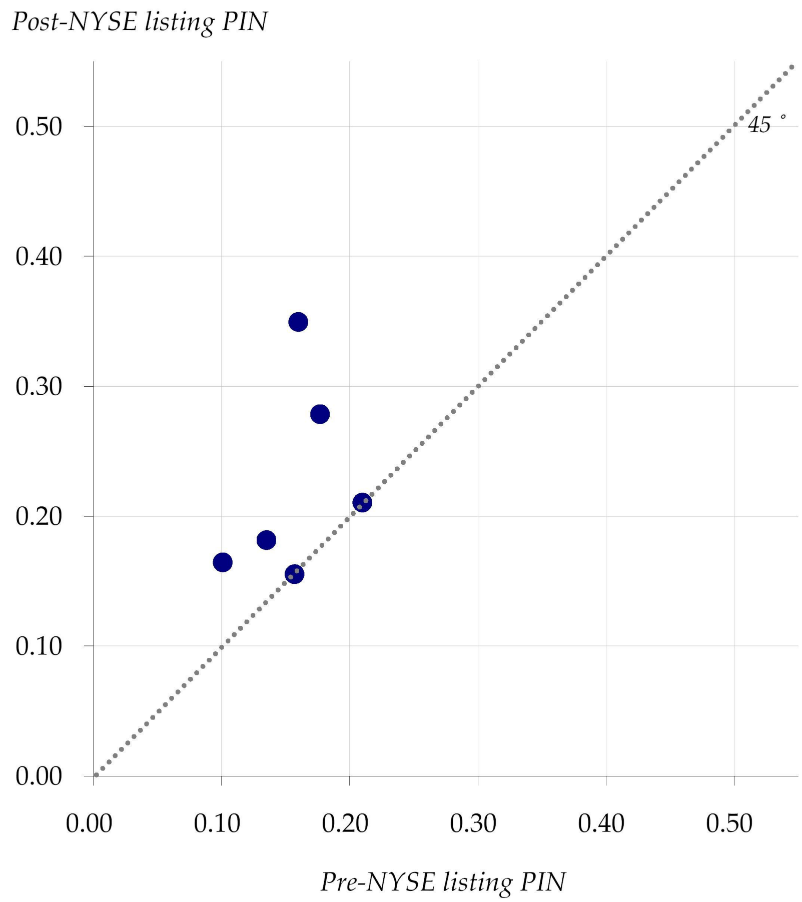
Each of the above four consecutive impulse response function plots of Aibiti Consolidate (co-listed on the TSX and on the NYSE) specifies the source of innovation by two standard deviations. The quotes on the NYSE rarely affect the quotes on the TSX. To the contrary, positive increases in ask and bid prices on the TSX are followed by changes in ask and bid prices on the NYSE, respectively.

Figure 3: Cross-listing effect on the PIN on the TSX, six-month ([-3M,+3M]) window



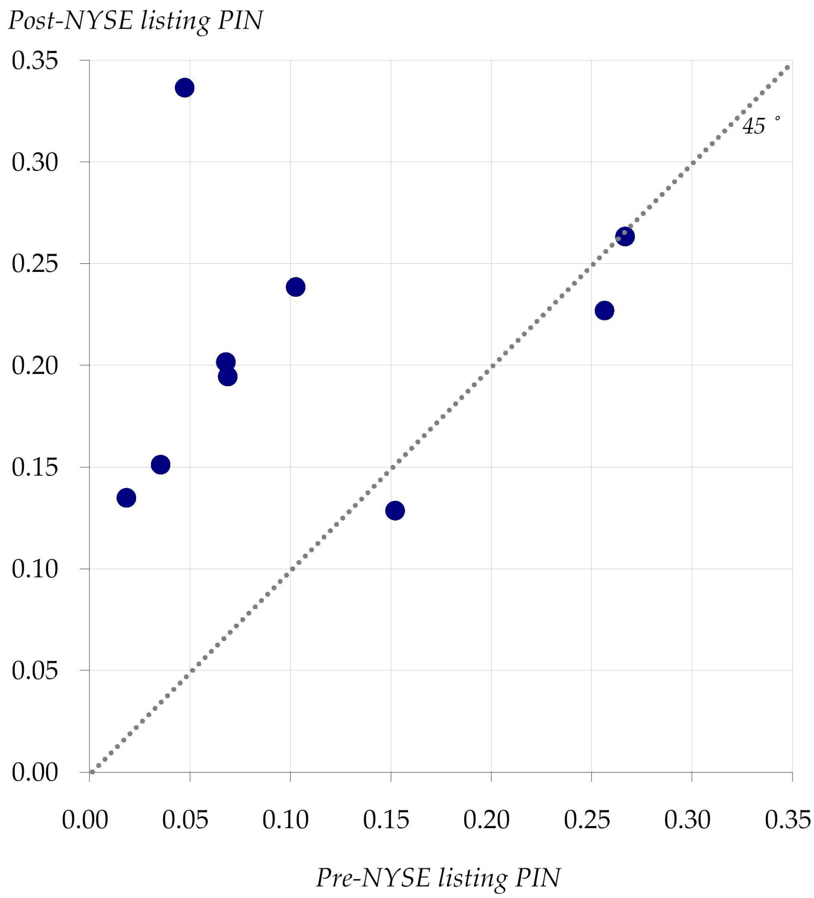
Above scatter plot describes various coordinates of the PIN on the TSX before (horizontal axis) and after (vertical axis) NYSE-listing. A coordinate in the upper 45°-line region denotes a rise in the PIN, whereas one in the lower region a decline.

Figure 4: Cross-listing effect on the PIN on the TSX, twelve-month ([-6M,+6M]) window



Above scatter plot describes various coordinates of the PIN on the TSX before (horizontal axis) and after (vertical axis) NYSE-listing. A coordinate in the upper 45°-line region denotes a rise in the PIN, whereas one in the lower region a decline.

Figure 5: Cross-listing effect on the PIN on the TSX, threshold monthly



Above scatter plot describes various coordinates of the PIN on the TSX before (horizontal axis) and after (vertical axis) NYSE-listing. A coordinate in the upper 45°-line region denotes a rise in the PIN, whereas one in the lower region a decline.

Appendix A1: PIN estimation algorithm

The PIN estimation algorithm is based on a symmetric Poisson intensity η for arrivals of both uninformed buyers and sellers. Information events occur at the market open with a probability α and, on a realization of such event, informed traders who arrive with an intensity μ perceive a binary signal with a probability either $\delta \equiv \mathbb{P}\{\text{share price falls}\}$ or $1-\delta = \mathbb{P}\{\text{share price rises}\}$.

The probability of informed trading (PIN) is the relative degree of private information (adverse selection) weighed on a randomly chosen transaction executed by an informed trader

$$\text{PIN} \equiv \frac{\alpha\,\mu}{\mathbb{E}\left[\text{B(uy)} + \text{S(ell)}\right]} = \frac{\alpha\,\mu}{\alpha\,\mu + \eta_{\text{B}} + \eta_{\text{S}}} = \frac{\alpha\,\mu}{\alpha\,\mu + 2\,\eta},$$

assuming symmetric intensity in uninformed trader arrivals, either buyers or sellers (see Figure 6). Empirically, a trade is considered buyer-initiated if it is higher than the five-second earlier mid-quote, or seller-initiated if lower (Lee and Ready (1991)).

I adopt a log-likelihood factorization from Easley, Engle, O'Hara, and Wu (2008) as follows

$$\begin{aligned}
\mathscr{L} &\equiv \ln \mathbb{P}\left(\{B_t, S_t\}_{t=1}^{T} \mid \alpha, \delta, \eta, \mu\right) \\
&= \sum_{t=1}^{T}\left[-2\,\eta + M\,\ln(x) + (B_t + S_t)\,\ln(\mu+\eta)\right] \\
&\quad + \sum_{t=1}^{T} \ln\left[\alpha\,(1-\delta)\,\exp(-\mu)\,x^{S_t - M_t} + \alpha\,\delta\,\exp(-\mu)\,x^{B_t - M_t} + (1-\alpha)\,x^{B_t + S_t - M_t}\right],
\end{aligned}$$

where *1.* $M_t \equiv \frac{\min(B_t,S_t) + \max(B_t,S_t)}{2}$; and *2.* $x \equiv \frac{\eta}{\mu+\eta}$. Thus, the parameters are estimated by maximum likelihood method such that

$$\hat{\Theta} \equiv \left(\hat{\alpha}, \hat{\delta}, \hat{\eta}, \hat{\mu}\right) = \arg\max_{\Theta}\left\{\mathscr{L} \mid (\eta,\,\mu) > \mathbf{0},\,(\alpha,\,\delta) \in [0,1]^2\right\},$$

hence the resulting PIN estimator is

$$\widehat{\text{PIN}} = \frac{\hat{\alpha}\,\hat{\mu}}{\hat{\alpha}\,\hat{\mu} + 2\,\hat{\eta}}.$$

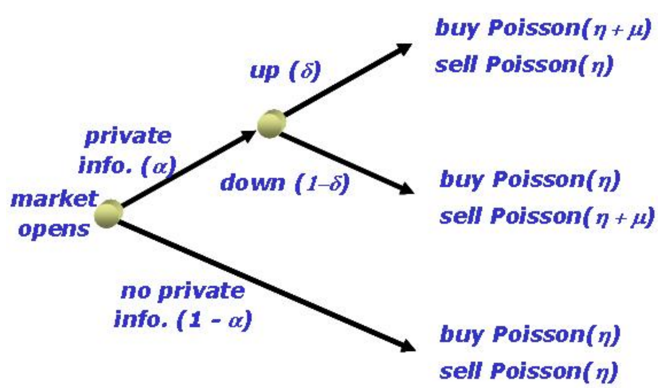


Figure 6: Derivation of PIN

Appendix A2: Information shares of stock exchanges

Consider a Canadian cross-listed pair $(p_{\rm T}, p_{\rm N})$ traded on both the TSX (T) and the NYSE (N). The time series of the pair has a common efficient price[1] (m_t) such that

$$\begin{bmatrix} p_{\rm T,t} \\ p_{\rm N,t} \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \end{bmatrix} m_t + \begin{bmatrix} c_{\rm T}\, q_{\rm T,t} \\ c_{\rm N}\, q_{\rm N,t} \end{bmatrix},$$

where $c_{\rm T}$ and $c_{\rm N}$, and $q_{\rm T}$ and $q_{\rm N}$ are market-specific cost coefficients and their associated trade volumes, respectively. Trade directions in the two markets may be contemporaneously associated as

$$\mathrm{Var}\left(\begin{bmatrix} q_{\rm T,t} \\ q_{\rm N,t} \end{bmatrix}\right) = \begin{bmatrix} 1 & \rho_q \\ \rho_q & 1 \end{bmatrix}.$$

An attractive trait of the common efficient price is that the securities with same underlying assets traded on distinct exchanges are linked by no-arbitrage condition in an equilibrium. An implied-vector moving average (VMA) formulation for the differences of prices is

$$\begin{bmatrix} \Delta p_{\rm T,t} \\ \Delta p_{\rm N,t} \end{bmatrix} = \begin{bmatrix} \epsilon_{\rm T,t} \\ \epsilon_{\rm N,t} \end{bmatrix} + \begin{bmatrix} q_{\rm T,t} \\ q_{\rm N,t} \end{bmatrix} = \begin{bmatrix} \theta_{\rm TT} & \theta_{\rm TN} \\ \theta_{\rm NT} & \theta_{\rm NN} \end{bmatrix} \begin{bmatrix} \epsilon_{\rm T,t-1} \\ \epsilon_{\rm N,t-1} \end{bmatrix},$$

then

$$\mathbb{E}_t \begin{bmatrix} p_{\rm T,t+1} \\ p_{\rm N,t+1} \end{bmatrix} = \begin{bmatrix} p_{\rm T,t} \\ p_{\rm N,t} \end{bmatrix} + \begin{bmatrix} \theta_{\rm TT} & \theta_{\rm TN} \\ \theta_{\rm NT} & \theta_{\rm NN} \end{bmatrix} \begin{bmatrix} \epsilon_{\rm T,t-1} \\ \epsilon_{\rm N,t-1} \end{bmatrix},$$

thus

$$\mathbb{E}_t \begin{bmatrix} p_{\rm T,t+1} \\ p_{\rm N,t+1} \end{bmatrix} - \mathbb{E}_{t-1} \begin{bmatrix} p_{\rm T,t} \\ p_{\rm N,t} \end{bmatrix} = \begin{bmatrix} \Delta p_{\rm T,t} \\ \Delta p_{\rm N,t} \end{bmatrix} + \begin{bmatrix} \theta_{\rm TT} & \theta_{\rm TN} \\ \theta_{\rm NT} & \theta_{\rm NN} \end{bmatrix} \begin{bmatrix} \Delta\epsilon_{\rm T,t-1} \\ \Delta\epsilon_{\rm N,t-1} \end{bmatrix}.$$

given that the two prices share the same efficient underlying price $(1+\theta_{\rm TT},\, \theta_{\rm TN}) = (\theta_{\rm NT},\, 1+\theta_{\rm NN})$.

Following Eun and Sabherwal (2003), the augmented Dickey-Fuller (1981) unit root test is conducted to each daily-price time series of the 55 TSX-NYSE cross-listed pairs with appropriate lag length, per Akaike (1974), to verify first-order integration ($I(1)$). Applying Johansen's (1991) either trace test or eigen-value test yielded one "cointegrating"[2] equation for each TSX-NYSE pair.

As a result, an econometric impasse is that since the cross-listed pairs are cointegrated, a vector moving average (VMA) representation cannot be recovered by Sims's (1980) vector autoregressive (VAR) structural formulation. Subsequently, in the absence of accounting for sources of shocks to fragmented shares, decomposing exchange-specific relative contribution to price discovery of the TSX-NYSE pairs poses an unwieldy task.

A breakthrough is introduced by Engle and Granger (1987) and Engle and Yoo (1987), and Hasbrouck (1995) adopts their error correction model (ECM) to arrive at the "information share": the percentage share of an exchange in price discovery of shares whose orders are executed from many markets. The vector error correction model (VECM) for the cointegrated trade-level quote prices is

$$\Delta p_t = \phi(L)\Delta p_t + \gamma\,(\alpha - z_{t-1}) + \epsilon_t,$$

[1] A security price time-series $\left(\{m_t\}_{t=0}^{\infty}\right)$ is *efficient* if, by definition, the conditional expectation of the first-order difference is zero. In other words, an efficient price is unpredictable given the presently available information. Equivalently, the increment of the price follows a martingale difference sequence: $m_t = m_{t-1} + u_t \;\Rightarrow\; \mathbb{E}\left(\Delta m_t |\, \{m_{s-1}\}_{s=1}^{t}\right) = \mathbb{E}\left(u_t |\, \{m_{s-1}\}_{s=1}^{t}\right) = 0$. See Lee, White, and Granger (1993).

[2] Security prices are cointegrated if there exists a linear combination of the non-stationary prices that can be toned stationary. A time series is strongly stationary if its probability distribution is time-invariant, and weakly stationary if up to its second moments: mean, variance, and covariance.

where *1.* $\phi(L)\Delta p_t$ are vector autoregressive terms; *2.* γ is a vector of cointegrating coefficients; *3.* $\alpha > 0$ is a vector of long-run cross-border bid-ask dollar spreads; and *4.* z_t is a vector of cross-border dollar spreads in ask $\left(p^a_{\mathrm{T},t}, p^a_{\mathrm{N},t}\right)$ and bid $\left(p^b_{\mathrm{T},t}, p^b_{\mathrm{N},t}\right)$ prices on the TSX and the NYSE, respectively, as:

$$z_t \equiv \begin{bmatrix} 1 & -1 & 0 & 0 \\ 1 & 0 & -1 & 0 \\ 1 & 0 & 0 & -1 \end{bmatrix} \begin{bmatrix} p^a_{\mathrm{T},t} \\ p^a_{\mathrm{N},t} \\ p^b_{\mathrm{T},t} \\ p^b_{\mathrm{N},t} \end{bmatrix} = \begin{bmatrix} p^a_{\mathrm{T},t} - p^a_{\mathrm{N},t} \\ p^a_{\mathrm{T},t} - p^b_{\mathrm{T},t} \\ p^a_{\mathrm{T},t} - p^b_{\mathrm{N},t} \end{bmatrix}.$$

A resulting VMA generalization is $\Delta p_t = \Theta(L)\,\epsilon_t$, where $\Omega \equiv \mathrm{Var}(\epsilon_t)$. Define $\sigma^2_\omega \equiv \beta\,\Omega\,\beta'$, where $\beta = (\beta_\mathrm{T}, \beta_\mathrm{N}) = (1+\theta_\mathrm{TT},\, \theta_\mathrm{TN}) = (\theta_\mathrm{NT},\, 1+\theta_\mathrm{NN})$. According to Hasbrouck (1995, 2007),

1. if Ω is *diagonal*, the *information share* of a market i (= T, N) is defined as

$$\mathrm{IS}_i \equiv \frac{\beta_i^2\,\mathrm{Var}(\epsilon_{i,t})}{\sigma^2_\omega}$$

   which is market i's proportional contribution to price discovery of a cross-listed pair.

2. If Ω is *non-diagonal*, the lower and upper bounds of information share can be obtained by re-ordering the sources of innovation (shock) with orthogonalized impulse response functions following Hasbrouck (2007). Given four quote prices $\left(p^a_{\mathrm{T},t}, p^a_{\mathrm{N},t}, p^b_{\mathrm{T},t}, p^b_{\mathrm{N},t}\right)$, there are 24 (= 4!) orderings in terms of Cholesky exogeneity. In other words, for each TSX-NYSE pair, there are 24 pairs of information shares of the TSX and the NYSE, respectively. Averaging across varying exogeneity reduces them to a single pair of information shares for each cross-listed pair.

The estimated information shares for 55 cross-listed pairs are listed in Table 1. The impulse response function plots of bid and ask quotes for Abitibi Consolidated, Inc., are shown in Figure 2. Each of the four consecutive charts specifies the source of innovation by two standard deviations. The quotes on the NYSE rarely affect the quotes on the TSX. To the contrary, positive increases in ask and bid prices on the TSX are followed by changes in ask and bid prices on the NYSE, respectively. This pattern does not hold for all cross-listed pairs, and the degree to which an exchange responds to the other side is reflected in the relative magnitude of information share.

Appendix A3: Proofs

From the model in Subsection 2.2, I have

$$\beta_i^0 = \frac{\overline{v}}{1+r} - \frac{\overline{y}_i}{(1+r)(\omega_{\mathrm{T}}^I + \omega_{\mathrm{T}}^U)},$$

$$\beta_i^S = \frac{1}{(1+r)(\omega_i^I + \omega_i^U)} \left\{ \omega_i^I \left(\frac{\tau_\epsilon}{\tau_\epsilon + \tau_v} \right) + \omega_i^U \left(\frac{\phi_i \tau_\epsilon}{\phi_i \tau_\epsilon + \tau_v} \right) \right\},$$

$$\beta_i^Y = \frac{\omega_i^I \left\{ \tau_\epsilon / (\tau_\epsilon + \tau_v) \right\}}{(1+r)(\omega_i^I + \omega_i^U)} \left\{ \omega_i^I \left(\frac{\tau_\epsilon}{\tau_\epsilon + \tau_v} \right) + \omega_i^U \left(\frac{\phi_i \tau_s}{\phi_i \tau_\epsilon + \tau_v} \right) \right\},$$

$$\beta_i^A = \frac{1}{(1+r)\left(\omega_i^I + \omega_i^U\right)},$$

where $\phi_i \equiv \frac{\pi_i^2 \eta^2 \tau_s \tau_y}{1+\pi_i^2 \eta^2 \tau_\epsilon \tau_y}$, $\omega_i^I \equiv \pi_i \eta (\tau_\epsilon + \tau_v)$, $\omega_i^U \equiv (1-\pi_i) \eta (\phi_i \tau_\epsilon + \tau_v)$, for all $i = \mathrm{T(SX)}, \mathrm{N(YSE)}$. For brevity, I omit the exchange subscript i in the following proofs.

Proposition 1. $\partial \beta^0(\pi)/\partial \pi > 0$, for all $\pi \in [0,1]$.

Proof. Note that $\partial \beta^0(\pi)/\partial(\omega^I + \omega^U) > 0$, and

$$\frac{\partial(\omega^I + \omega^U)}{\partial \pi} = \frac{\eta \tau_\epsilon}{(\tau_y \tau_\epsilon \pi^2 \eta^2 + 1)^2} \left(-\tau_y \tau_\epsilon \pi^2 \eta^2 + 2\tau_y \tau_\epsilon \pi \eta^2 + 1 \right),$$

where the quadratic solutions for $-\tau_y \tau_\epsilon \pi^2 \eta^2 + 2\tau_y \tau_\epsilon \pi \eta^2 + 1 = 0$ are

$$\pi = \frac{1}{\eta \tau_y \tau_\epsilon} \left(\sqrt{\tau_y \tau_\epsilon + \eta^2 \tau_y^2 \tau_\epsilon^2} + \eta \tau_y \tau_\epsilon \right) > 1,$$

$$\pi = -\frac{1}{\eta \tau_y \tau_\epsilon} \left(\sqrt{\tau_y \tau_\epsilon + \eta^2 \tau_y^2 \tau_\epsilon^2} - \eta \tau_y \tau_\epsilon \right) < 0,$$

thus $\pi \in [0,1]$ implies $-\tau_y \tau_\epsilon \pi^2 \eta^2 + 2\tau_y \tau_s \pi \eta^2 + 1 > 0$, hence $\partial(\omega^I + \omega^U)/\partial \pi > 0$. Therefore,

$$\partial \beta^0(\pi)/\partial \pi = \left\{ \partial \beta^0(\pi)/\partial(\omega^I + \omega^U) \right\} \left\{ \partial(\omega^I + \omega^U)/\partial \pi \right\} > 0 \text{ for all } \pi \in [0,1].$$

Proposition 2. $\partial \beta^S(\pi)/\partial \pi > 0$, for all $\pi \in [0,1]$.

Proof. An analogous argument to the proof of *Proposition 1* leads to

$$\frac{\partial \beta^S(\pi)}{\partial \pi} = \frac{(\tau_v \tau_\epsilon) \left(-\tau_y \tau_\epsilon \pi^2 \eta^2 + 2\tau_y \tau_\epsilon \pi \eta^2 + 1 \right)}{\left(\tau_y \pi^2 \eta^2 \tau_\epsilon^2 + \tau_v \tau_y \pi^2 \eta^2 \tau_\epsilon + \pi \tau_\epsilon + \tau_v \right)^2} > 0 \text{ for all } \pi \in [0,1].$$

Proposition 3. $\partial \beta^Y(\pi)/\partial \pi < 0$, for some large π.

Proof. A direct partial differentiation gives

$$\frac{\partial \beta^Y(\pi)}{\partial \pi} = -\frac{(\tau_\epsilon/\eta) \left(\pi^2 \eta^4 \tau_y^2 \tau_\epsilon^2 + \tau_v \pi^2 \eta^4 \tau_y^2 \tau_\epsilon + 2\pi \eta^2 \tau_y \tau_\epsilon + 2\tau_v \pi \eta^2 \tau_y - \tau_v \eta^2 \tau_y + 1 \right)}{\left(\tau_y \pi^2 \eta^2 \tau_\epsilon^2 + \tau_v \tau_y \pi^2 \eta^2 \tau_\epsilon + \pi \tau_\epsilon + \tau_v \right)^2},$$

where the solutions for $\pi^2\eta^4\tau_y^2\tau_\epsilon^2 + \tau_\upsilon\pi^2\eta^4\tau_y^2\tau_\epsilon + 2\pi\eta^2\tau_y\tau_\epsilon + 2\tau_\upsilon\pi\eta^2\tau_y - \tau_\upsilon\eta^2\tau_y + 1 = 0$ are

$$\pi = -\frac{1}{\eta^2\tau_y\tau_\epsilon\left(\tau_\upsilon + \tau_\epsilon\right)}\left\{\tau_\upsilon + \tau_\epsilon + \sqrt{\tau_\upsilon\left(\tau_\upsilon + \tau_\epsilon\right)\left(\eta^2\tau_y\tau_\epsilon + 1\right)}\right\} < 0,$$

$$\pi = -\frac{1}{\eta^2\tau_y\tau_\epsilon\left(\tau_\upsilon + \tau_s\right)}\left\{\tau_\upsilon + \tau_\epsilon - \sqrt{\tau_\upsilon\left(\tau_\upsilon + \tau_\epsilon\right)\left(\eta^2\tau_y\tau_\epsilon + 1\right)}\right\} \lesseqgtr 0 \ \text{ if } \tau_\upsilon\eta^2\tau_y \lesseqgtr 1.$$

Thus, if $\tau_\upsilon\eta^2\tau_y < 1$, there exists some constant $c \in [0,1]$ such that $\partial\beta^Y(\pi)/\partial\pi \gtreqless 0$ for $\pi \lesseqgtr c$; and if $\tau_\upsilon\eta^2\tau_y > 1$, then $\partial\beta^Y(\pi)/\partial\pi < 0$ for all $\pi \in [0,1]$. Therefore, $\partial\beta^Y(\pi)/\partial\pi < 0$ for some large π.

Proposition 4. $\partial\beta^A(\pi)/\partial\pi < 0$, for all $\pi \in [0,1]$.

Proof. Note that $\partial\beta^A(\pi)/\partial(\omega^I + \omega^U) > 0$ and, from the proof of *Proposition 1*,

$$\partial\left(\omega^I + \omega^U\right)/\partial\pi > 0 \text{ for all } \pi \in [0,1].$$

Therefore, $\partial\beta^A(\pi)/\partial\pi = \left\{\partial\beta^A(\pi)/\partial(\omega^I + \omega^U)\right\}\left\{\partial(\omega^I + \omega^U)/\partial\pi\right\} > 0$ for all $\pi \in [0,1]$.

Proposition 5. There exists no arbitrage in an equilibrium if $p_{\text{N}} - p_{\text{T}} = \beta^0_{\text{N}} - \beta^0_{\text{T}}$.

Proof. The prices of a TSX-NYSE cross-listed pair are, respectively,

$$p_{\text{T}} = \beta^0_{\text{T}} + \beta^S_{\text{T}}\Delta S - \beta^Y_{\text{T}}\Delta Y_{\text{T}} - \beta^A_{\text{T}}x^A_{\text{T}},$$

$$p_{\text{N}} = \beta^0_{\text{N}} + \beta^S_{\text{N}}\Delta S - \beta^Y_{\text{N}}\Delta Y_{\text{N}} - \beta^A_{\text{N}}x^A_{\text{N}}.$$

In a disequilibrium, arbitrageurs' profit in excess of the required cross-listing dollar premium is

$$\left(p_{\text{N}} - p_{\text{T}}\right) - \left(\beta^0_{\text{N}} - \beta^0_{\text{T}}\right) = \left(\beta^S_{\text{T}} - \beta^S_{\text{N}}\right)\Delta S + \beta^Y_{\text{N}}\Delta Y_{\text{N}} - \beta^Y_{\text{T}}\Delta Y_{\text{T}} - \beta^A_{\text{N}}x^A_{\text{T}} + \beta^A_{\text{T}}x^A_{\text{N}},$$

then given perfect hedging ($\mu \equiv x^A_{\text{T}} = -x^A_{\text{N}}$), arbitrageurs' short (long) position on the TSX (NYSE) is

$$\mu = \frac{\left(\beta^0_{\text{N}} - \beta^0_{\text{T}}\right) - \left(p_{\text{N}} - p_{\text{T}}\right) + \left(\beta^S_{\text{T}} - \beta^S_{\text{N}}\right)\Delta S + \beta^Y_{\text{N}}\Delta Y_{\text{N}} - \beta^Y_{\text{T}}\Delta Y_{\text{T}}}{\beta^A_{\text{N}} + \beta^A_{\text{T}}},$$

thus, in an equilibrium ($\Delta S = \Delta Y_{\text{T}} = \Delta Y_{\text{N}} = 0$), the no-arbitrage ($\mu = 0$) condition must be

$$p_{\text{N}} - p_{\text{T}} = \beta^0_{\text{N}} - \beta^0_{\text{T}}.$$