ONE SECURITY, FOUR MARKETS: CANADA-US CROSS-LISTED OPTIONS AND UNDERLYING EQUITIES

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Abstract

In this paper we examine the relative contributions of US and Canadian markets to price discovery for Canadian cross-listed options and their cross-listed underlying stocks. We use two different econometric approaches in assessing the contributions of each market to price discovery, the information shares approach and the common factor approach. Our empirical results are consistent in both approaches. We show that on average price discovery for cross-listed Canadian stocks and options takes place overwhelmingly in the underlying asset markets, where Canadian equity markets dominate the discovery process. The results show that option markets information shares remain comparable, although slightly higher in the US, which contrasts with the fact that its relative volume is almost ten times greater than that of Canadian options markets. The results also indicate a high degree of integration between Canadian and US markets for the underlying stocks of cross-listed options and show that the foreign exchange market does not contribute to the co integration between these markets to any significant extent. An analysis of the determinants of the relative information shares between firms with all markets analyzed simultaneously shows that the most important factor explaining the information shares is the volatility of underlying returns.

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I. Introduction

It is well known that price discovery for optioned stocks, the process by which new information is embodied in trading activity, can take place either in the option market or in the market for the underlying asset.[1] Similarly, when a security is cross-listed in two different international markets the discovery process can take place in either market. The increased trend in international cross-listing of securities, particularly in US venues, has stimulated a growing body of research on this issue.[2] There are several arguments on whether the home venue or the US venue is the most appropriate for the discovery process, the former because of the obvious information advantages and the latter because of the higher liquidity. Likewise, there are advantages and disadvantages in using the option rather than the underlying asset for price discovery. In this paper we use an integrated sample of Canadian optioned stocks, and their options all of which are cross-listed in the US, in order to assess the importance of each one of the four markets for the price discovery process. We then examine the factors that determine the relative weight of each market in that process.

We use two complementary econometric approaches in our empirical work: the information shares approach as in Hasbrouck (1995), and the common factor approach as in Gonzalo and Granger (1995).[3] We find consistent results in both cases. Specifically, we find that Canadian and US markets are highly integrated for options and their underlying stocks. We also find that contrary to the results of Chakravarty *et al* (2004) almost all discovery takes place in the underlying stock markets in both Canada and the US. These two markets, though, are major contributors to the discovery process, and none of the two is dominant in that process, although Canada has a significantly larger information share on average. As for the foreign exchange

[1] For empirical evidence on this issue see Stephan and Whaley (1990), Chan, Chung and Johnson (1993), and Chakravarty, Gulen and Mayhew (2004).
[2] See, for instance, Eun and Sabherwal (2003), and Grammig, Melvin and Schlag (2005).
[3] We also used the lead-lag analysis, as in Stephan and Whaley (1990); the results are available from the authors on request. Although this analysis has several biases as discussed in Hasbrouk (1995), its results point to a large and consistent degree of integration between all four markets.

market, it does not seem to contribute to the price discovery process to any significant extent. Finally, these average results do in fact correspond to significant differences in the discovery process pattern between the firms in our sample. Thus, although the insignificance of the options market is present in most cases, there are a small number of firms in both Canada and the US for which an important amount of price discovery takes place in the option markets. An analysis of the determinants of the discovery process shows that the most important factor explaining the differences in information shares of the two underlying national stock markets is the volatility of underlying returns.

The key issue in the literature on international cross-listing is the informational advantage of the home venue as compared to the superior liquidity of the foreign venue. It could be argued that the home market where information presumably originates, should dominate price discovery, as in Solnik (1996), and Bacidore and Sofianos (2002). On the other hand, the sheer breadth and depth of the foreign venue, particularly if it is the U.S. market, suggests that it may assume a leading role in this regard. Several studies that have examined this issue from the perspective of the international cross-listing of stocks have reported mixed results. Methodologically the earlier studies rely mostly on the lead-lag analysis, while the post-1995 studies adopt primarily the information shares approach of Hasbrouck (1995). Lieberman et al. (1999) find that the price discovery of five out of six Israeli stocks cross-listed on NYSE occurs in the home market and Kato et al. (1990) reach the same conclusion for seven UK, eight Japanese and eight Australian stocks, also cross-listed on NYSE. Similarly, Grammig et al. (2005) report that price discovery of the three German stocks interlisted on NYSE and Frankfurt mainly takes place in the home venue. On the other hand Law and Diltz (1994) and Wang et al. (2002) report that causality is bi-directional, but with a stronger impact of the foreign venue in the first study and the opposite in the second study. In Canada-US cross-listing Eun and Sabherwal (2003) have analysed the extent of U.S. exchanges contribution to the price discovery of 62 Canadian stocks listed on the Toronto Stock Exchange (TSE) and cross-listed in the US by examining midpoint bid-ask quotes at 10 minute intervals for a six month period. They report, on the basis of the magnitude of the coefficients of adjustment of TSE prices to price deviations on U.S. markets, that prices on the TSE and U.S. stock markets are cointegrated and mutually adjusting but that the TSE dominates price discovery for a majority of stocks. These cointegration results are not surprising, given that most studies have found that Canadian and US financial markets are highly integrated.[4]

When there are also traded options on a given stock, price discovery can take place either in the underlying or in the option market. With their greater potential for leverage and their bounded downside risk, option markets may presumably attract informed trading, resulting in turn in option prices leading stock prices whenever new information arrives. On the other hand these advantages are severely curtailed by the fact that financial markets are both dynamically incomplete and are subject to frictions such as transaction costs. In particular, option markets are less liquid and have much wider quoted spreads than stock markets. So, it is perhaps not surprising that empirical evidence on the lead-lag relationship between observed stock prices and stock prices implied by observed option values has yielded mixed results. Manaster and Rendleman (1982) find, on the basis of daily data on call option implied prices compared to those of their underlying stocks that price changes in option markets lead price changes in stock markets. Anthony (1988) also concludes from causality tests that trading in call options leads trading in their stocks. Kumar, Sarin and Shastri (1992) report abnormal option returns 30 minutes before the execution of block trades in their underlying stocks and Cao, Chen and Griffin (2000) find abnormal trading volume in options prior to takeover announcement. Under a different approach, Gendron, Khoury and Yourougou (1994) estimate the probability of price reversals in Canadian options and in their underling stocks and conclude that new information arrives first in option markets. On the other hand, Stephan and Whaley (1990) by analysing data on CBOE call options for the first quarter of 1986 find that price changes in the stock market lead price changes in the option market by about 15 to 20 minutes on average. Chan, Chung and Jonhson (1993) also find no evidence that options lead their underlying stocks. More recently Chakravarty, Gulen and Mayhew (2004) find evidence that about 18% of price discovery occurs in the option market and that it increases when the volume of transactions in options is higher than that of their underlying stocks and when the option effective bid ask spread is narrower.

[4] See, for instance, Bracker, Docking and Koch (1999), Carmichael and Samson (1996), Normandin (2004), and Kryzanowski and Zhang (2002).

In this paper we take advantage of the unique structure of the Canadian financial markets and their close integration with the US with respect to the trading of securities of the major Canadian firms. These firms are all optioned, and both their common shares and the options written on them are cross-listed in the US. We may thus use a sample of these firms to analyse the contribution of the foreign and home venue option and equity markets to the price discovery process using an integrated approach where all option and underlying equity markets are considered simultaneously, together with the foreign exchange market. We use two different sets of statistical hypotheses, one based on a modified version of Hasbrouk's (1995) methodology adapted to the issue under study and a second model based on the Gonzalo and Granger (1995) common factor approach. The price discovery performance of each market is then analyzed using a statistical procedure adapted to panel data in order to identify its most important determinants. The paper thus contributes to the price discovery literature by providing, to the best of our knowledge, the first evidence on the relative shares of U.S. and Canadian markets in the discovery process of cross-listed Canadian options and their underlying stocks, and on the determinants of those shares with all markets analyzed simultaneously.

In the next section we describe the econometric methodologies embodied in the two different approaches that we adopt in the empirical work. Section III contains the results of these approaches and section IV analyzes the differences in the determinants of information shares between the firms in our sample. Section V concludes.

II. The empirical models

II.1 Economic & Econometric Theory

The empirical work of this paper is based on two different market microstructure models developed simultaneously by Hasbrouck (1995) and by Gonzalo and Granger (1995), with an important earlier contribution by Stephan and Whaley (1990). There is an unobservable efficient price for a Canadian firm's stock expressed in Canadian currency that follows a logarithmic random walk, which is equivalent to the standard setting in the asset pricing theory that the asset prices net of dividends are martingales. This price is embodied in the observable prices of four distinct instruments trading in four markets, two of which are in Canadian and two in US currency.[5] Let $S_t^k,\ k = C,U$, denote the stock prices in \$Can and \$US respectively, and $I_t^k,\ k = C,U$, similarly denote the stock prices implied from the option markets. The logarithmic exchange rate E_t in \$Can/\$US also follows a random walk.

$$E_t = E_{t-1} + v_t . \tag{1}$$

Without loss of generality we assume that S_t^C is the efficient price following the random walk and introducing the innovation component γ_t

$$S_t^C = S_{t-1}^C + \gamma_t . \tag{2}$$

All error terms have zero mean and are serially and contemporaneously uncorrelated. For instance, $E(\gamma_t) = 0,\ E(v_t \gamma_t) = 0,\ E(\gamma_i \gamma_j) = 0,\ i \neq j$, etc. A similar random walk characterizes the US share price, which adjusts to the last observed exchange rate and Canadian price and includes its own random error δ_t

$$S_t^U = S_{t-1}^C + E_{t-1} + \delta_t \tag{3}$$

The implied stock prices from the option markets are obtained by inverting the corresponding observed option prices in the Canadian and US markets. We use the Black-Scholes-Merton (BSM) expression as a simple translation formula without necessarily assuming that this expression is a valid representation of the option value. A key issue is the volatility to be used in the BSM expression, which may itself be following its own random process. We use a lag of one minute[6] in estimating the implied volatility (IV) $\sigma_{t-\Delta}^k,\ k = C,U$ from the corresponding option market, which is then used as an input at time t for the inversion of the BSM expression $F_t(I_t^k, \sigma_{t-\Delta}^k)$, set equal to the corresponding observed option price O_t^k at time t. Thus, we have

[5] In what follows all symbols in our expressions denote the natural logarithms of the corresponding dollar prices and exchange rates.
[6] We also tried various lags between 3 and 60 minutes without any appreciable difference in the results.

$$I_t^C = F_t^{-1}(O_t^C, \sigma_{t-\Delta}) = S_{t-1}^C + \varsigma_t, \quad I_t^U = F_t^{-1}(O_t^U, \sigma_{t-\Delta}^U) = S_{t-1}^C + E_{t-1} + \xi_t. \tag{4}$$

Neglecting for the moment the exchange rate and focusing on the two pairs of national markets, we note that one approach to the analysis of the price discovery process is the *lead-lag* model, which considers the structure of the error terms in the actual and the implied stock prices. For instance, in the case of the Canadian market this lead-lag model would consist of the relationship between the error terms γ_t and ς_t. In a perfect market without any frictions and any observational delays these two terms should be equal. Since this is not the case, price discovery can be studied by a pair of models of the following form[7]

$$\varsigma_t = a + \sum_{k=-K}^{k=K} b_k \gamma_{t-k} + \varepsilon_t \qquad \delta_t = c + \sum_{k=-K}^{k=K} d_k \gamma_{t-k} + \eta_t, \tag{5}$$

where K is the arbitrarily chosen number of leading and lagging regressors. Price discovery is represented by the nonzero and non-contemporaneous coefficients.

Apart from the fact that this model cannot account for the analysis of price discovery in more than two markets, especially in the presence of exchange rate effects, the lead-lag model may be misleading when the variables are cointegrated. For this reason, we shall focus our cointegration analysis on a number of different combinations of the random walks given by expressions (1)-(4). In general terms, let P_t denote a vector of prices that in the empirical applications will contain a number n of elements ranging from 2 to 5, as well as one or two common trends, associated with the stock price and the exchange rate. Since the prices observed in different markets are kept from drifting apart by intermarket arbitrage both internationally and between the options and the underlying trading venues, the prices are cointegrated of order one ($I(1)$). In other words, the price vector P_t may be represented by a nonstationary vector autoregression with q lags. Then it can be shown by the Granger Representation Theorem[8] that there exists a vector error correction representation (VECM)

[7] See Stephan and Whaley (1990).
[8] See Engle and Granger (1987).

$$\Delta P_t = \alpha\beta' P_{t-1} + \sum_{i=1}^{q} A_i \Delta P_{t-q} + e_t, \quad (6)$$

where α and β are [nxr] matrices containing respectively adjustment parameters and cointegrating vectors, r is the cointegration rank, [nxn] matrices A_i describe the short-term dynamics of the process and Ω is the covariance of the serially-uncorrelated error terms e_t. The term $\alpha\beta' P_{t-1}$ represents the equilibrium dynamics between the prices. The cointegration rank r is determined by the number of common stochastic trends in the data.[9] In particular, we expect to have the cointegration rank r equal to n – 1 when there is no exchange rate in model (6), since in this case there is a single common trend, the efficient price. The inclusion of the exchange rate in model (6) will add an additional common trend, thus setting the cointegration rank r equal to n – 2. In all empirical applications we use the Johansen (1990) test to determine this cointegration rank.

Even though the common efficient price is not observable, its random-walk variance may be estimated in model (6) as[10]

$$\sigma^2_{RW} = \psi\Omega\psi', \quad (7)$$

where ψ are rows of an [nxn] matrix Ψ given by[11]

$$\Psi = \beta_\perp \left(\alpha'_\perp \left(I - \sum_{i=1}^{q} A_i \right) \beta_\perp \right)^{-1} \alpha'_\perp, \quad (8)$$

where [nx(n–r)] matrices $\alpha_\perp$ and $\beta_\perp$ are non-trivial orthogonal complements to α and β in (6), the A_i matrices are as in (6) and I is an identity matrix.[12,13] Note that if there is no exchange rate

[9] See Stock and Watson (1988).
[10] See Hasbrouck (1995).
[11] See Johansen (1990).
[12] See Johansen (1995) for estimation methods of these orthogonal complements.

in the model (6), all rows of Ψ are identical, otherwise we have a row corresponding to the exchange rate random walk variance that is clearly different from the others. This case is outside the scope of this paper, and in what follows we define ψ as corresponding to the common efficient price. Then the information share (IS) of a given market is defined[14] as the proportion of the random walk variance that is attributable to the innovations in that market. If the covariance matrix Ω is diagonal then we have a clean decomposition into contributions of each market to the total variance of the permanent component, with the contribution for the *j*-th market equal to $\frac{\psi_j^2 \Omega_{jj}}{\sigma_{RW}^2}$. This diagonal property will hold if the underlying random walk hypothesis is well satisfied by the data, i.e. if there is little contemporaneous correlation between the residuals in (6). If the off-diagonal elements are non-zero then we apply the Cholesky decomposition to the covariance matrix Ω. In this case, which is the one that prevails in our data, the contribution of each market to the price discovery is not unique, varying with the ordering of variables in the Cholesky decomposition. Accordingly, we search over all possible rotations for the minimal and maximal IS for each market, which constitute the bounds on this quantity.[15]

The Gonzalo and Granger (1995) decomposition into the permanent and transitory components starts with the same VECM model (6). Then we have the following decomposition of the price vector:

$$P_t = C_1 f_t + C_2 Z_t, \tag{9}$$

where f_t and Z_t respectively represent the permanent and transitory components, C_1 and C_2 are loading matrices, and $f_t = \alpha_\perp' P_t$ and $Z_t = \beta' P_t$ with $\alpha_\perp$ and β as before. Note that the $I(1)$ permanent component f_t need not be a random walk. Of interest to us is the [*n*x(*n*–*r*)]

[13] In most of the market microstructure applications of this model the matrices Ψ were estimated as cumulative impulse-response functions whose convergence properties are not well known. Baillie *at al*. (2002) pointed out that (8) is a superior estimation approach.
[14] See Hasbrouck (1995).
[15] See Hasbrouck (1995).

matrix $\alpha_\perp$, specifically its column corresponding to the price vector.[16] Under the additional assumption that Z_t does not Granger-cause[17] f_t this matrix may be identified up to a non-singular multiplication matrix. The interpretation of the permanent component f_t is that it is a weighted average (linear combination) of the observed prices with the component weights in $\alpha_\perp$. Booth *et al.* (1999), Chu *et al.* (1999), and Harris *et al.* (1995) suggest measuring price discovery by using component weights normalized to 1 or shares (CS). The interpretation of CS is that the market which reacts the least to the innovations in other markets will display the highest relative weight in the permanent component.

As shown in Baillie *at al.* (2002) and De Jong (2002), CS may be estimated also by normalizing to 1 the row vector ψ in (8).[18] This approach stipulates that IS and CS are clearly related. As demonstrated in the former study, IS is a second-degree rational function of CS and of Cholesky decomposition terms for a non-diagonal VECM error covariance matrix. Baillie *at al.* (2002) also showed that for symmetrical systems, i.e. with the number of markets *n* even and with the cointegrating vectors coefficients in β in (6) close in magnitude but of reciprocal signs in different markets, as we may expect in our setup for the models without the exchange rate, the midpoint values of IS are close to CS. In our data we observe substantive correlations between the residuals in the VECM model (6) even at the highest admissible sampling frequency. Hence, the Gonzalo and Granger (1995) approach offers an *a fortiori* important cross-validation for the results of the Hasbrouck (1995) model.[19]

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[16] In case there is exchange rate in model (6) one of the two columns in $\alpha_\perp$ will correspond to the exchange rate permanent component.

[17] See Granger (1980).

[18] See Gonzalo and Granger (1995) for an alternative estimation method.

[19] There is an ongoing debate in the market microstructure and the related econometric literature about the relative merits of the Hasbrouck (1995) and Gonzalo and Granger (1995) approaches. As De Jong (2002) points out, CS for a given market ignores the variance of an innovation in this market while it measures the weight of this innovation in the increment of the efficient price. On the other hand, IS measures the share in the total variance of the efficient price contributed by a given market. In a recent work, Yan and Zivot (2007) analyze the performance of IS and CS in the structural VAR framework and point out that IS at high sampling frequencies may be adversely affected by noise. In conclusion, the authors recommend using these two measures in conjunction.

II.2 Applications of the Econometric Model

We apply the above VECM model (6) to the following price vector cases. First there are the prices in the two purely national markets, in which the exchange rate E_t does not enter, n=2 and $P_t = [S_t^k, I_t^k],\ k = C, U$. Here we have a single common trend. Next we introduce the exchange rate and we consider n=3 and $P_t = [E_t, S_t^k, S_t^l],\ k, l = C, U,\ k \neq l$ or $P_t = [E_t, I_t^k, I_t^l],\ k, l = C, U,\ k \neq l$. Last, we examine the most general case n=5 and $P_t = [E_t, S_t^C, S_t^U, I_t^C, I_t^U]$. In all these cases there are two common trends and the rows of the matrix Ψ are not identical.

The number of cointegrating relations is equal to n-1 when the exchange rate does not enter and to n-2 when there are two common trends. This translates to single hypothesized cointegrating vector $\beta' = [1, -1]$ in equation (6) for the case where $P_t = [S_t^k, I_t^k],\ k = C, U$, but also to the single cointegrating vector hypothesized $\beta' = [1, -1,\ 1]$ for the cases $P_t = [E_t, S_t^k, S_t^l],\ k, l = C, U,\ k \neq l$ and $P_t = [E_t, I_t^k, I_t^l],\ k, l = C, U,\ k \neq l$. In this last case the elements ψ_{ij} of the [3x3] matrix $\Psi = \begin{bmatrix} \psi_{11} & \psi_{12} & \psi_{13} \\ \psi_{21} & \psi_{22} & \psi_{23} \\ \psi_{31} & \psi_{32} & \psi_{33} \end{bmatrix}$ denote the cumulative effects on price i of a unit shock in price j. If we denote the top row of the matrix as corresponding to the exchange rate and the two bottom rows as corresponding to, say, the US- and Canadian-traded stock prices respectively, then we anticipate certain particular properties of the matrix Ψ. Specifically, we expect $\psi_{12} = \psi_{21} = 0$, $\psi_{22} = \psi_{32}$ and $\psi_{23} = \psi_{33}$. The cumulative effects of the exchange rate on the respective stock prices ψ_{21} and ψ_{31} remain ambiguous since the prices of particular equities may differ with respect to their sensitivity to the exchange rate. Since we are not interested in this study in the exchange rate *per se*, we do not report any results related to the information shares in the market for the exchange rate. In addition, as our results in a later section will demonstrate, the exchange rate has a small effect on the information shares of the considered securities. Therefore, in the majority of applications we drop this variable from the estimation of the system (6). Last, the vector $P_t = [E_t, S_t^C, S_t^U, I_t^C, I_t^U]$ has *n*-2=3 cointegrating relations. The corresponding hypothesized cointegrating matrix is $\beta' = \begin{bmatrix} 1 & 0 & 0 & -1 & 1 \\ 0 & 1 & 0 & -1 & 0 \\ 0 & 0 & 1 & 0 & -1 \end{bmatrix}$

We estimate system (6) and derive the error correction form and the covariance matrix Ω for each day for each one of the interlisted underlying securities in our sample in the various settings described above. In preliminary steps, we derive the optimal number of lags estimated by minimizing the Akaike[20] information criterion for an unrestricted vector auto regression (VAR) and apply the Johansen (1990) test to VECM model (6) to determine the number of cointegrating relations. As suggested in the previous section, we adopt Johansen (1990) maximum likelihood estimation for VECM as an econometric approach to derive the estimates for our two main models based on Hasbrouck (1995) and Gonzalo and Granger (1995).[21]

II.3 Data and empirical methodology

Our study uses data on quotes in equity and option markets both in Canada and in the US. More specifically, the initial sample consists of intraday quotes on options traded both in Canadian and US markets during the 6 months from September 2007 to February 2008 inclusively.[22] As noted in Hasbrouck (1995), the use of quotes rather than trade prices is supported by the fact that option quotes change more frequently than trade executions, which makes it more likely to observe the required lack of correlation in cross market innovations. The data[23] include all available time stamped price quotes on the selected option series. In total 62 different option series were included in the analysis, which number was reduced to 50 by our filters as explained below. Each option quote was first matched to the corresponding time stamped quotes on the underlying security that was obtained from the Toronto Stock Exchange data tapes. The data was then

[20] The use of this criterion resulted in better residuals' autocorrelation properties compared to the use of the Schwarz information criterion, which systematically resulted in a lower number of included lags.
[21] Gonzalo (1994) presents the evidence in favor of the use of maximum likelihood VECM compared to other estimation methods. This approach performs well even if the system is overparametrized by including a large number of lags.
[22] Quotes that were not updated in the 15 minutes prior to each observation were eliminated from the analysis.
[23] The data was made available to the authors by the Montreal Exchange (ME).

matched to US market information, which is comprised of national best bid and offer (NBBO) quotes obtained from an independent source[24] that compiles data from all US option markets and their corresponding underlying security's quote information. Each observation was also matched to the contemporaneous quote on the exchange rate. Table I presents the descriptive statistics for all markets in this analysis and

For the period under study, we have 122 days for which there was trading in both the US and Canada, which results in potentially 6050 company-days. By accounting for the availability of data,[25] we note the following numbers of company-days simultaneously available for all the specified variables: S^C, I^C- 5930; S^U, I^U- 5891; S^C, S^U- 6041; I^C, I^U- 5791; S^C, I^C, S^U, I^U- 5752.

Table I approximately here

For the implied prices (I_t^C, I_t^U) derived from the option quotes we first obtain the implied volatilities $\sigma_{t-\Delta}^k,\ k = C,U$ by inverting the BSM expression at time $t-\Delta$ by using the contemporaneously observed option and underlying security prices, and then we use this volatility to compute (I_t^C, I_t^U) as in (4). In all cases we use the bid-ask midpoint as a measure of the stock and option prices. In the results that we present we used a one-minute time lag Δ between the implied price estimates at t and the corresponding implied volatility estimates at $t-\Delta$. We also verified that varying this lag between one and sixty minutes did not significantly affect our results. Since the data includes quotes for several contracts on each underlying security at each instant, our final estimates of the implied stock prices are averages across all observed quotes for each series at any given instant. These averages were stratified with respect to the option contracts' moneyness and time to maturity.

As mentioned earlier, this estimation of implied underlying security prices is then matched with the corresponding price quotes in the observed equity markets and included in the estimation of each market's information share using equation (8). A key empirical issue is the chosen length of the sampling interval. It is important to note that in order for the IS estimates to be informative

[24] See marketdataexpress.com
[25] The most important factor in limiting the use of data is the availability of options' quotes.

the correlations of the price innovations across the markets under study should be minimized by selecting as short a sampling interval as the data may afford.[26] A suggested, one second sampling interval may minimize potential correlations even if they are not eliminated completely.[27] Grammig et al. (2005) use a 10 second and a 1 minute sampling intervals and also find that the time aggregation is likely to influence the degree of correlation across markets, but that the two intervals yield similar results.[28]

A problem that arises in Canadian option markets in this context is that they have been shown[29] to be often extremely thin for many option series, where price quotes are not updated as frequently as in more liquid markets. The Canadian information share resulting from information flows may thus be diluted by the greater liquidity levels in the US to the extent that the frequency of price quote updates is positively related to market activity. A ten second sampling is thus used in this study as a compromise between the issue of market thinness in Canadian option markets and the need to minimize the correlation in cross market innovation.

We further deal with the problem of option market thinness by restricting our empirical results to a subsample of the observations that satisfies the following frequency of quoting criteria. We eliminate from our sample all firms that did not show at least 80 days of data out of a possible 122 days. Of the remaining firms we eliminate all those that did not show at least 100 observations for a given option contract. These filters eliminated 12 of the 62 firms. To verify the uniformity of the remaining sample, we split it into a "frequently updated quotes" subsample of 28 firms with at least 500 observations for a given option contract, and an "infrequently updated quotes" subsample of 22 firms with less than 500 but above 100 such observations. We report separately the results for these two subsamples, as well as for the aggregate sample and as the results show, in almost all cases the differences between the two subsamples are well within the limits of statistical error.

[26] In our data for a one-minute sampling interval the correlation of the Canadian and US underlying stock price increments was of the order of 0.9, resulting in bounds on IS of app. 0 and 1.

[27] See Hasbrouck (1995). Yan and Zhivot (2009), however, argue that very short sampling intervals lead to incorporating the microstructure noise in the estimates.

[28] See Grammig, Melvin and Schlag (2005).

[29] See Khoury, Perrakis and Savor (2010).

As noted earlier, the existence of contemporaneous correlations of residuals in the VECM model (6) yields lower and upper bounds on IS. We establish these bounds by searching over all possible Cholesky factorizations of the covariance matrix Ω. Then we compare the midpoints of these bounds to the Gonzalo and Granger component shares (CS), whose estimation doesn't depend on the random walk hypothesis and thus admits contemporaneous correlation of residuals without resulting in a bounded quantity.

III. Empirical Results

III.1 The Hasbrouck (1995) information shares results for market pairs

Next we estimate the Hasbrouck (1995) information shares model, by applying the vector autoregressions error correction form (VEC) (6) and then estimating the information shares bounds for each market as analyzed in the previous section. In order for the information bounds to be informative the sampling interval must be such as to minimize the effects of potential contemporaneous correlations. Our analysis shows that the sampling interval that best suits our study in terms of controlling potential contemporaneous correlations and providing reliable information bounds is a 10 seconds interval. We will therefore use this time frame in the remaining analysis. We start from pairwise comparisons of the information shares of relevant markets and then proceed to an examination of all four markets put together.

Tables II and III approximately here

Tables II and III presents the results of each market compared separately to each one of the other relevant markets. In the equity markets pair Table III shows that the Canadian equity markets have a significantly higher information share than their US counterparts. For the aggregate sample the average information share for Canadian as shown in Table III equities is bounded between 40.2% and 81.0%, while the US equities' average bounds are 19.0% and 59.8% for the lower and upper bounds respectively. When the foreign exchange market is included in the analysis, its average information share appears negligible. These results can be contrasted with those pertaining to the pair of option markets, for which Table III shows that Canadian options contain on average between 40.7% and 44.8% of the information share while US options contain a slightly higher information share of between 55.2% and 59.3%. Again, when the foreign exchange market is considered separately, unreported results show that its average information share is negligible.[30]

On the other hand, the results for the two pairs of option and equity markets within each country show that most of the average information share is associated with equity markets for both US and Canada. Indeed, Table II shows that the Canadian equity markets' average information share lies between 93.5% and 96.4% compared to 89.8% and 95.0% for US equities. The same pair-wise comparison shows that the two option markets' average information shares are bounded between only 3.6% and 6.5% and between 5.0% and 10.2% in Canada and in the US respectively. These results contrast with those of Chakravarty et al (2004), where option markets have significantly higher average information shares compared to their corresponding equities, ranging from 17.5% to 18.3%. Note also that our results exhibit considerably tighter bounds when analyzing equity versus option markets within each country compared to inter-country comparisons. As noted in Hasbrouck (1995) the width of the information share bounds increases with the correlation of the residuals. Table IV shows that this correlation remains very strong between Canadian and US equity markets (ρ = 63.2% on average) and much weaker for other market pairs (2.8% $\leq \rho \leq$ 16.5%) This result is indicative of the strong co-movement between Canadian and US equity markets.[31]

III.2 The Hasbrouck (1995) information shares results for all markets considered simultaneously

Tables V and VI show the results for the Hasbrouck (1995) information market shares model with all markets considered simultaneously. More specifically, the information shares are

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[30] For conciseness purposes all results for the analysis where the foreign exchange markets are considered separately are not reported but remain available from the authors upon request.
[31] These results contrast with those of Grammig et al (2005) using German internationally cross-listed stocks.

estimated for options and their underlying equity markets both in Canada and in the US, with all markets being integrated in the model on a common currency basis. The results show a wide range of equity average information share bounds between firms. For the aggregate sample in the Canadian market for the underlying securities the range extends from a low of 35.9% to a high of 76.4% while the bounds for US equity markets range from 16.4% to 57.0%. The corresponding results for the information shares of option implied prices also provide consistent results with tighter share bounds. The information share of Canadian options exhibits an average lower bound of 2.4% and an average upper bound of 4.9%. The information share of the Canadian option market is slightly lower than that of the US option market, where average information shares range from 3.2% to 7.7%. The inclusion of the foreign exchange rate in the simultaneous analysis does not however affect the information shares results of the four other markets to any significant extent.

Table IV approximately here

The results of Tables V and VI, where all four markets are examined simultaneously, are fully consistent with those of the pair-wise comparisons of Tables II and III. The relative importance of each market's information share reveals that Canadian equity markets have a greater information share than US equities, while the Canadian option markets' information share is less important than its US counterparts. These results are all the more relevant when relative transactions volumes of these markets are taken into consideration. Indeed the Canadian equity market information share is higher than that of its US counterpart even though its proportional share in total volume of transactions in both markets is 38.7% compared to 47.8% for the US equity market. The contrast is even more striking in the option markets, where the US market exhibits only slightly higher information than its Canadian counterpart while its proportional share in total volume of transactions average 12.3% compared to 1.3% for the Canadian option market. These results are also consistent with those reported by Solnik (1996), Bacidore and Sofianos (2002), Lieberman et al. (1999), Kato et al. (1990) and Grammig et al. (2005) lending support to the higher informativeness of the home market in spite of the superior liquidity of the foreign venue where the securities are cross listed and contrast the findings of Law and Diltz (1994), and Wang et al. (2002) in this regard.

III.3 The Gonzalo-Granger (1995) results for all markets considered simultaneously

Table VI displays the results of the Gonzalo-Granger (1995) component shares model (CS) and compares them to the corresponding midpoints of the Hasbrouck (1995) information share model (IS). As this table shows, the results for the Gonzalo-Granger (1995) model coincide, on average, almost exactly with the Hasbrouck (1995) model average mid-points when we consider a symmetrical system in VECM model (6), i.e. when there is no exchange rate in the model. This is an expected result since, as indicated in Baillie at al. (2002), IS midpoints for symmetrical systems coincide with CS. The inclusion of the exchange rate in model (6) on average raises the exchange rate CS relative to the midpoint IS for this variable. One of the advantages of CS is that a χ^2-distributed likelihood ratio test is available.[32] Table VI also displays aggregated results for this test, i.e. it indicates the total proportion of days that CS for a given variable was statistically different from zero at the 10% significance level for the Gonzalo and Granger (1995) Q-test, which in this case is χ^2-distributed with one degree of freedom. The coincidence of the midpoint IS and CS shown in Table VI validates the use of the former quantity as the dependent variable for the explanatory models presented in the next section.

Tables V and VI also confirm the uniformity of the sample that we used in our empirical work, since the results for the "frequently quoted" and "infrequently quoted" subsamples are virtually identical in most cases to those of the aggregate sample. The table also shows the midpoint IS and the CS measures for all pairs of markets. The coincidence of the IS and CS results is also preserved in the pairwise comparisons between markets, with both measures showing the dominant role played by the underlying stock in the discovery process in both Canada and the US.

Tables V and VI approximately here

[32] See Gonzalo and Granger (1995) for details.

III.5 Factors driving the information shares between firms

As noted earlier, the information shares differ substantially among firms in all four markets. In the equity markets the average information shares bounds midpoint varies from a low of 37.1% to a high of 60.7% for Canada, and from 20.1% to 45.7% for the US. Similarly, for the two national option markets the average information shares are almost always low, but a small number of firms, 6 in Canada and 7 in the US out of the 62 firms of the total sample, have average information shares bounds midpoints that exceed 10%, while 1 firm in Canada and 3 firms in the US have average information above 20%, of a magnitude comparable to the results of Chakravarty *et al* (2004) for the major US firms' options. Panels A to D in Figure 1 show the information shares midpoints distributions for the Canadian and US equity and option markets respectively. Similar variability also exists for the *intertemporal* evolution of average information shares in the four markets, aggregated for all 50 firms in our sample and shown in Panels A and B of Figure 2; this intertemporal variation will not be examined in this version of the paper. In this subsection we seek to identify observable market or firm characteristics that drive the differences in information shares between firms and determine the market where most price discovery takes place.

(Figure 1 about here)

(Figure 2 about here)

There is relatively little theoretical research on the location of price discovery when a security trades in multiple markets. It is clear that such discovery will be driven by the choices of informed traders. Chowdhry and Nanda (1991) show that under certain conditions one of the markets emerges as the dominant location for trading in the multimarket security. Nonetheless, the factors that determine this dominant location are not easy to identify empirically. Easley, O'Hara and Srinivas (1998) identify conditions that induce informed trading in the option, rather than in the underlying stock market; these, however, have little relevance to most of the stocks in our case, since the option markets have small information shares.

We investigate the determinants of the information shares by panel least squares regressions with a total of 50 cross sections (one for each firm), resulting in 6050 potential observations. Table VII presents the results of the regressions for the four separate pairs of markets, the two national stock and option markets and the underlying and implied US and Canadian markets respectively. We choose one of the shares as the dependent variable. For the independent variables we use first of all two variables that reflect the relative liquidity of the two markets, namely the relative volume and the relative effective spread of the two markets. Second, we use where appropriate an indicator of market uncertainty, the intraday variance in the underlying stock market. As noted in Chakravarty et al. (2004) and Capelle-Blancard (2003), in the pairs of national stock and option markets this variable will have a negative effect on the price discovery in the option market. Last, we include in the pairwise regressions where the two markets are in different countries an indicator of the exchange rate uncertainty, the intraday variance of the exchange rate, as well as a first-order autoregressive term. The model is as follows:

$$SHARE_{it} = \alpha_i + \beta_1 VEX_{it} + \beta_2 VS\_CA_{it} + \beta_3 VS\_US_{it} + \beta_4 RSPR_{it} + \beta_5 RVOL_{it} + AR(1) + \varepsilon_{it}$$

(10)

Where *SHARE* is the midpoint of the upper and lower bound of the first market's information share, *VEX* is the intradaily variance of the exchange rate, *VS_CA* and *VS_US* are the integrated intraday variances for the Canadian-traded and US-traded underlying securities respectively, *RSPR* is the ratio of the first market's effective spread to the second market's, *RVOL* is the ratio of the first market's volume to the second market's, and AR(1) is the autoregressive term.

Table VII exhibits the results of the market pairs analysis. In the first two panels representing the national markets the dependent variables are the option information shares in the US and Canada respectively. The relative volume and spread variables' coefficients have the expected signs everywhere but only one of them is significant. In the other two panels it is the US option and underlying stock information shares that are the dependent variables. Here the market liquidity variables' coefficients, the relative spreads and volumes of the Canadian to the US market have the expected signs whenever they are significant, in the case of the spreads for the option markets pair and in the case of volume for the underlying stock pair; the remaining coefficients have the wrong sign but are not significant.[33]

More interesting are the estimates of the coefficients of the uncertainty variables, the intraday variances of the underlying stocks and the exchange rate. For the latter, we note that although it is not significant (and very small) in the purely national markets, it is a strongly negative and highly significant determinant of the US option market and stock market information shares. Since the firms are Canadian, these results conform to our intuition that the informed traders are also Canadian, who would trade at home when subjected to exchange rate risk. On the other hand, the effects of the volatility of the underlying stocks in Canada and the US are less easy to interpret. The Canadian volatility shifts informed trading away from Canadian and towards US stocks and options, as expected. It also, however, shifts such trading towards options from underlying in both Canada and the US, with all effects being highly significant. Although this last shift contradicts the results of Chakravarty *et al* (2004) and the theoretical conjectures of Capelle-Blancard (2003) about uncertainty shifting informed trade away from the option market, it is consistent with traders using the option market to speculate on volatility changes. As for the US volatility, it shifts informed trading from US towards Canadian stocks and options, but it also shifts such trading away from the options and towards the underlying in both Canada and the US as predicted by the earlier studies, with all effects being again significant.

Table VI approximately here

We now analyse the factors affecting each market share with all market considered simultaneously as in the analysis underlying Table V and VI and within the framework of equation (10), as follows:

$$\begin{aligned} SHARE_{it} = {} & \alpha_i + \beta_1 VEX_{it} + \beta_2 VS\_CA_{it} + \beta_3 VS\_US_{it} + \beta_4 RSPR\_S_{it} + \beta_5 RSPR\_O_{it} + \\ & \beta_6 RVOL\_S_{it} + \beta_7 RVOL\_O_{it} + AR(1) + \varepsilon_{it} \end{aligned} \tag{11}$$

[33] Note the extreme volatility for the CA to US option volume ratio reported in Table I on a firm-day basis, which indicates a need for a normalization of this variable for the regression analysis.

Where *SHARE* is the midpoint of the upper and lower bound of each market's information share, *VEX* is the intradaily variance of the exchange rate, *VS_CA* and *VS_US* are the integrated intraday variances for the Canadian-traded and US-traded underlying securities respectively, *RVOL_S* (*RVOL_O*) is the ratio of Canadian share volume (option contract volume) to the similar quantity in the US, *RSPR_S* (*RSPR_O*) is the ratio of the underlying security (option) average effective spread in Canada to the similar quantity in the US, and *AR(1)* is the first-order autoregressive term.

The results, shown in Table VIII, confirm the conclusions of the pairwise information share analysis. The market liquidity variables, the relative spreads and relative volumes, have weak and mostly non-significant effects on information shares.[34] Most of the relative spread coefficients have the right sign but none of them is significant. Of the relative volume variables' coefficients only one is significant and has the wrong sign; most of the coefficients are very small. As for the volatility variables' coefficients, they confirm strongly the pairwise results. The US intraday variance has strong and significant impacts in shifting informed trading away from both US-traded stocks and options and towards the Canadian market for the underlying security. The Canadian intraday variance has similarly strong and significant positive effects on both US underlying and option information shares, a corresponding negative effect on the Canadian underlying information share, but a positive and significant effect on the Canadian option market's information share, which can again be interpreted as evidence of trading on volatility. Last, the exchange rate uncertainty has strongly positive effects on both Canadian markets' information shares and a similarly strong negative effect on the US option market's information share. As already noted, this is evidence that price discovery, presumably by informed traders, takes place in the home market when trading in the US is subjected to exchange rate uncertainty.

[34] This is perhaps not surprising, since the market structure of the Canadian option market has been shown to be competitive even without any consideration of the cross-listing of options in the US, implying that the market makers' spread is close to the perfectly competitive level. See Khoury, Perrakis and Savor (2010).

IV. Conclusion

This paper examines the issue of price discovery for optioned Canadian securities cross listed in US markets. More specifically, the study provides an analysis of the relationship between Canadian and US option and equity markets for cross listed securities in an integrated model that also accounts for the foreign exchange dynamics between the two countries. We find that the foreign exchange market's contribution to the price discovery process is insignificant and we drop it from our empirical work. We then use two different econometric approaches to the cointegration analysis of the four markets and find essentially the same results with all approaches, which adds to the robustness of our findings. In unreported results we also study the pair-wise lead-lag relationships that exist among the various pairs of Canadian and US stock and option markets, and we find a high level of integration between all four markets..

The information share analysis was conducted using the Hasbrouck (1995) methodology for market pair settings and was modified to account for the aggregate dynamics of all markets simultaneously. In addition, the proposed approach was validated using an alternative methodology, which is an adaptation of Gonzalo & Granger (1995). The findings contrast with previous results by Chakravarty et al (2004) and show that equity markets exhibit on average a much higher information share than option markets both in local pair-wise comparisons and in the integrated model that accounts for all markets simultaneously. The analysis also concludes that Canadian equity markets' information shares dominate their US counterparts while the opposite result can be observed for option markets. These results are all the more relevant when relative transactions volumes of these markets are taken into consideration. Our data shows that US markets exhibit greater relative volumes than in Canada. This difference is almost tenfold for options, even though the Canadian options' information share is only slightly lower than its US counterpart, while the information share is greater in Canada for equity markets. The analysis also shows that the estimates derived from the proposed adaptation of Gonzalo & Granger (1995) coincide, on average, almost exactly with our proposed Hasbrouck (1995) adaptation, which further validates the conclusions presented in this paper.

In both the pair-wise and integrated models, the foreign exchange dynamics exhibit little or almost no information share in the price discovery process. The analysis also shows that the integrated model information shares differ from those of the pair-wise analysis. The integrated model results exhibit lower information shares for each individual market although the overall relative importance of each market in the price discovery process is maintained. This observation points to the importance of analysing the Canadian and US multi-market setting using an integrated approach where all markets are considered simultaneously. The results also validate the importance of the home market in the price discovery process for the securities of interest in this study.

Since there are wide variations in information shares in the cross section of the firms in the sample, but also in the intertemporal variation of the shares across the 122 days of our sample, we also examine the determinants of the information shares of each market in panel regressions. We find that market liquidity variables such as relative spread and relative volume have very little impact on the information shares, thus contradicting strongly the results of Chakravarty *et al (2004).* On the other hand, uncertainty in the two national stock markets and in the foreign exchange market turns out to be a strong determinant of the information shares in each market. We find strong evidence that foreign exchange uncertainty shifts price discovery towards the home market. As for uncertainty in the underlying equity markets, it also shifts discovery towards the competing equity and option markets in the other country; we also find some evidence of volatility trading in the form of increased information share in the Canadian market in response to an increase in uncertainty in the Canadian equity market.

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Table I – Descriptive statistics

This table provides the descriptive statistics for variables used in estimating equations (10) and (11) as well as other relevant descriptors of the data. The variables include integrated variances calculated on an intraday basis for C$/C$, the Canada-US foreign exchange rate return, CA Underlying, the Canadian-traded equity return, US Underlying, the US-traded equity return (if not stated otherwise, all quantities were derived per firm-day; all variance statistics are annualized). Correlations [4]-[6] were derived first for each firm and then summarized in the presented statistics. Effective spreads are computed as double the absolute value of the difference between transaction price and the average between quoted bid and ask prices. The effective spread ratios are calculated on a common currency basis. All volume figures are calculated on a daily basis per firm for the underlying markets and per contract for options.

#	Variable	N	Mean	Median	5^{th} Perc.	95^{th} Perc.	St. Dev
1	Integrated Variance of C$/U$	122	0.008	0.007	0.003	0.020	0.005
2	Integrated Variance of CA Underlying	6081	0.135	0.088	0.017	0.380	0.199
3	Integrated Daily Variance of US Underlying	6041	0.145	0.096	0.018	0.407	0.271
4	Correlation between [2] and [3]	50	0.974	0.987	0.895	0.995	0.045
5	Correlation between [1] and [2]	50	0.198	0.204	0.038	0.309	0.080
6	Correlation between [1] and [3]	50	0.210	0.215	0.028	0.324	0.090
7	Ratio of CA to US Stock Effective Spreads	5565	0.939	0.897	0.340	1.626	0.491
8	Ratio of CA to US Options Effective Spreads	4750	1.523	1.177	0.342	3.436	2.353
9	Ratio CA to US Stock Share Volume	5226	1.828	0.744	0.118	7.624	3.304
10	Ratio CA to US Stock Share Volume (per firm)	50	0.757	0.804	0.545	0.854	0.102
11	Ratio CA to US Option Contract Volume	5253	6.900	0.209	0.011	12.900	122.601
12	Ratio CA to US Option Contract Volume (per firm)	50	0.198	0.181	0.163	0.298	0.045
13	Ratio of CA Options to Stock Effective Spreads	5131	7.549	5.952	2.351	15.625	14.543
14	Ratio of US Options to Stock Effective Spreads	5492	6.598	4.274	1.501	14.167	40.643
15	Ratio of CA Options Contract to Stock Share Volume	5441	0.041	0.024	0.002	0.129	0.065
16	Ratio of US Options Contract to Stock Share Volume	5113	0.155	0.098	0.004	0.443	0.229

Table II – Pair-wise minimal and maximal information share aggregate results estimated separately for national equity-options markets

This table provides minimal and maximal information share bounds calculated based on the Hasbrouck (1995) model where each national market pair is considered separately.

Options		Stocks		Options		Stocks	
min	max	min	max	min	max	min	max
A: Frequently updated quotes sub-sample							
Canadian markets pair-wise comparison (3369 firm days)				US markets pair-wise comparison (3412 firm-days)			
0.017	0.052	0.948	0.983	0.028	0.105	0.895	0.972
B: Infrequently updated quotes sub-sample							
Canadian markets pair-wise comparison (2561 firm-days)				US markets pair-wise comparison (2479 firm-days)			
0.060	0.082	0.918	0.940	0.082	0.098	0.902	0.918
C: Aggregate sample							
Canadian markets pair-wise comparison (5930 firm-days)				US markets pair-wise comparison (5891 firm-days)			
0.036	0.065	0.935	0.964	0.050	0.102	0.898	0.950

Table III – Pair-wise minimal and maximal information share aggregate results estimated separately for Canada-US stock and options markets

This table provides minimal and maximal information share bounds calculated based on the Hasbrouck (1995) model where each market pair is considered separately according to the type of security.

Min	max	min	max
A: Frequently updated quotes sub-sample (3413 firm-days for stocks, 3368 firm-days for options)			
Canadian stocks		US stocks	
0.373	0.822	0.178	0.627
Canadian options		US options	
0.392	0.447	0.553	0.608
B: Infrequently updated quotes sub-sample (2628 firm-days for stocks, 2423 firm-days for options)			
Canadian stocks		US stocks	
0.440	0.793	0.207	0.560
Canadian options		US options	
0.427	0.448	0.552	0.573
C: Aggregate sample (6041 firm-days for stocks, 5791 firm-days for options)			
Canadian stocks		US stocks	
0.402	0.810	0.190	0.598
Canadian options		US options	
0.407	0.448	0.552	0.593

Table IV– Average residual correlations from VEC model estimated for integrated Canadian and US stock and options markets

This table provides the average residual correlation matrix from VEC model estimated on a four market common currency basis.

	CA underlying	CA implied	US underlying	US implied
CA underlying	1	0.101	0.632	0.108
CA implied	0.101	1	0.077	0.028
US underlying	0.632	0.077	1	0.165
US implied	0.108	0.028	0.165	1

Table V – Minimal and maximal information share aggregate results estimated for integrated Canadian and US stock and options markets

This table provides minimal and maximal information share bounds calculated based on the Hasbrouck (1995) model where all markets are considered simultaneously on a common currency basis.

Canadian markets integrated comparison				US markets integrated comparison			
Options		Stocks		Options		Stocks	
min	max	min	max	min	max	min	max
A: Frequently updated quotes sub-sample (3365 firm-days)							
0.012	0.040	0.347	0.798	0.018	0.078	0.154	0.608
B: Infrequently updated quotes sub-sample (2387 firm-days)							
0.042	0.062	0.376	0.716	0.052	0.075	0.177	0.516
C: Aggregate sample (5752 firm-days)							
0.024	0.049	0.359	0.764	0.032	0.077	0.164	0.570

Table VI – Information shares (midpoints) and component shares aggregate results estimated for integrated Canadian and US stock and options markets

This table provides midpoint information shares calculated based on the Hasbrouck (1995) model and Gonzalo and Granger (1995) component shares where, for both models, all markets are considered simultaneously on a common currency basis.

Type of estimate	Canadian markets		US markets	
	Options	Stocks	Options	Stocks
A: Frequently updated quotes sub-sample (3365 firm-days)				
Information shares	0.026	0.572	0.048	0.381
Component Shares	0.012	0.569	0.040	0.346
Statistically significant days (%)	9.4	31.9	10.7	14.5
B: Infrequently updated quotes sub-sample (2387 firm-days)				
Information shares	0.052	0.546	0.063	0.346
Component Shares	0.024	0.577	0.038	0.361
Statistically significant days (%)	10.7	41.6	11.5	19.3
C: Aggregate sample (5752 firm-days)				
Information shares	0.037	0.561	0.054	0.367
Component Shares	0.017	0.572	0.039	0.372
Statistically significant days (%)	9.9	36.0	11.0	16.5

Table VII – Pair-wise model information share drivers

This table provides the results for model (10) that estimates the impact on Hasbrouck (1995) information shares where each market pair is considered separately. The variables include integrated variances calculated on an intraday basis for VEX, the Canada-US foreign exchange rate return, VS_CA, the Canadian-traded equity return, VS_US, the US-traded equity return (all variance statistics are annualized), RSPR_CA (RSPR_US), the ratio of the option average effective spread to the average underlying effective spread for Canada (US) where effective spreads are computed as double the absolute value of the difference between transaction price and the average between quoted bid and ask prices, RSPR_S (RSPR_O), the ratio of the underlying security (option) average effective spread in Canada to similar quantity for US where effective spread ratios are calculated on a common currency basis, and RVOL_S (RVOL_O), the ratio of the share volume (option contract volume) in Canada to similar quantity for US where volume figures are calculated on a daily common-currency basis per firm for the underlying markets and per contract for options. AR(1) is a first-order autoregressive term.

	OPTIONS vs. STOCKS				CANADA vs. US			
	US markets		Canadian markets		Option markets		Stock markets	
Dependent Variable	Implied Price Information Share		Implied Price Information Share		Implied Price Information Share (US)		Underlying Price Information Share (US)	
Explanatory Variables	estimate	p-value	estimate	p-value	estimate	p-value	estimate	p-value
Constant	0.063554	0.0000	0.035735	0.0000	0.576936	0.5769	0.414311	0.0000
VEX	-0.000267	0.8232	0.001321	0.1979	-0.022332	-0.0223	-0.018450	0.0000
VS_CA	0.024810	0.0001	0.021401	0.0000	0.091562	0.0915	0.086143	0.0000
VS_US	-0.017794	0.0022	-0.012042	0.0059	-0.095153	-0.0951	-0.073664	0.0000
RSPR_CA	-	-	-2.54E-05	0.7090	-	-	-	-
RSPR_US	-2.79E-06	0.9155	-	-	-	-	-	-
RVOL_CA	-	-	-0.000263	0.9868	-	-	-	-
RVOL_US	-0.011029	0.0876	-	-	-	-	-	-
RSPR_S	-	-	-	-	0.008319	0.0083	-0.009697	0.2417
RSPR_O	-	-	-	-	0.007527	0.0075	-	-
RVOL_S	-	-	-	-	0.002398	0.3479	-0.003523	0.0698
RVOL_O	-	-	-	-	0.000103	0.5736	-	-
AR(1)	0.129357	0.0144	0.143308	0.0148	0.226506	0.0000	-0.009582	0.5139
Adjusted R squared	0.42245		0.3716		0.30040		0.06385	
F-Statistic p-value	0.0000		0.0000		0.0000		0.0000	
N cross-sections	43		49		42		43	
N obs	4575		4612		3686		4717	

Table VIII – Integrated model information share drivers

This table provides the results for model (11) that estimates the impact on Hasbrouck (1995) information shares where all markets are considered simultaneously. The variables include integrated variances calculated on an intraday basis for VEX, the Canada-US foreign exchange rate return, VS_CA, the Canadian-traded equity return, VS_US, the US-traded equity return (all variance statistics are annualized), RSPR_S (RSPR_O), the ratio of the underlying security (option) average effective spread in Canada to similar quantity for US where effective spread ratios are calculated on a common currency basis and where effective spreads are computed as double the absolute value of the difference between transaction price and the average between quoted bid and ask prices, and RVOL_S (RVOL_O), the ratio of the share volume (option contract volume) in Canada to similar quantity for US where volume figures are calculated on a daily common-currency basis per firm for the underlying markets and per contract for options. AR(1) is a first-order autoregressive term.

	Canadian Markets				US Markets			
Dependent Variable	Implied Price Information Share		Underlying Price Information Share		Implied Price Information Share		Underlying Price Information Share	
Explanatory Variables	estimate	p-value	estimate	p-value	estimate	p-value	estimate	p-value
Constant	0.026050	0.0000	0.558994	0.0000	0.041783	0.0000	0.396043	0.0000
VEX	0.001803	0.0215	0.011958	0.0017	-0.000821	0.4392	-0.012684	0.0007
VS_CA	0.007984	0.0470	-0.094047	0.0000	0.021523	0.0001	0.068600	0.0003
VS_US	-0.004815	0.1916	0.079797	0.0000	-0.015163	0.0024	-0.061024	0.0005
RSPR_S	-0.001254	0.5714	0.014874	0.1675	0.003127	0.2976	-0.015746	0.1346
RSPR_O	-0.000203	0.5434	-0.002028	0.2162	0.000292	0.5213	0.001768	0.2699
RVOL_S	-0.000205	0.6396	0.002979	0.1473	3.93E-05	0.9463	-0.002942	0.1418
RVOL_O	-1.07E-05	0.7373	-4.53E-05	0.7726	0.000230	0.0000	-0.000163	0.2869
AR(1)	0.153182	0.0000	0.011129	0.5030	0.090765	0.0000	0.001989	0.9046
Adjusted R squared	0.3154		0.04888		0.30781		0.05651	
F-Statistic p-value	0.0000		0.0000		0.0000		0.0000	
N cross-sections	42		42		42		42	
N obs	3686		3686		3686		3686	

Figure 1 – Distribution of time-average information shares for 50 firms in our sample from four-market model

This figure provides an illustration of the distribution of time-average information shares calculated based on the Hasbrouck (1995) model where all markets are considered simultaneously on a common currency basis.

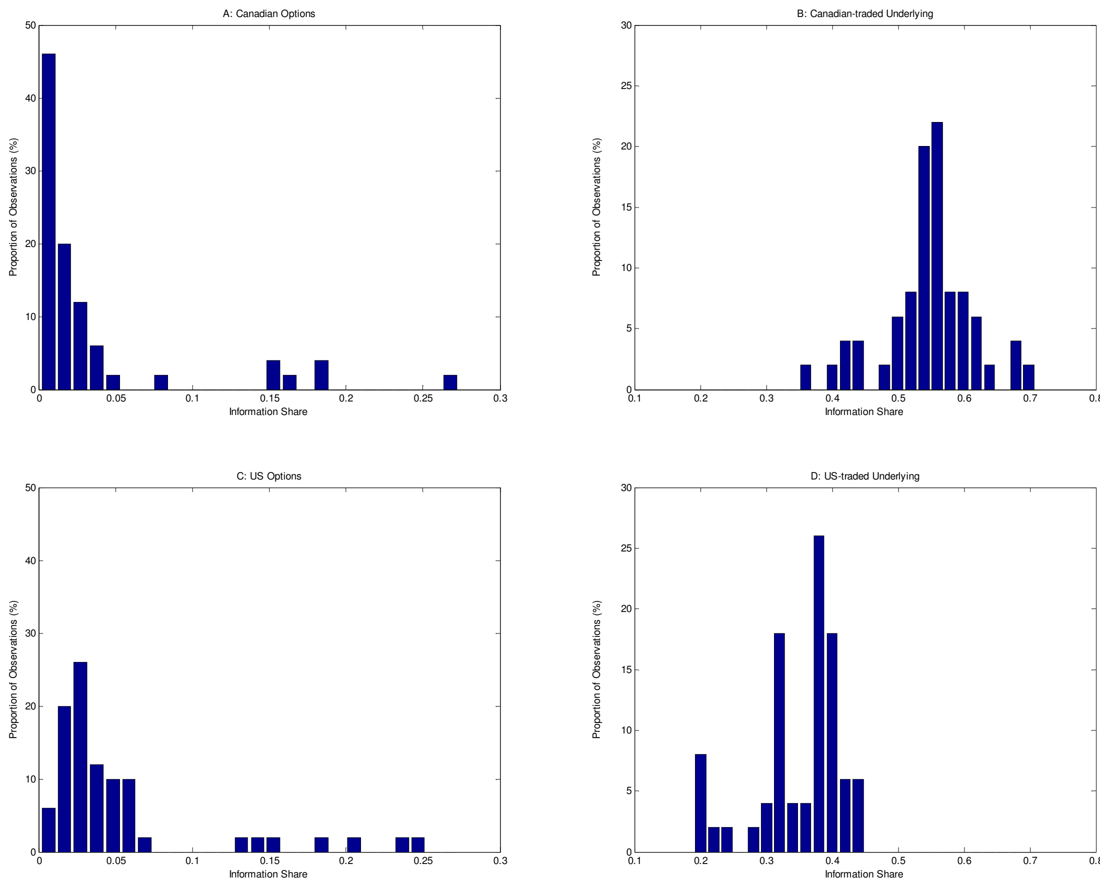

Figure 2 – Intertemporal variation for firm-average information shares from four-market model

This figure provides an illustration of the distribution of the cross-sectional average information shares calculated on a daily basis using the Hasbrouck (1995) model where all markets are considered simultaneously on a common currency basis.