THE ROLE OF U.S. TRADING IN PRICING INTERNATIONALLY CROSS-LISTED STOCKS

by

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Abstract: This paper addresses two issues: 1) where does price discovery occur for firms that are traded simultaneously in the U.S. and in their home markets and 2) what explains the differences across firms in the share of price discovery that occurs in the U.S? The answer to the first question is that the home market is typically where the majority of price discovery occurs, but there are significant exceptions to this rule and the nature of price discovery across international markets during the time of trading overlap is richer and more complex than previously realized. For the second question, the results provide strong support that liquidity is an important factor. For a particular firm, the greater the liquidity of U.S. trading relative to the home market, the greater the role for U.S. price discovery.

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I. INTRODUCTION

When a firm's stock is traded simultaneously in both the United States and another country, what should we expect regarding the role of U.S. trading in price discovery? If the evidence indicates that there is a bigger role for U.S. price discovery for some firms than others or for stocks of some countries than others, what determines this different role for different stocks? There is only a small literature on the topic of price discovery for internationally cross-listed firms, and the evidence regarding where price discovery occurs is mixed. There is some support for an important role for both the home and foreign market and there is also support for the home market dominating price discovery. Studies using high-frequency intradaily data include Ding, Harris, Lau, and McInish (1999), Hupperets and Menkveld (2002), Eun and Sabherwal (2003); and Phylaktis and Korczak (2004). All four papers find support for significant price discovery in both the home and the foreign market. Grammig, Melvin, and Schlag (2005) study German and U.S. trading and find support for the home market dominating.

Studies based upon lower frequency daily data include Kim, Szakmary, and Mathur (2000) who find a small role for U.S. price discovery in the case of firms from Japan, the Netherlands, the U.K., Sweden, and Australia. Lau and Diltz (1994) detect two-way causality between Japanese and U.S. prices of Japanese firms cross-listed in the U.S., while Lieberman, Ben-Zion, and Hauser (1999), studying Israeli firms also traded in the U.S., find that price discovery occurs in Israel with the exception of Teva, where the U.S. price leads the Israeli price. Wang, Rui, and Firth (2002) and Agarwal, Liu, and Rhee (forthcoming) conclude that for Hong Kong stocks listed in London, Hong Kong is the dominant market, whereas von Furstenberg and Tabora (2004) find two-way causality for two Mexican firms also traded in the U.S.

One major purpose of the present study is to contribute new evidence on the location of price discovery. Specifically, the analysis focuses on the overlap of trading for firms from Canada, France, Germany, and the U.K. with the U.S. Models of the information shares from each market are estimated for the major traded firms. So in contrast to most of the other studies, our paper has a multi-country perspective, and we are also able to see if there are structural differences between firms from different countries. This is of special interest with respect to a comparison of French, British, and German firms to Canadian firms, since the equity of the latter is traded in the U.S. via ordinary shares and the overlap with NYSE trading times is longest.

Our empirical results indicate that the share of price discovery of the home market (and, analogously, for the foreign market) can vary considerably across stocks. For example, in our sample there are stocks with a home market information share of almost 100 percent, while for other firms this number is less than 50 percent. Interestingly, the Canadian firms are by no means those for which the relative importance of the U.S. price is largest. U.S. information shares for the five firms listed in Toronto and New York vary from roughly 10 percent to around 55 percent and, thus, are covered by the full range of values obtained for firms from other countries.

These findings are the motivation for a subsequent cross-section analysis, where we try to identify the important determinants of this variation in information shares.

Theory suggests that the share of price discovery in a given market is closely linked to the relative liquidity of this market compared to the other market, and this intuition is the guideline for our choice of variables for the regression analysis. As it turns out, the differences in realized bid-ask spreads between the home and the foreign market and the ratio of turnover on the foreign and the domestic market can almost perfectly explain differences in information shares across stocks.

As shown in the literature review, the frequency of the data employed in the empirical study is of crucial importance for the results. The time-series evidence on price discovery in our paper comes from high-frequency data sampled at 10-second intervals. Sampling at lower frequencies (even 1-minute intervals), as is commonly done in the literature, can result in rather wide bounds on the information shares of different markets so that the true causality is blurred.

Our methodology differs from that used in other studies also with respect to the treatment of the exchange rate. In most cases first one stock price is converted from foreign into domestic currency (or vice versa) using the current exchange rate, and then the analysis is done in terms of just the two stock prices. This approach may introduce some problems in inferring price discovery as the effect of exchange rate change is incorrectly being ascribed to the stock price incorporating the exchange rate, as shown via Monte Carlo simulation in Grammig, Melvin, and Schlag (2005). Intuitively, this effect becomes more pronounced with an increasing volatility of the exchange rate. As a consequence, if the goal is to infer price discovery of the two trading locations, a three variable system with the exchange rate, the home market price, and the foreign market price should be modeled. We follow such a strategy to allow a clear focus on the contribution of each market to price discovery. A by-product of this estimation strategy is that we can estimate the adjustment of the two market locations to exchange rate shocks, which is an interesting result by itself.

To summarize the main findings of our analysis, the estimated models reveal that for most stocks price discovery largely occurs in the home market with a relatively small role for U.S. trading. However, results differ substantially across firms and some firms cast a larger role for U.S. than home market price discovery. The cross-sectional analysis contains a very high degree of explanatory power and indicates that the differences between firms are driven by differences in the relative liquidity of the U.S. market versus the home market. The more liquid is U.S. trading in a stock, the larger the role for U.S. price discovery relative to the home market. With respect to the exchange rate effects, it appears that the adjustment to exchange rate shocks mostly takes place via the U.S. price rather than the home market price. The bottom line of our paper, therefore, is that the dynamics of international price discovery are more complex than previously thought.

The study is organized as follows: section II provides information on each of the stock markets studied and their trading mechanisms along with information on the firms in the sample. Section III describes the data to be used for estimation. Section IV offers a description of hypothesized equilibrium relationships and the econometric methodology employed. Estimation results and discussion are presented in section V. A conclusion and summary is given in the final section VI.

II. TRADING VENUES AND FIRMS

This study involves data on stocks traded on five different exchanges in five different countries. The exchanges and countries are: the New York Stock Exchange (NYSE)/United States; The Toronto Stock Exchange (TSE)/Canada; the Xetra system operated by the Deutsche Börse/Germany; the London Stock Exchange (LSE)/Great Britain; and the Paris Bourse/France. These locations are chosen for analysis because they have trading hours that overlap U.S. trading hours and high-frequency intra-daily quote data are available. As mentioned in the introduction the goals of this study require data sampled at very high frequencies to reveal the causality present in the data (if any). Daily data, which is available for all exchanges, would not be useful. In addition, only those firms which are most actively traded can be usefully included in a study of price discovery as infrequent trading would result in either many data holes with high-frequency sampling or else a level of time aggregation that blurs the true causality in the data.

<Table 1 goes here>

A brief summary of each trading venue is provided in Table 1. It can be seen that most firms listing their shares in the United States do so with an American Depositary Receipt (ADR). ADRs are issued by a depositary bank accumulating shares of the underlying foreign stock. ADRs are issued at a fixed multiple relative to the underlying shares (like 5 ADRs per underlying share of Alcatel or 1 ADR per 6 underlying shares of BP Amoco). They tend to trade in a very limited range around the price of the underlying share, exchange-rate adjusted. ADRs and underlying shares are close, but not perfect, substitutes. Gagnon and Karolyi (2003) have an extensive discussion of differences between ADRs and underlying shares and the issues involved in arbitraging this market.

Focusing on a different but related issue Moulton and Wei (2005) provide evidence of how NYSE specialist behavior is affected by the presence of the underlying shares in Europe as substitutes for New York trading.

DaimlerChrysler (DCX) is a special case in our sample, since it trades in the United States as a global registered share (GRS). This is a single security that is traded globally although it is quoted and settled in the respective local currency. GRSs differ from ADRs in that they do not involve a depositary intermediary and have no issues of conversion between different forms since the same security is traded internationally. A GRS should therefore be an even closer, albeit still not perfect, substitute for the underlying stock across international markets as it allows all stockholders to participate in corporate matters (dividends, distributions, and control issues) regardless of their location.

As mentioned above Canadian firms traded in the United States are listed as ordinary shares. One might therefore think that Canadian ordinary shares trading in the United States may be more fungible with the home market than ADRs since the certificates traded in both countries are identical and there are no conversion fees. Our empirical work below will provide evidence on the degree to which U.S. and Canadian prices move together relative to prices of other countries' shares.

III. DATA

For the purpose of this study, we focus on bid and ask quotes submitted during the period of continuous trading in each market. Table 1 indicates that the intersection of the continuous trading hours of all exchanges is from 9:30-11:00 New York time. As a result, the empirical work will focus on this common interval of time for all markets. In order to avoid the problem of infrequent quoting, we focus on the firms from each home market that are most heavily traded on the NYSE. If we employed more thinly traded stocks, then we would have a problem of many "data holes" in our sample which would bias the results due to non-synchronous quoting in the home market and New York. Table 2 lists the firms and number of shares traded on the NYSE in 1999 along with the dollar value of these trades. The sample contains five firms from the TSE, four from the Paris Bourse, three from Xetra/Deutsche Börse, and five from the LSE. These were the top-traded firms from each home market and there was a fairly steep drop-off in trading volume at the next lower firms. In 1999, the total number of firms listed on the NYSE from these countries was: Canada, 70; U.K., 46; France, 16; and Germany, 9.

<Table 2 goes here>

While Canadian trading overlaps the entire New York trading day, the European markets only overlap the New York morning. We use the same sample period for all firms so that we have the same number of observations and hold everything constant other than the firm used for estimation. The New York data are from the TAQ data set available from the NYSE. Frankfurt data are proprietary data from the XETRA trading system of the Deutsche Börse. London data are the tick data set available from the London Stock Exchange. Paris trade and quote data were privately obtained, while Toronto data are the Equity Trades and Quotes data set from the Toronto Stock Exchange. The intradaily exchange rates were obtained from Olsen Data in Zurich and are indicative quotes as posted by Reuters.

Table 3 provides basic trading information for each firm. The first column lists the NYSE stock symbols for each firm (Table 2 linked symbols with firm names). The second column provides the conversion ratios between ADRs and the underlying home-market shares at the beginning of our sample. For instance, 12 SAP ADRs are equivalent to 1 share of SAP in Frankfurt during our sample period. Following a 3 to 1 stock split on 1 May, 2000, SAP ADRs now trade at a 4 to 1 ratio against the German shares. Stock splits occurring during our sample period are: Nortel (NT), 1:2 on August 13 on TSE and August 20 on NYSE; Vodafone (VOD), 1:5 on October 1 at LSE and October 4 on NYSE; and BP Amoco (BPA), 1:2 on October 1 on both LSE and NYSE. An asterisk denotes firms for which no ADRs, but ordinary shares or a GRS (in the case of DCX) are traded on the NYSE. In the empirical work that follows, the NYSE prices are adjusted by the appropriate conversion rate to be comparable to the underlying share prices. The third column of Table 3 lists the home market of each firm. The next two columns show the average relative spreads at home and on the NYSE. These are computed by taking sample averages of the spreads relative to the mid-quotes over the first 1.5 hours of New York trading. Volume and turnover data are reported in the remaining columns of Table 3. This average daily information is reported for the home market and the NYSE and for the overlap period of the New York morning as well as all day. Note that in the majority of cases the relative spread is larger on the NYSE than on the home market, and that the degree to which the NYSE spread exceeds that of the home market varies considerably across firms. For example, for ALA the ratio of the NYSE spread to the spread on the home market is more than 2.5:1, whereas for NT the NYSE spread is just 10 percent higher than on the home market. However, there are also firms for which the relative spread on the home market is higher than on the NYSE (VO, BPA, SBH, VOD).

Turnover is expressed in U.S. dollars using the sample average exchange rates to convert home market trades into dollars. For most firms, home market trading is heavier than New York trading. However, Canadian firms trade more in New York than at home. In addition, STM trades more in New York than Paris during the New York morning, but over the entire trading day, Paris trades STM more than New York.

With 90 minutes the joint overlap of all markets under consideration in our analysis might seem short, given that a full trading day can last up to 8 or 9 hours. It is therefore of some interest to see if the overlap period is sufficiently representative. Based on the values in table 3 the ratios of NYSE to home market volume and of NYSE to home market turnover for the overlap and for the full trading day exhibit nearly perfect correlations with values greater than 0.98. Although this does not constitute a full test it nevertheless yields strong support for the hypothesis that the overlap period is not too special.

<Table 3 goes here>

In summary, table 3 provides a portrait of the home market as the primary market (in terms of trading activity) for most firms. However, one can see that the difference between New York and home market trading activity differs greatly across firms. Next we turn to a more detailed description of the sampling methodology.

All asset price series are in logarithms of the average of the bid and ask prices. As mentioned above, the asset prices were sampled at 10-second intervals to assemble the basic data set. A preliminary analysis was conducted over alternative sampling frequencies and we chose 10 seconds as being suitable relative to lower frequencies like 1 minute or 10 minutes. Estimates using 1-minute sampling revealed an increase in the information share for New York prices that is misleading in that the New York price change includes both the effects of NYSE price shocks as well as the effects of the NYSE price adjusting to exchange rate shocks. At an even lower sampling frequency like 10 minutes, the contemporaneous correlation results in estimation bounds on the information shares so wide that one cannot clearly identify where price discovery occurs. At higher sampling frequencies than 10 seconds there was no gain in terms of reducing significant contemporaneous correlation, but there is a trade-off with microstructural issues like non-synchronous quoting or other sources of microstructure "noise".

Since our econometric model also involves lagged values of the price variables and the exchange rate, an additional sampling issue is with regard to overnight returns and lags. In our sample no overnight returns were used and no lags reached back to prior days. For instance, if the model calls for three lags in the variables, the data used for estimation begin with the fourth observation on each day. The initial observation each day for each stock is determined by the first 10-second interval following the NYSE open containing a quote in both markets.[1]

[1] To ensure the integrity of the data set, screening of the time series was performed for each stock. It was determined that ELF shares in Paris experienced an unusual divergence from the New York price for a few days in September 1999. Further research revealed that this was probably due to the forthcoming merger with TotalFina (TOT). The offer period to exchange ELF shares for TOT shares began on September 23 in France and September 29 in the United States. Anyone buying shares of ELF after those dates was not able to participate in TOTs offer (19 TOT shares for 13 ELF shares). We omit all ELF quotes after September 27, 1999 in order to avoid any inferential problems arising from the merger-related price dynamics. Other than this brief period for ELF, no other unusual patterns were found in the data.

IV. PRICE FORMATION AND DETERMINANTS: METHODOLOGY

IV.A. Liquidity and the price discovery in internationally cross listed stocks

A recent paper by Baruch, Karolyi, and Lemmon (2003) provides a theoretical model and empirical support for trading volume of cross-listed firms to be concentrated in the market with the highest correlation of cross-listed asset returns with other asset returns in that market. As the authors point out, the determination of such asset returns remains to be explained. Our expectation is that the relative liquidity of each market should be a major factor in determining location of price discovery. As Harris (2003, p. 243) states: "How informative prices are depends on the costs of acquiring information and on how much liquidity is available to informed traders. If information is expensive, or the market is not liquid, prices will not be very informative." The relation between informativeness of price and liquidity is also supported by finance theory as seen in papers like Admati and Pfleiderer (1988) or Hong and Rady (2002). In such models, price innovations are smaller, the deeper or more liquid the market. So any given change has a larger information component in the more liquid market. Models like Foucault (1999) or Foucault, Kadan, and Kandel (2003) have limit orders of liquidity traders priced with wider spreads as the uncertainty regarding information increases. The market location where information is embedded in price should have greater liquidity than the other market. Harris, McInish, and Wood (2003) make a connection between liquidity, information, and home bias in international investment. Domestic investors may be better informed about and better able to monitor local firms than foreign firms. They point to studies by Low (1993), Brennan and Cao (1997), and Coval (1996) as offering support for such information-based home bias.

The following simple model in which liquidity influences price discovery in internationally cross listed stocks is similar to the one presented in Grammig, Melvin and Schlag (2005). Assume that the log of the exchange rate at time t, E_t, is exogenous with respect to U.S. and home-market shares and evolves as a random walk with white noise innovation ε_t^e:

$$E_t = E_{t-1} + \varepsilon_t^e . \tag{1}$$

The log of the home-market share price, P_t^h, may follow a random walk and, thereby, introduce the innovation or random-walk component in the intrinsic value of the firm. Alternatively, it may follow the last observed log of the U.S. price, P_t^u, adjusted by the exchange rate. In the most general setting, P_t^h represents a weighted average of these two prices, where the weight l_h is determined by the relative liquidity of the two trading venues:

$$P_t^h = l_h P_{t-1}^h + (1 - l_h)(P_{t-1}^u - E_{t-1}) + \varepsilon_t^h . \tag{2}$$

with ε_t^h as the white noise innovation associated with the home market. Similarly, the log of the U.S. price, P_t^u, evolves as:

$$P_t^u = l_h (E_{t-1} + P_{t-1}^h) + (1 - l_h) P_{t-1}^u + \varepsilon_t^u \tag{3}$$

where ε_t^u is the white noise innovation associated with the U.S. market. In the one extreme case where $l_h = 1$ the home market price and the exchange rate are completely determined by their own innovations, and the long run development of the U.S. price depends on the home market and the exchange rate innovations. The U.S. market innovations exert only a transitory effect on the U.S. price. In this situation the home market is the primary and the U.S. market the derivative market. Put differently, price discovery for the stock is exclusively taking place in the home market. In the other extreme case, where $l_h = 0$, the home market is the derivative market, and it is only the U.S. market and the exchange rate innovations which determine the long run development of the home market price.

In our empirical model, we allow the innovations of both home market price, exchange rate, and U.S. market price to exert permanent effects on the two price series and the exchange rate. The magnitude and composition of the permanent effects are allowed to be different and estimated empirically so that the data will reveal where price discovery occurs. The estimate of the information share of innovations of the home market for the foreign market then represents an indirect estimate of the parameter l_h.

Arbitrage would force the two stock prices, denominated in the same currency, to move closely together over time. Subtracting the log of the U.S. price from the log of the dollar value of a home-market share we get

$$E_t + P_t^h - P_t^u = \varepsilon_t^e + \varepsilon_t^h - \varepsilon_t^u , \qquad (4)$$

i.e. the linear combination of the log exchange rate, log home-market price, and log U.S. price is a linear combination of three stationary variables. In other words, E_t, P_t^h, and P_t^u are cointegrated with the single (normalized) cointegrating vector $A = (1,1,-1)'$.

IV.B. Estimation of information shares for internationally cross-listed stocks

One of the key contributions of this paper is to address the relative importance of the innovations in the home and the U.S. market price and those in the exchange rate for the long-run development of the price series.

The methodology employed to address the issue of price discovery in internationally cross listed stocks is based on, but in some important aspects different from, the methodology introduced by Hasbrouck (1995).[2] The differences are caused by the fact that an asset is traded in dollars in the U.S. market and in local currency in the home market, so that the concept of "a single efficient price" for an asset that is traded simultaneously on *n* markets has to be re-thought if there is variation in the exchange rate.

It is assumed (and will be tested empirically) that there is a single cointegrating relation between E_t, P_t^h, and P_t^u with normalized cointegrating vector $A = (1,\ 1,\ -1)'$. The dynamics of home market price, U.S. market price and exchange rate can be represented in a non-stationary vector autoregression (VAR), and the model outlined in equations (1)-(3) is a special case of such a VAR. The Granger Representation Theorem (Engle and Granger, 1987) then implies that we can write the cointegrated three variable system in vector error (or equilibrium) correction form (VECM). The stationary vector process of the innovations $\{\varepsilon_t^e, \varepsilon_t^h, \varepsilon_t^u\}$ is assumed to have zero mean, contemporaneous covariance matrix Ω, and to be serially uncorrelated. Using Johansen's (1991) maximum likelihood methodology one can estimate the VECM parameters and test for the number

[2] An alternative method for inferring price discovery follows Gonzalo and Granger's (1995) common factor approach. A special issue of the *Journal of Financial Markets* is devoted to discussion and estimation of the two different methods (see Lehmann, 2002, for further elaboration).

of linearly independent cointegrating vectors. We expect only one cointegrating relation, but there could also be either none or two. In both of the latter cases the validity of the model would be questionable. The bootstrap methodology for cointegrated systems proposed by Li and Maddala (1997) is applied to estimate the standard errors (in fact the whole joint distribution) of the VECM parameter estimates and also of the derived statistics discussed below.

A very useful representation of the cointegrated three variable system is its infinite-order vector moving average (VMA) representation. Summing up the VMA weights and adding the identity matrix, we obtain a matrix Ψ, the elements of which represent the permanent impact of a one unit innovation in ε^e, ε^h and ε^u on the two price series and the exchange rate. Economic common sense suggests that the impact of both price series on the exchange rate should be small in magnitude, as the exchange rate is expected to be exogenous in our system.

It was Hasbrouck's (1995) insight to interpret a variance decomposition of the permanent impact on the efficient price of an asset that is cross-listed in n different (national) markets as a means to assign an information share to each of the n markets. The transfer of the idea to internationally cross-listed stocks is straightforward, once the effect of the exchange rate is properly accounted for. In the case of uncorrelated innovations, the information share of the U.S. market for the home market would then simply be equal to the share of the total variance of the permanent impact attributable to the U.S. price, and analogous computations would yield the information shares of the home market and the exchange rate innovations. A decomposition of the variance of the permanent impact on the U.S. price and on the exchange rate could be conducted in the same fashion. Due to contemporaneous correlation of the innovations (i.e., Ω will not be diagonal), the computation of information shares is a bit more involved. The Cholesky factorization of the innovation covariance matrix Ω is the standard solution to this problem. A potential problem of this method is that the ordering of the variables can influence the results, since the innovation ordered first in the Cholesky decomposition is assigned the highest information share, while the one ordered last receives the smallest share. The larger the contemporaneous correlation of the innovations, the wider the bounds of the information shares generated by different orderings of the variables. In our empirical application, we therefore permute the ordering of the variables in the Cholesky factorization and assess the consequences of the ordering on the results. It turns out that choosing the appropriate sampling frequency is the key to reducing the contemporaneous correlation of the innovations such that the ordering becomes practically irrelevant. Furthermore, we also report the average of the highest and the lowest information shares which result from the different orderings. The bootstrap methodology adopted in this paper further allows us to compute standard errors for these (averaged) information shares.

Collecting the information shares in a matrix yields

$$IS = \begin{pmatrix} I^{\varepsilon^e \to E} & I^{\varepsilon^h \to E} & I^{\varepsilon^u \to E} \\ I^{\varepsilon^e \to P^h} & I^{\varepsilon^h \to P^h} & I^{\varepsilon^u \to P^h} \\ I^{\varepsilon^e \to P^u} & I^{\varepsilon^h \to P^u} & I^{\varepsilon^u \to P^u} \end{pmatrix}.$$

For example, $I^{\varepsilon^u \to P^h}$ denotes the information share (averaged over highest and lowest) of the (orthogonalized) U.S. market innovation with respect to the home market price. By construction, the rows of the matrix IS sum to one. If the exchange rate is exogenous, then we expect that the estimates of both $I^{\varepsilon^h \to E}$ and $I^{\varepsilon^u \to E}$ are close to zero.

IV.C. Determinants of information shares

Our second main objective is to study, in a cross sectional analysis, the determinants of the information shares, and especially to test the hypothesis that liquidity is an important factor explaining the information share of the U.S. market for internationally cross listed stocks. For this purpose we focus on explaining the information share of the U.S. market innovations with respect to the home market price. Having estimated these information shares for a sample of NYSE listed international firms we estimate a cross sectional logistic regression, where the dependent variable is transformed to take into account the fact that, by construction, the information shares are bounded between 0 and 1:

$$\ln\left(\frac{I_i^{\varepsilon^u \to P^h}}{1 - I_i^{\varepsilon^u \to P^h}}\right) = x_i'\beta + u_i \quad (5)$$

x_i denotes a vector of explanatory variables serving as proxies for the relative liquidity of the home and the U.S. market of firm i. β is a vector of parameters to be estimated, and u_i a firm specific disturbance, where $E(u_i) = 0$. The variables used to proxy for liquidity are the difference between the U.S. market and home market realized bid-ask spreads and the ratio of U.S. to home market value and volume of traded stocks per day. We are aware that if these variables appear on the right hand side of equation (5) we have to deal with the problem of endogenous regressors, as the information share, in turn, may explain the (relative) liquidity for a stock. Endogeneity implies that OLS estimation would produce inconsistent parameter estimates. We therefore use instruments which are assumed to be uncorrelated with the disturbances u_i, but correlated with the endogenous liquidity proxies. These instruments are a) the number of U.S. analysts following firm i, b) the ratio of U.S. to non-U.S. fund holdings of NYSE-listed shares and c) the ratio of foreign to total sales of firm i. Standard GMM inference is employed to estimate the parameters β and to compute parameter standard errors. If the hypothesis is true that the more liquid the U.S. market is relative to the home market, the higher the information share of the U.S. market, then we would expect statistically and economically significant parameter estimates for the liquidity proxies and considerable explanatory power of the regressors.

V. ESTIMATION RESULTS

V.A. Information Shares in Price Discovery: Time-Series Evidence

Augmented Dickey-Fuller tests reveal unit roots in the log of each asset price and the variables are identified as being integrated of order one. The results of Johansen cointegration tests clearly support the hypothesis of one cointegrating vector among the three variables. With the variables ordered as exchange rate, home-market price, and U.S. price, the estimated cointegrating vectors are close to the vector $A = (1,1,-1)'$ indicated by theory. Due to the number of firms in the sample, estimates of the cointegration models are not reported. Instead, we focus on the estimates of the VECM equation and the associated information shares. The choice of lag length is determined by the Schwarz Information Criterion (SIC). We start with 18 lags, which represent three minutes in a sample with observations at 10-second intervals. Then, using the same set of observations that was used for the estimation of the model with 18 lags, we estimate the VECM at each shorter lag length down to one lag to determine the lag structure that minimizes the SIC. Lag lengths range from 3 for ALA, ELF, DT, and SAP to 7 for VO.

As explained above, the Cholesky factorization of the innovation variance-covariance matrix results in an upper bound on the estimated information share for the variable that comes first in the ordering and a lower bound on the information share for the variable that comes last in the ordering. We report the averages between the two after permuting the order to obtain both extreme bounds. First, an ordering of exchange rate, home-market price, and U.S. price is used to estimate the information shares and then a reordering with exchange rate, U.S. price, and home-market price is used and the average of the two information shares is reported in Figure 1.

The numbers given in parentheses are the bootstrap standard errors of the estimated information shares. For instance, in the top left figure of Figure 1, we see that the home market information share for TOT is about 0.9 with the standard error of this estimate equal to 0.022. The data plotted in the top left figure shows that the home-market information shares range from about 0.9 for TOT, ALA, ELF, and DT to about 0.4 for BPA. In general, the information shares of home market prices for the U.S. price are greater than 50 percent with only two exceptions, BPA and VO.

The top right of the figure contains the estimates and standard errors for the information share of U.S. price innovations on the U.S. price. We can see the close relationship between the two top figures in Figure 1. BPA and VO have information shares that are not significantly different from 50 percent in the top right figure while the other firms are generally much less than 0.5.

<Figure 1 goes here>

The middle row of Figure 1 presents the estimated information shares for the home and U.S. price innovations on the home market price. Once again it is seen that only BPA and VO have home-market price innovation information shares that are not significantly different from 50. The graphs in the upper two rows of Figure 1 are almost exactly the same

The bottom row of Figure 1 plots the average information shares attributable to exchange rate innovations on the home and U.S. price. It is clear that the exchange rate plays a small role in price discovery for these internationally-listed firms. The bottom left figure shows that the largest information share for exchange rate innovations on the home market price is estimated to be about 3 percent for BPA with much smaller values for the other firms (the average across all firms is 0.006). The bottom right figure shows that the exchange rate information shares are larger for the U.S. price (the average across all firms is 0.026). This indicates that the U.S. price responds more to an exchange rate shock than does the home-market price. The exchange rates employed in this study were fairly stable over the sample. In a different sample with more volatile exchange rates, the exchange rate contribution to stock price changes may be more substantial.

In summary, Figure 1 clearly shows the dominance of the home market price in price discovery. The information shares for U.S. price innovations are seen to be somewhat of a mirror image of the home-price information shares. The higher the information share of the home-market price innovations in explaining home-market price, the lower the U.S. information shares.

We do not report a figure for the information shares related to explaining the variance of innovations in the exchange rate. The exchange rate innovations account for essentially all price discovery in the exchange rate with the stock prices contributing essentially nothing. This is consistent with the exchange rate being exogenous with respect to the two stock prices and is reflected in the information share of the exchange rate in explaining the variance of exchange rate innovations equaling one while the information shares for the home-market and U.S. prices are essentially zero. This exogeneity of the exchange rate is supported across all firms.

Figure 1 clearly indicates that for the average firm, the home market is the primary market and the U.S. is the derivative market. However, 9 firms have a sizeable (information share greater than 20 percent) role for U.S. price discovery and two firms (BPA and VO) exhibit an even larger information share for U.S. price innovations than for home-market (London and Toronto) price innovations. The interesting question of what explains the differences across firms will be addressed in the cross-section analysis below.

As already mentioned, the exchange rates appear to be exogenous as there is no economically significant role for the stock prices in exchange rate price discovery. Yet how do the stock prices adjust to exchange rate shocks? To avoid arbitrage and restore the law of one price, the stock prices must change following a change in the exchange rate. Comparing the exchange rate information shares for home-market and U.S. prices underlying the plots in Figure 1, it is clear that generally the U.S. price bears the burden of adjustment to an exchange rate shock as the values of the exchange rate information shares in explaining U.S. prices are significantly greater than those for home-market prices in all but 3 cases. The exceptions for BPA and VO, are consistent with the U.S. being the primary market for these stocks. In addition, the exchange rate information share in the U.S. price is slightly larger than that for the home-market price for AL.

Our study is international in the sense that we examine cross-listed stocks from four different countries. This means that it is also interesting to check if there are any substantial differences between firms with different home markets. Especially, one might expect Canadian firms to be essentially 'U.S. firms', since the two markets are so close geographically, and both trading volume and turnover are larger on the NYSE than on the TSE for all Canadian firms (for both the overlap and the whole trading day). A look at Figure 1, however, clearly shows that Canadian firms are in no way special compared to the other firms in our sample. For example, the range of information shares of home market prices for U.S. prices is almost the same as for UK firms, with values from roughly 0.5 to 0.8. This shows that pure geographical proximity is not a reliable predictor for the informational content of a foreign listing, which is an interesting result per se in an international finance context. So the cross-sectional variation in information shares still remains an open issue, and in the next section we will focus on explanations based on microstructure arguments.

V.B. Information Shares in Price Discovery: Cross-Firm Evidence

As shown in Figure 1 the U.S. information shares for home market prices range from less than 1 percent (DT) to about 60 percent (BPA). In between these extremes, we see that in some cases, there is a sizeable role for U.S. price innovations in home market price discovery while in other cases, there is but a small role.

We now analyze the determinants of these cross-firm differences using the logistic regression model that was described above in equation (5). The focus is on assembling a data set that would include measures of liquidity in both stock markets. However, since endogeneity issues arise in a regression of information shares on measures of liquidity we also assembled data on additional variables that could reasonably serve as instruments. An extensive search for data on instrumental variables was undertaken. These variables include the extent to which a firm is mainly a domestic firm rather than a multinational, and the "U.S. following" that firms have. Data on the following measures of liquidity were obtained for the time period of the NYSE and home market trading overlap:

- NYSE and home market turnover (from NYSE and home market)
- NYSE and home market volume (from NYSE and home market)
- NYSE and home market realized bid-ask spreads (from NYSE and home market).

The realized spread is computed as twice the absolute difference between the transaction price at time t and the midquote at $t+5$ minutes.[3] Relative realized spreads were then calculated as the realized spread divided by the midquote at time t. The realized spread is preferred to the quoted spread at t as quoted spreads include an informational aspect that is purged when using realized spreads. As stated in Boehmer (2004, p. 13) "Realized spreads can be interpreted as a market's inherent execution cost,

[3] The spreads were calculated for medium-sized trades, with a dollar value of $50,000-$300,000, in order to capture "normal" spreads. Small and, particularly, large trades are more subject to idiosyncratic deals.

because they exclude the effects of the information content of order flow."[4] To serve as instruments, data on the following variables were obtained:

- the ratio of foreign to total sales (from Worldscope)
- U.S. analysts following (from I/B/E/S)[5]
- U.S. and non-U.S. fund holdings of NYSE listed shares (from Thompson Financial Spectrum).

The dependent variable in the regression is the information share in home market prices that is attributed to innovations in New York prices. These data are found in the section labeled "Info share attributable to US market innovations (home market))" in Figure 1. Estimation is carried out using Generalized Method of Moments (GMM). The GMM orthogonality conditions are that the instruments are uncorrelated with the residuals of the specified model of information shares as a linear function of a constant and the liquidity indicators. The weighting matrix used is White's heteroskedasticity-consistent covariance matrix. Initial analysis indicates that, not surprisingly, there is considerable collinearity among the three measures of liquidity. In particular, turnover and volume essentially convey practically the same information. Since turnover has marginally greater explanatory power, it is employed (in logs) in the reported estimations along with the difference of the realized relative spreads.

Estimation results are reported in Table 4. Both measures of liquidity have the expected effect on information shares and both have statistically significant coefficient

[4] Since November 2000, the U.S. Securities and Exchange Commission requires market centers to publish monthly data on realized spreads and effective spreads along with execution speed as indicators of market quality. See Boehmer (2004) and the American Stock Exchange website www.amex.com/amextrader/tradingdata for further discussion of realized spreads.

[5] Specifically, this is the number of U.S. analysts making a recommendation on a stock in 1999. Jennifer Juergens provided valuable advice in identifying the firms and locations of analysts.

estimates. The results support the following inference: the greater the NYSE trading activity relative to the home market, the greater the share of price discovery in New York; and the larger the realized spread on a firm's shares in New York trading relative to the home market, the lower the New York price discovery. The evidence is consistent with liquidity playing an important role in understanding the link between U.S. trading and price discovery for internationally cross-listed firms. In addition, the model developed here is able to explain a large proportion of the cross-firm variation in information shares as reflected in the R^2 of 0.989. Finally, the J-statistic of 0.21 reported in Table 4 has an associated p-value of 0.64. Therefore, we cannot reject the null hypothesis that the moment conditions are correct at any reasonable significance level.

<Table 4 goes here>

Given the positive impact of relative turnover on U.S. information shares, the results for the Canadian stocks deserve closer attention. As discussed above the ratio of NYSE to home market turnover is large (greater than one) for all Canadian stocks, so that based on just this variable the logistic regression would predict a generally larger U.S. information share for these firms. However, a detailed analysis of the differences in realized spreads between the NYSE and the TSE for the Canadian firms shows that this cost of trading is always higher on the NYSE than on the TSE, whereas we observe either the opposite sign of the difference (for UK firms) or mixed signs for the German and French stocks. So the effect of a higher relative turnover of the NYSE relative to the home market is outweighed by higher implicit transaction costs, and as a result the average Canadian firm is not substantially different from, e.g., the typical UK firm.

VI. SUMMARY AND CONCLUSIONS

This paper addresses two issues: 1) Where does price discovery occur for firms that are traded simultaneously in New York and in other markets in other countries and 2) what explains the differences across firms in the share of price discovery that occurs in New York? The short answer to the first question is that most firms have the largest fraction of price discovery occur at home with New York taking a smaller role. However, the data reveal important exceptions to this finding. It is simply not true that New York trading always lags the home market and there is no significant role for price discovery to occur in New York. The estimates for the information share of U.S. prices for home market prices range from almost zero to more than 50 percent. The answer to the second question is found by modeling the information share of New York trading in price discovery of home-market prices across firms as a function of variables related to New York liquidity relative to liquidity in the home market. The data strongly support liquidity as an important factor in understanding the role of the U.S. in price discovery. For a particular firm, the greater the liquidity of U.S. trading relative to the home market, the greater the role for NYSE price discovery for that firm.

An additional issue of interest arises from our modeling strategy of allowing an independent effect for the exchange rate, which is different from other studies in the same area. The results indicate strong support for the exchange rate as an exogenous variable in the cross-country pricing of a firm's stock. Furthermore, our results indicate that the NYSE price usually bears the burden of adjustment to the law of one price following an exchange rate shock. This is interpreted as further evidence that the NYSE is typically the derivative market for non-U.S. firms and the home market is the primary market. However, it is important to realize that this is not a universal truth. For those firms where the NYSE has the dominant price discovery role, the exchange rate adjustment comes more from the home market than the NYSE. Thus, it is not always true that an ADR provides exposure to currency fluctuations for a U.S. investor. For those ADRs with greater liquidity in U.S. trading than at home, we would find little price response to an exchange rate change.

Overall, the results indicate that the nature of price discovery across international markets during the time of trading overlap is richer and more complex than previously realized. While the home market is typically where the majority of price discovery occurs, there are significant exceptions to this rule.

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Table 1

A Comparison of Trading Venues

	New York	**Frankfurt**	**London**	**Paris**	**Toronto**
Major Index	S&P 500	DAX	FTSE 100	CAC 40	S&P TSX Composite
Currency	U.S. dollar	euro	British pounds	euro	Canadian dollar
Price Increments	Now $0.01 for 1999 sample period: $ 1/16	€0.01	Stock price: 0-9.9999, £0.0001 10-499.75, £0.25 500-999.50, £0.5 ≥ 1000, £1	Stock price: 0.01-49.99, €0.01 50-99.95, €0.05 100-499.90, €0.10 ≥ 500, €0.50	Stock price: < 0.50, C$0.005 ≥ 0.50, C$0.01
Trading System	Market maker specialists	XETRA electronic order book	SETS electronic order book	Euronext electronic order book	Market maker specialists
Trading Hours (local time)	9:30-16:00	Now 9:00-17:30 for 1999 sample period: 9:00-17:00	8:00-16:30	9:00-17:30	9:30-16:00
Trading Hours (New York time)	9:30-16:00	3:00-11:00	3:00-11:30	3:00-11:30	9:30-16:00

Table 2

Most active firms for NYSE trading in 1999

	Shares traded (millions)	Value (million $)
Toronto:		
Nortel (NT)	607	41,645
Seagram (VO)	257	12,644
Barrick Gold Corp (ABX)	381	7,325
Newbridge Networks (NN)	272	7,156
Alcan Aluminum (AL)	182	5,775
Paris:		
STMicroelectronics (STM)	124	11,589
Alcatel (ALA)	174	4,871
TOTALFina (TOT)	71	4,482
Elf Aquitaine (ELF)	52	3,996
Frankfurt:		
DaimlerChrysler (DCX)	170	14,794
SAP (SAP)	196	6,800
Deutsche Telekom (DT)	38	1,655
London:		
Vodafone (VOD)	383	43,858
BP Amoco (BPA)	476	41,443
SmithKline Beecham (SBH)	152	10,027
Glaxo Wellcome (GLX)	111	6,537
AstraZeneca (AZN)	98	4,085

Table 3
Descriptive Statistics for Firms and Markets

Summary statistics are reported for German, Canadian, British, and French companies with the largest NYSE trading volume. The sample period ranges from August 1, 1999 to October 31, 1999. Relative spreads are computed by taking sample averages of the ratio of spread to mid-quotes at the 10 second sampling interval considering only the spreads and mid-quotes during the daily trading overlap period of the first 1.5 hours of New York trading. Trade volume and turnover are reported both for the New York morning and all day. The trade turnover is expressed in US $ by using the sample average of the respective exchange rate to convert from local currencies. Trade volumes were computed by converting the NYSE traded ADRs into home-market equivalents. The column *ADR ratio* reports the conversion rate from ADRs into home-market stock. These ADR ratios refer to the beginning of the sample periods, before any stock splits. Stock splits occurred for NT (1:2 implemented August 13, 1999 on TSE and August 20, 1999 on NYSE), for VOD (1:5, implemented after October 1, 1999 at LSE and after October 4, 1999 at NYSE) and for BPA (1:2, implemented after October 1, 1999 at LSE and NYSE). DCX is traded as a globally registered share (GRS), i.e the unit of stock is the same at both the home market and the NYSE. Similarly, TSE stocks trade on the NYSE as ordinary shares, not ADRs. Trade volumes refer to units of stocks at the beginning of the sample period, before eventual stock splits.

					First 1.5 hours of overlap				Whole trading day			
Stock	ADR ratio	Home market	Relative spread home market	Relative spread NYSE	Trade volume home market	Trade volume NYSE	Turnover home market	Turnover NYSE	Trade volume home market	Trade volume NYSE	Turnover home market	Turnover NYSE
DCX	*	Xetra	0,107%	0,197%	694.046	191.814	51.528.693	14.228.694	2.905.670	484.184	215.366.677	35.799.818
DTE	1:1	Xetra	0,166%	0,361%	875.623	46.698	37.580.050	1.994.945	3.747.518	100.964	161.125.301	4.307.691
SAP	12:1	Xetra	0,175%	0,392%	78.682	27.317	33.602.328	11.859.883	330.121	76.542	141.447.885	33.199.945
ABX	*	TSE	0,280%	0,397%	656.598	678.708	13.657.798	14.108.793	1.811.664	1.882.666	37.454.097	38.959.813
AL	*	TSE	0,272%	0,290%	247.325	345.109	8.211.594	11.462.946	701.569	854.338	23.174.438	28.329.124
NN	*	TSE	0,335%	0,484%	176.210	240.555	4.381.832	6.046.260	562.857	723.956	13.799.781	17.966.281
NT	*	TSE	0,193%	0,221%	701.799	947.341	36.256.367	51.326.652	2.043.588	2.870.513	105.966.209	154.431.852
VO	*	TSE	0,348%	0,303%	156.979	309.328	7.495.220	14.617.631	558.623	993.028	26.677.862	46.833.469
AZN	1:1	LSE	0,191%	0,299%	646.448	154.541	32.646.959	6.315.050	2.975.335	395.723	136.066.262	16.264.166
BPA	1:6	LSE	0,193%	0,129%	3.684.905	3.123.947	48.988.226	45.092.071	13.807.599	8.356.922	194.712.299	121.570.006
GLX	1:2	LSE	0,193%	0,266%	1.193.917	326.431	39.243.013	8.950.115	5.496.750	841.888	162.460.030	23.002.738
SBH	1:5	LSE	0,277%	0,261%	1.999.612	1.241.117	29.828.594	15.472.396	9.394.953	3.154.039	127.110.541	39.114.665
VOD	1:10	LSE	0,216%	0,166%	7.109.291	6.309.281	69.158.792	69.300.596	32.780.446	19.087.688	301.014.118	203.257.944
ALA	5:1	Paris	0,154%	0,424%	188.520	30.942	27.447.956	4.507.972	650.620	105.683	94.607.842	15.459.105
ELF	2:1	Paris	0,140%	0,205%	192.174	50.030	34.867.412	9.088.520	767.866	120.663	138.353.741	21.829.475
STM	1:1	Paris	0,182%	0,249%	333.169	354.409	25.394.057	27.514.187	959.302	790.316	73.398.025	61.093.536
TOT	2:1	Paris	0,142%	0,229%	407.985	52.551	52.684.674	6.775.357	1.640.752	155.484	213.098.811	20.101.310

Table 4
Cross-Firm Estimation Results: Information Shares as a Function of Liquidity Indicators

This table summarizes logistic-regression results for a model where the dependent variable is the information share of U.S. price innovations in explaining home-market prices for a cross-section of the most heavily traded firms on the NYSE from the following locations: Frankfurt, London, Paris, and Toronto. Data are for 1999. Explanatory variables are NYSE/Home market turnover and the difference of realized relative spreads averaged over the sample period for each firm. Estimation is via GMM with the White heteroskedasticity-consistent covariance matrix used as the weighting matrix. Instruments are the ratio of foreign to total sales, U.S. analysts following, and the ratio of U.S. to non-U.S. fund holdings of NYSE-listed shares.

Variable	**Coefficient**	**Standard Error**	**P-value**
Constant	-0.862	0.042	0.000
NYSE/Home Turnover	0.820	0.031	0.000
NYSE spread-Home spread	-255.78	71.84	0.003

$R^2 = 0.989$

J-statistic = 0.21 (p = 0.64)

Figure 1: Information shares: estimates and standard errors.

The estimated information shares represent averages of two alternative orderings FX→home→US and FX→US→home. The values in parentheses are the standard errors of these averaged information shares. The standard errors are obtained by applying the procedure for bootstrapping cointegrating relations suggested by Li and Maddala (1997). We conduct 1000 bootstrap replications. In each replication the VECM is estimated and the $\psi(1)$ Matrix computed. In each replication the pairs of information share vectors resulting from the orderings FX→home→US and FX→US→home are averaged. The standard errors are obtained by computing the sample standard deviation (based on the sample of 1000 bootstrap replications) of the averaged information shares.