JOURNAL OF FINANCIAL INTERMEDIATION **7,** 263–292 (1998)
ARTICLE NO. JF980237

When Does Internationalization Enhance the Development of Domestic Stock Markets?*

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Received September 5, 1996

We develop a model to examine the impact of international cross-listing on domestic market liquidity and trading volume to determine when domestic market development is likely to follow. Greater information transparency between markets increases domestic market liquidity and volume, resulting in market development. Conversely, post-listing order flow migration away from the domestic market reduces its liquidity and volume, resulting in retardation. The net impact is positive and greater when market professionals acquire rather than reveal information, for smaller previously restricted markets, and for cross-listings in larger more transparent markets that have a greater potential to expand the shareholder base. *Journal of Economic Literature* Classification Numbers: D44, D82, F36, G15. © 1998 Academic Press

1. INTRODUCTION

The simultaneous trading of securities across multiple markets is commonplace with the globalization and emergence of trading venues. For example, cross-exchange equity trading increased from 0.3 trillion to 2.3

* We have received valuable insights on previous drafts of the paper from Bob Chirinko, Anne Villamil, Larry Neal, Werner Baer, Raul Feliz, John Welch, Maureen O'Hara (the editor), two anonymous referees, and seminar participants at the Board of Governors of the Federal Reserve System, the Federal Reserve Bank of New York, the Centro de Investigacion y Docencia Economicas (CIDE), the University of Illinois, the University of South Carolina, the University of Central Florida, and the 1996 meetings of the Latin American and Caribbean Economic Association.

1042-9573/98 $25.00

trillion dollars between 1988 and 1995, while the number of foreign equities listed on the New York Stock Exchange rose from 59 in 1986 to 290 in 1996 (Smith and Sofianos, 1997a). The concern among policy makers in emerging markets is that globalized trading will divert order flow from their domestic markets to more developed foreign markets (*Revista Bovespa,* 1996), impeding stock market development and potentially lowering future economic growth (King and Levine, 1993; and Levine and Zervos, 1995a).

The empirical evidence, however, does not support the fear that foreign investment liberalization will impede domestic market development. Table I documents the growth of Latin American equity markets since liberalization in 1989. Total capitalization grew from \$65 billion in 1990 to \$434 billion in 1996. Over the same period, total volume rose from \$22 to \$245 billion, with domestic volume expanding from \$19 to \$168 billion despite the Mexican crisis in 1994. Karolyi's (1996) survey of the empirical literature also provides evidence of the positive impact of investment liberalization on market development. He finds that with the listing of domestic securities on foreign markets, "liquidity ... improves overall, ... total post-listing trading volume increases on average, and, for many issues, home trading volume also increases." Hargis (1997) and Smith and Sofianos (1997a) find that cross-listing thus far has resulted in a "win–win" situation with volume and liquidity improving in the domestic market even though the foreign market dominates trading.

While these empirical studies are suggestive, there remains considerable controversy over the effects of internationalization. Moreover, what causes these effects is also unclear. For example, Domowitz *et al.* (1996) argue that liquidity and volume effects will depend on prior ownership restrictions across share classes, ownership restrictions across markets, and listing classifications. Karolyi (1996) documents that liquidity improvement "depends on the increase in total trading volume, the listing location, and the scope of foreign ownership restrictions in the home market." Hargis (1997) finds the total and home market volume of cross-listed equities is larger for those originating from emerging markets than for those originating from developed markets as documented by Foerster and Karolyi (1993 and 1994) and depends on the ability of cross-listing to expand the international shareholder base.

The suggestive nature of the empirical studies and their conflict with the fears of policy makers raise the following question: under what conditions will investment liberalization result in market development? We develop a model to address this question. The model delineates the impact of specific aspects of liberalization (e.g., degree of intermarket transparency and prior foreign investment restrictions) on various market characteristics (e.g., liquidity, total and home trading volume, price volatility, and informativeness

TABLE I
Evolution of Latin American Equity Markets, 1989–1996
(Currency Amounts in Millions of Dollars, End of Period)

	1990	1991	1992	1993	1994	1995	1996
A. Market Capitalization							
Latin America	65,992	187,430	232,599	388,690	424,586	349,973	434,149
Argentina	3,268	18,509	18,633	43,967	36,864	37,783	44,679
Brazil	16,354	42,759	45,261	99,430	189,281	147,636	216,990
Chile	13,645	27,984	29,644	44,622	68,195	73,860	65,940
Mexico	32,725	98,178	139,061	200,671	130,246	90,694	106,540
B. Value Traded and Turnover							
Latin America	22,114	65,511	109,831	178,895	312,699	210,908	245,211
Domestic Trading Value	19,445	51,820	82,815	132,998	209,097	129,229	167,990
U.S. Trading Value[1]	2,669	13,691	27,016	45,897	103,602	81,679	77,221
Turnover Ratio	33.5%	34.9%	47.2%	46.0%	73.6%	60.3%	56.4%
Argentina	852	4,824	15,679	16,464	23,984	20,273	16,827
Domestic Trading Value	852	4,824	15,679	10,339	11,372	4,594	4,382
U.S. Trading Value	0	0	0	6,125	12,612	15,679	12,445
Turnover Ratio (%)	26.1%	26.0%	84.4%	37.4%	65.0%	53.6%	37.7%
Brazil	5,598	13,373	20,674	57,505	109,782	82,470	137,909
Domestic Trading Value	5,598	13,373	20,525	57,409	109,498	79,186	112,108
U.S. Trading Value	0	0	149	96	284	3,284	25,801
Turnover Ratio (%)	34.2%	31.2%	45.3%	57.8%	58.0%	55.9%	63.2%
Chile	875	2,093	2,635	5,165	12,473	22,672	18,044
Domestic Trading Value	783	1,900	2,029	2,796	5,263	11,072	8,460
U.S. Trading Value	92	193	606	2,369	7,210	11,600	9,584
Turnover Ratio (%)	6.4%	7.5%	8.9%	11.6%	18.3%	30.7%	27.3%
Mexico	14,789	45,221	70,843	99,761	166,460	88,777	72,431
Domestic Trading Value	12,212	31,723	44,582	62,454	82,964	34,377	43,040
U.S. Trading Value	2,577	13,498	26,261	37,307	83,496	54,400	29,391
Turnover Ratio (%)	45.2%	46.1%	50.9%	49.7%	127.8%	97.9%	67.9%

[1] Value traded in the domestic market includes all companies. Value traded in the United States includes only equities traded on a major exchange (NYSE, NASDAQ, and AMEX). U.S. trading in 1996 is for the NYSE.

of trades). In addition to explaining empirical results, the model provides insights into the underlying process at work which cannot be inferred from empirical observations alone, because of the confounding effects that investment liberation has on market development.

The model incorporates four key attributes of liberalization. First, market professionals across international markets share trading information on cross-listed equities. This assumption is motivated by our observation that market makers in Mexico routinely examine trading in New York when setting terms of trade in their local markets. The shared information is noisy due to quoted spreads that hide effective spreads, delays in posting trades, and restricted access to limit orders. Thus information sharing is imperfect. Information sharing may also be asymmetric. Incentives to reveal versus acquire information differ across markets, thus each market will observe trading in the other market with unequal precision. We consider information sharing among professionals as opposed to traders because it has a greater potential to impact markets (see Pagano and Roell, 1996).

Second, addressing concerns of policy makers, we examine the impact of cross-listing on order flow migration. As investment barriers fall and domestic securities are cross-listed in foreign markets, institutional investors will reallocate trades to minimize trading costs. This initiates order flow migration, whose impact on market quality will depend on the amount of information market professionals share. Sharing information will also influence how informed traders trade across markets to keep their private information from being revealed (see Kyle, 1985).

Third, we see how prior foreign ownership restrictions alter the net impact of intermarket transparency and order-flow migration on domestic market development following cross listing. For example, Chile imposes restrictions on foreign ownership in the domestic market. Thus, cross-listing will not result in significant foreign order flow migration away from the domestic market. Conversely, for those shares open to foreign investment in Mexico, order flow migration away from Mexico can be expected following cross-listing. However, both Chile and Mexico will benefit comparably from intermarket transparency when observing trading in New York.

Fourth, the benefit of cross-listing to domestic markets depends on the ability to expand both the domestic and international shareholder base. The potential to increase international shareholder base is greater when shares are cross-listed on larger foreign markets. Thus, the impact of a Chilean firm cross-listing in the U.S. will be greater than a U.S. firm cross-listing in Chile. The expansion of the domestic shareholder base depends on the propensity of local investors to enter markets as domestic liquidity improves. Both aspects are incorporated in our model.

The primary conclusion of this study is that the overall impact of international cross-listing on domestic market liquidity and volume traded is positive. However, this depends on a complex interaction of the model's attributes, namely, market transparency, order flow migration, foreign ownership restrictions, response of domestic retail traders to changes in domestic market liquidity, and relative market size. Order flow migration following cross-listing negatively affects liquidity and volume in the domestic market. However, liquidity improves significantly in both the domestic and foreign market with increased information sharing between market professionals. Volume may increase or decrease depending on the type of information sharing.

Acquiring information is more beneficial than revealing it, increasing both volume and liquidity. Thus volume increases are usually accompanied by liquidity improvements, whereas liquidity improvements are not necessarily accompanied by volume increases. The negative effect of order flow migration will be less in markets with foreign ownership restrictions, accentuating the positive effect of information transparency. The net positive effect is larger when smaller domestic markets cross list on larger foreign markets and when local investors have a higher propensity to enter markets as domestic liquidity improves, showing the importance of expanding the shareholder base.

The remainder of the paper is organized as follows. Section 2 provides a brief survey of our innovations relative to prior research on dual listings and multimarket trading. Section 3 describes the model and characterizes the equilibrium. The model's predictions for the impact of cross-listing on market liquidity, trading volume and other equilibrium characteristics is presented in Section 4, examining the marginal impact of order flow migration across markets, degrees of information transparency between market professionals, prior foreign ownership restrictions, endogenous entry of retail traders, relative market size, and portfolio diversification effects. Section 5 concludes.

2. INNOVATIONS RELATED TO PREVIOUS RESEARCH

Previous models that examine the impact of dual listing the firm's securities on foreign capital markets fall into two categories. The first includes asset pricing models based on portfolio theory assuming perfect integration between the underlying domestic and cross-listed equity (Errunza and Losq, 1985 and 1989; and Eun and Janakiramanan, 1986). The benefits of integration are realized by the firm in terms of a lower cost of capital (Karolyi, 1996). However, perfect integration between the underlying asset in the domestic market and the cross-listed equity in the foreign market is unlikely to hold due to frictions in emerging markets such as lack of security market regulations and information disclosures. Indeed, the lack of information and liquidity in emerging markets are cited as important barriers to investing in these markets (Chuhan, 1994; and Bekaert, 1995). The assumption of perfect integration between the domestic and foreign market is also at variance with the evidence in Kleidon and Werner (1996) for U.K. cross-listings in the U.S.

The second category of models addresses microstructure issues in the context of multiasset/ multimarket trading, dealing with the structure of markets and characteristics of the securities traded. Chowdhry and Nanda (1991) model multimarket trading of a single asset, and Bhushan (1991) models multiasset trading in a single market. These early models clarify the impact on market liquidity and trading volume of informed and liquidity traders who trade across markets and securities in discriminating ways. However, they assume either perfect information sharing (i.e., integration) or complete lack thereof (i.e., fragmentation) between market professionals. Integration and fragmentation alone are insufficient ways to characterize market transparency. The issue is one of degree of transparency between markets. An important innovation of our model is the analysis of imperfect transparency and well as transparency asymmetries between markets.

Pagano and Roell (1996) clarify various types of market transparency and distinguish between pre-trade and post-trade transparency. They find that, on average, greater transparency increases liquidity. Domowitz *et al.* (1996) apply the notion of varying degrees of transparency for international cross-listing, arguing that dual listing results in order flow migration, which reduces liquidity in the domestic market. However, liquidity may improve because of intermarket competition from increased transparency. The interplay of these forces will be influenced by foreign ownership restrictions. While Domowitz *et al.* (1996) discuss the potential implications of transparency, we explicitly model it and analyze the resulting rational expectations equilibrium for varying degrees of transparencies and transparency asymmetries. This permits us to delineate the marginal impact of information transparency and order flow migration. The implication of foreign ownership restrictions can then be analyzed because they largely affect order flow migration and information transparency to a much lesser extent.

The findings of previous studies on the degree to which markets integrate can be summarized as follows. Chowdhry and Nanda (1991) show that dealers in different markets have incentives to reveal information to each other, thereby integrating markets. Their finding is challenged by Madhavan (1995) who demonstrates that dealers have the incentive to profit from their private information, thereby keeping markets fragmented. Lyons (1996) evaluates the tradeoffs that market transparency offers and concludes that dealers will optimally choose imperfect transparency. We find that market makers have a greater incentive to acquire information than to reveal it. Thus imperfect transparency is likely to hold supporting Lyons (1996).

A key simplifying feature in most previous models of multiasset/multimarket trading including Chowdhry and Nanda (1991) and Bhushan (1991) is that the number of traders remains constant, and that the relative differences in market liquidity influences only the distribution of trading across assets/markets. They fail to account for the fact that the number of market participants expands as liquidity improves. These assumptions are unreasonable given the findings of Karolyi (1996) and Hargis (1997) that expansion of shareholder base is an important determinant of volume changes in multimarket trading. Following Domowitz *et al.* (1996), we allow for an increase in retail trading as market liquidity improves.

3. THE MODEL

Our model builds on the work of Kyle (1985), Chowdhry and Nanda (1991), Bhushan (1991), Spiegal and Subrahmanyan (1992), Caballe and Krishnan (1994) and Pagano and Roell (1996). The model is summarized in Fig. 1. We consider:

(1) Two markets:	foreign and domestic
(2) Three types of securities:	a foreign security traded in the foreign market; a domestic security traded in the domestic market; and a domestic security that is cross-listed in the foreign market, i.e., traded in both the domestic and foreign markets
(3) Three types of traders:	profit maximizing informed traders; utility maximizing liquidity traders; and noise traders who trade for reasons exogenous to the model (the intensity of noise trading is later endogenized, depending on the market's liquidity, thereby permitting endogenous entry of traders into markets).
(4) Four market makers:	market makers are risk neutral and price securities competitively; one market maker trades the foreign security, another the domestic security, and the remaining two the cross-listed security in the domestic and foreign markets, respectively.

Trading occurs as in Kyle (1985). First, informed, liquidity, and noise traders submit orders to market makers. Then, market makers set prices at which trade occurs, absorbing the excess order flow.

A single period economy is analyzed where investments in securities are made at time 0 based upon expectations of their future values at time 1. Market prices of the securities at time 0 are denoted by P_{f}, P_{d}, P_{cf}, and P_{cd} and their future values at time 1 are given by

$$S_{\mathrm{f}} = 1 + \mu + \gamma_{\mathrm{f}} + \nu_{\mathrm{f}} \tag{1a}$$

$$S_{\mathrm{d}} = 1 + \mu + \gamma_{\mathrm{d}} + \nu_{\mathrm{d}} \tag{1b}$$

$$S_{\mathrm{c}} = 1 + \mu + \gamma_{\mathrm{d}} + \nu_{\mathrm{c}}, \tag{1c}$$

where the subscripts signify foreign (f), domestic (d), and cross-listed (c). The mean future values of the securities are normalized to unity. Deviations about the mean arise due to a global factor μ, country factors γ_{f} and γ_{d}, and firm-specific factors ν_{f}, ν_{d}, and ν_{c}, reminiscent of the market model for stock returns applied to international equities. For convenience, we assume unit factor sensitivities although this assumption can be easily relaxed (e.g., for the cross-listed security). The firm-specific factors (ν_{f}, ν_{d}, and ν_{c}), the country factors (γ_{f} and γ_{d}), and the global factor (μ) are

Markets:	Foreign Market		Domestic Market	
Risky Securities:	Foreign Security	Cross-Listed Domestic Security Traded in Foreign Market	Cross-Listed Domestic Security Traded in Domestic Market	Domestic Security
<u>Future Value of Risky Securities</u>: (influenced by market factor γ and firm-specific factor υ; firm-specific factors are independent and market factors are not perfectly correlated)	$S_f = 1 + \gamma_f + \upsilon_f$	$S_c = 1 + \gamma_d + \upsilon_c$	$S_c = 1 + \gamma_d + \upsilon_c$	$S_d = 1 + \gamma_d + \upsilon_d$
	imperfectly correlated market factors permit global diversification			
<u>Informed Trade</u>: (each informed trader observes one firm-specific factor υ; maximizes conditional expected profits and trades accordingly)	X_f	X_{cf}	X_{cd}	X_d
		Informed trader observing υ_c trades in both markets		
<u>Liquidity Trade</u>: (exogenously specified random amount Y is traded across markets/securities in a utility maximizing way)	Y_f	Y_{cf}	Y_{cd}	Y_d
		Sum of these trades equals the exogenously specified amount Y		
<u>Noise Trade</u>: (random and independent across markets/securities; noise-trading intensity is endogenized)	Z_f	Z_{cf}	Z_{cd}	Z_d
<u>Total Order Flow</u>: (in each market/security)	$\omega_f = X_f + Y_f + Z_f$	$\omega_{cf} = X_{cf} + Y_{cf} + Z_{cf}$	$\omega_{cd} = X_{cd} + Y_{cd} + Z_{cd}$	$\omega_d = X_d + Y_d + Z_d$
<u>Market Transparency</u>: (order flow observed by market maker)	ω_f	ω_{cf} and $\omega'_{cd} = \omega_{cd} + \varepsilon_{cd}$	ω_{cd} and $\omega'_{cf} = \omega_{cf} + \varepsilon_{cf}$	ω_d
		Each market maker for the cross-listed security observes a noisy signal of the other market's order flow.		
<u>Equilibrium Prices</u>: (market maker is risk neutral; sets price equal to security's conditional expected future value)	$P_f = E[S_f \mid \omega_f] = 1 + \lambda_f\omega_f$	$P_{cf} = E[S_c \mid \omega_{cf}, \omega'_{cd}] = 1 + \lambda_{cf}\omega_{cf} + \lambda'_{cd}\omega'_{cd}$	$P_{cd} = E[S_c \mid \omega_{cd}, \omega'_{cf}] = 1 + \lambda_{cd}\omega_{cd} + \lambda'_{cf}\omega'_{cf}$	$P_d = E[S_d \mid \omega_d] = 1 + \lambda_d\omega_d$

FIG. 1. Model of a domestic security cross-listed in a foreign market.

independent and normally distributed with zero means. To simplify the notation, we subsume the global factor into the country factors; i.e., we replace $\mu + \gamma_f$ by γ_f and $\mu + \gamma_d$ by γ_d in (1). Hereafter, γ_f and γ_d are referred to as market factors, which have a positive but imperfect correlation reminiscent of the correlation in market returns across international markets.

3.1. *Informed Trading*

There are three risk-neutral informed traders. Each observes one of the three firm-specific factors (ν_f, ν_d, and ν_c), and submits an expected profit-maximizing trade to the corresponding market maker. The informed trader who observes the firm-specific factor of the cross-listed security, ν_c, trades in both the foreign and domestic markets. The country factors with the subsumed global factor (γ_f and γ_d) are unobservable. Informed traders optimize

$$\underset{X_f}{\text{Max}}\, E[(S_f - P_f(X_f))X_f | \nu_f] \tag{2a}$$

$$\underset{X_d}{\text{Max}}\, E[(S_d - P_d(X_d))X_d | \nu_d] \tag{2b}$$

$$\underset{X_{cf}, X_{cd}}{\text{Max}}\, E[(S_c - P_{cf}(X_{cf}, X_{cd}))X_{cf} | \nu_c] + E[(S_c - P_{cd}(X_{cf}, X_{cd}))X_{cd} | \nu_c] \tag{2c}$$

respectively, where X_f, X_d, X_{cf}, and X_{cd} are the quantities traded with the corresponding market makers. In (2), profit equals the security's future value (S) less the current price paid (P) times the number of shares traded (X). The riskless rate is normalized to unity. Informed traders consider the impact of their trade on price. Hence the optimal trade size will depend on the functional relation between price and the informed trader's quantity traded, $P(X)$. For the cross-listed security, price in each market (foreign and domestic) will depend on the informed trader's quantity traded in both markets (see Eq. (2c)). This follows because prices in the two markets are set by market makers who share trading information among themselves.

3.2. *Liquidity Trading*

There is one risk-averse liquidity trader, although it is straightforward to extend the formal model to multiple liquidity traders (see, e.g., Bhushan, 1991). The liquidity trader can be thought of as a portfolio manager or institutional investor. The manager does not have private information. Instead, he is endowed with a cash position, W_0, and trades a total of Y shares (normally distributed with zero mean) for portfolio rebalancing reasons. The portfolio manager hedges the trade of Y shares across the three securities/four market makers (see Spiegal and Subrahmanyam, 1992). Denoting the quantities traded with the respective market makers as Y_{f}, Y_{d}, Y_{cf}, and Y_{cd}, the portfolio's time-1 value, denoted by W_1, is

$$\begin{aligned} W_1 = W_0 &+ (S_{\mathrm{f}} - P_{\mathrm{f}}(Y_{\mathrm{f}}))Y_{\mathrm{f}} + (S_{\mathrm{d}} - P_{\mathrm{d}}(Y_{\mathrm{d}}))Y_{\mathrm{d}} \\ &+ (S_{\mathrm{c}} - P_{\mathrm{cf}}(Y_{\mathrm{cf}}, Y_{\mathrm{cd}}))Y_{\mathrm{cf}} + (S_{\mathrm{c}} - P_{\mathrm{cd}}(Y_{\mathrm{cf}}, Y_{\mathrm{cd}}))Y_{\mathrm{cd}}. \end{aligned} \tag{3}$$

The portfolio manager is assumed to have negative exponential utility, and accordingly, optimizes

$$\operatorname*{Max}_{Y_{\mathrm{f}}, Y_{\mathrm{d}}, Y_{\mathrm{cf}}, Y_{\mathrm{cd}}} E[W_1 | Y] - \frac{\tau}{2} \mathrm{Var}[W_1 | Y], \tag{4}$$

subject to the constraint $Y_{\mathrm{f}} + Y_{\mathrm{d}} + Y_{\mathrm{cf}} + Y_{\mathrm{cd}} = Y$. In (4), the parameter τ measures the portfolio manager's aversion to risk. Expected utility is maximized considering trading impact on prices.

3.3. *Noise Trading*

Noise trading is exogenous to the model. The level of noise trading in each market/security is denoted by Z_{f}, Z_{d}, Z_{cf}, and Z_{cd}, respectively. These are independent, normally distributed random variables, with zero means, and represent the sum of trades executed by a large number of small retail customers. Standard deviations of Z_{f}, Z_{d}, Z_{cf}, and Z_{cd} measure noise-trading intensity in the respective securities/markets (see Domowitz *et al.*, 1996). Initially, we assume this intensity is constant; later, we endogenize the intensity with respect to the market's liquidity. In doing so, we can analyze the impact of an increase in shareholder base on market quality.

3.4. *Prices*

Market makers do not have private information about the security's future value. However, they observe the order flow in their respective markets. Identities of traders (informed, liquidity or noise) are obscured, thus components of the order flow from these sources are unknown. Only the total order flow, denoted by ω, is observed:

$$\omega_i = X_i + Y_i + Z_i, \qquad i = \mathrm{f, d, cf, and\ cd}. \tag{5}$$

Total order flow is a noisy signal of the security's value because the informed trader's component (X_i) signals value. As such, market makers have the incentive to observe total order flow across markets/ securities. Those market makers who set prices P_{f} and P_{d} (i.e., market makers of securities that are not cross listed) find there is no additional information that can be inferred about their respective security's value from observing order flow to other market makers. In contrast, those who set P_{cf} and P_{cd} (i.e., market makers of the cross-listed security) can benefit from observing each other's order flow because the informed trader who knows the firm-specific component of the cross-listed security, ν_c, trades in both the foreign and domestic markets.

We assume that the domestic market maker observes a noisy signal of the foreign market maker's order flow and vice versa. The respective noisy signals are

$$\begin{aligned} \omega'_{cf} &= \omega_{cf} + \varepsilon_{cf} \\ \omega'_{cd} &= \omega_{cd} + \varepsilon_{cd}. \end{aligned} \tag{6}$$

Thus the market makers' information sets are $\{\omega_f\}$, $\{\omega_d\}$, $\{\omega_{cf}, \omega'_{cd}\}$, and $\{\omega_{cd}, \omega'_{cf}\}$, and these are used to set the prices P_f, P_d, P_{cf}, and P_{cd}, respectively. Market makers are risk-neutral and price securities competitively; accordingly, price equals the security's conditional expected future value:

$$P_f = E[S_f|\omega_f] = 1 + \lambda_f\omega_f \tag{7a}$$

$$P_d = E[S_d|\omega_d] = 1 + \lambda_d\omega_d \tag{7b}$$

$$P_{cf} = E[S_c|\omega_{cf}, \omega'_{cd}] = 1 + \lambda_{cf}\omega_{cf} + \lambda'_{cd}\omega'_{cd} \tag{7c}$$

$$P_{cd} = E[S_c|\omega_{cd}, \omega'_{cf}] = 1 + \lambda_{cd}\omega_{cd} + \lambda'_{cf}\omega'_{cf}. \tag{7d}$$

The conjectural assumption for this equilibrium follows from Kyle (1985). Traders conjecture a linear price function when forming expectation on which optimal actions are based. Market makers conjecture that trades are linear with respect to signals. In equilibrium both conjectures hold. Competitive pricing by market makers holds so long as traders split orders across markets but not across market markers within a specific market (see Bernhardt and Hughson, 1997, pp. 86).

From (6) and (7), it is apparent that the degree of intermarket transparency depends on the precision with which order flow is observed by market professionals across markets. Informationally fragmented markets are represented by variances of ε_{cf} and ε_{cf} that increase without bound. By letting these variances approach zero, we are able to model markets that are informationally integrated. Markets that are integrated to some degree are characterized by intermediate values, and unequal values of these variances are used to distinguish markets that are asymmetrically integrated. These notions of transparency are generalizations of those discussed in Pagano and Roell (1996).

Equilibrium is specified by the informed traders' optimal trades (X_{f}, X_{d}, X_{cf}, and X_{cd}) obtained from Eqs. (2), the optimal allocation of liquidity trades (Y_{f}, Y_{d}, Y_{cf}, and Y_{cd}) obtained from Eqs. (3) and (4), and the equilibrium prices (P_{f}, P_{d}, P_{cf}, and P_{cd}) that are specified by the coefficients (λ_{f}, λ_{d}, λ_{cf}, λ_{cd}, λ'_{cf}, λ'_{cd}) in Eqs. (7). Equilibrium depends on the following set of variance parameters: market factors $\Gamma_i = \mathrm{Var}(\gamma_i)$ for i = f and d; firm-specific factors $N_j = \mathrm{Var}(\nu_j)$ for j = f, d, and c; liquidity trades $\Theta = \mathrm{Var}(Y)$; noise trades $\Omega_k = \mathrm{Var}(Z_k)$ for k = f, d, cf, and cd; market transparency $\Delta_n = \mathrm{Var}(\varepsilon_n)$ for n = cf and cd; and the correlation ρ between market factors γ_{f} and γ_{d}. Because of the model's generality, a closed-form solution for the equilibrium is unavailable, and therefore we analyze the model numerically for a wide range of parameter values. The numerical procedure, along with justifications for parameter choices, is detailed in the Appendix.

4. MAIN RESULTS

We analyze four equilibrium characteristics: market liquidity, trading volume, price volatility, and informativeness of prices. For each characteristic, we examine the effect of order flow migration, symmetric and asymmetric information transparency, foreign ownership restrictions, and increasing domestic and international shareholder base. Results are displayed in Figs. 2 through 5. Liquidity is displayed in Fig. 2, volume is displayed in Fig. 3, and price volatility and informativeness are displayed in Fig. 4. The impact of increasing shareholder base on liquidity and volume is displayed in Fig. 5.

4.1. *Market Liquidity*

The market's liquidity is defined as the (inverse) of the expected trading cost that noise traders bear conditional on the trade size:

$$E[(P_i - S_i)Z_i | Z_i] = \lambda_i Z_i^2, \qquad i = \mathrm{f, d, cf, and\ cd}. \tag{8}$$

The cost is the expected value of the current price P less the security's future value S times the trade size Z. As λ_i decreases, noise-trading costs fall and liquidity improves. While this relation is reminiscent of Kyle's (1985) result, our definition of liquidity clarifies the role of λ'_{cd} and λ'_{cf} in Eqs. (7c) and (7d), respectively. The order flow signals, ω'_{cd} and ω'_{cf}, do not directly influence the market's liquidity through their respective coefficients, λ'_{cd} and λ'_{cf}. Instead, these signals impact liquidity indirectly through their

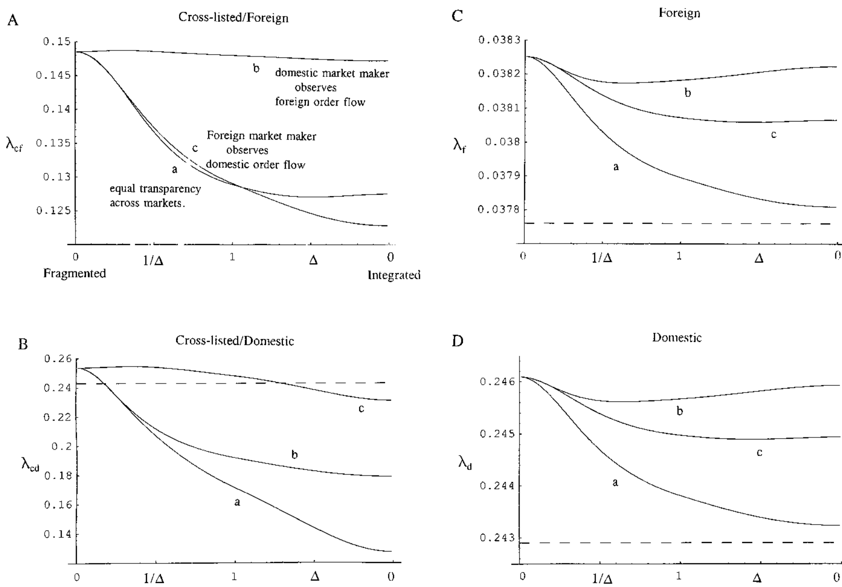

FIG. 2. Liquidity in markets 1, 2, 3, and 4 for varying levels of information transparency and transparency asymmetries across markets.

influence on λ_{cf} and λ_{cd}. This indirect impact of transparency on liquidity is hitherto unaddressed in the literature.

We now turn our attention to how the different investment liberalization attributes affect market liquidity. These results are displayed in Fig. 2. The horizontal axis represents the degree of market transparency (i.e., the variances Δ of the noise terms ε in Eq. (6)). Because Δ takes on values from zero to infinity, it is convenient to display Δ in two finite ranges: $1/\Delta$ from 0 to 1, and Δ from 1 to 0. When $1/\Delta$ equals zero, the order-flow signal ω' is uninformative; conversely, ω' is a noiseless signal of order flow when Δ equals zero. Perfect fragmentation holds if both $1/\Delta_{cf} = 0$ and $1/\Delta_{cd} = 0$, and perfect integration obtains if both $\Delta_{cf} = 0$ and $\Delta_{cd} = 0$. For the latter case, prices of the cross-listed security in both the foreign and domestic markets are equal.

The vertical axes in Panels A, B, C, and D exhibit (inverse) market liquidities, λ_{cf}, λ_{cd}, λ_f, and λ_d, respectively. Panel A displays the liquidity of the cross-listed security in the foreign market (denoted Market 1) and Panel B shows the liquidity of the cross-listed security in the domestic market (denoted Market 2). Panels C and D exhibit the liquidities of the remaining foreign and domestic securities in their respective markets (denoted Markets 3 and 4, respectively).

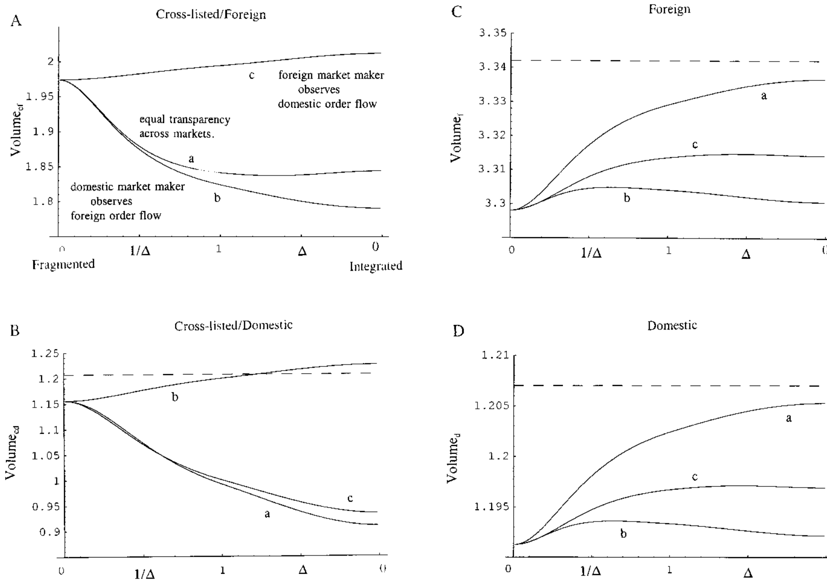

FIG. 3. Volume in markets 1, 2, 3, and 4 for varying levels of information transparency and transparency asymmetries across markets.

In each panel of Fig. 2, Line a characterizes the equilibrium for various degrees of integration assuming *symmetric* transparency, i.e., $\Delta_{cf} = \Delta_{cd}$. Lines b and c depict the equilibrium assuming *asymmetric* transparency. For example, Line b shows the equilibrium when the domestic market maker observes the foreign market's order flow with varying precision, i.e., $1/\Delta_{cf}$ takes on values that range from zero to infinity; conversely, the precision with which the foreign market marker observes the domestic market's order flow in this case is zero, i.e., $1/\Delta_{cd}$ equals 0. Line c depicts the equilibrium when this directional transparency between market makers is reversed. These symmetric as well as asymmetric cases are sufficient to yield general insights into the nature of equilibrium. The dashed lines in Panels B, C and D depict liquidity prior to cross-listing. Liquidity of the cross-listed security in the foreign market (Panel A) is undefined prior to listing.

4.1.1. *Order Flow Migration.* Order-flow migration in the absence of intermarket transparency reduces liquidity. To see this, we examine the impact of cross-listing on liquidity assuming perfect fragmentation, comparing the dashed lines to the solid lines in Panels B, C and D, when $1/\Delta$ equals zero. Liquidity is reduced in Markets 2, 3, and 4 (i.e., λ increases). This holds because the newly created cross-listed security's foreign market

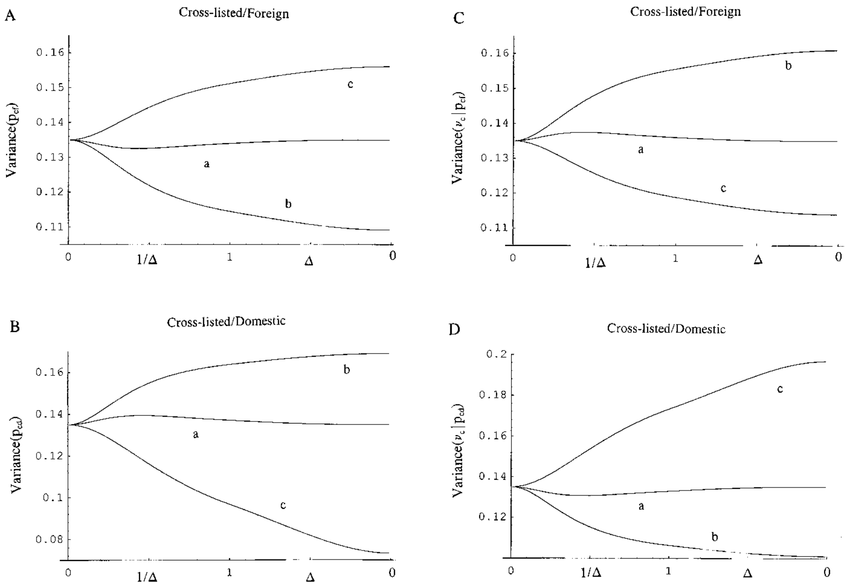

FIG. 4. Price volatility and informativeness of prices in markets 1 and 2 for varying levels of information transparency and transparency asymmetries across markets.

(i.e., Market 1) draws institutional trades from each of the remaining three markets. Institutional trades are redirected because Market 1 offers improved diversification benefits relative to Market 3 (with a marginal loss in liquidity) and improved liquidity benefits relative to Markets 2 and 4 (with comparable diversification benefits).

4.1.2. *Symmetric Transparency.* Next, we consider the marginal impact of transparency on liquidity in the symmetric case, i.e., when each market maker for the cross-listed security observes the other market's order flow with equal precision (line a). Increased symmetric transparency improves liquidity in all four markets. The relation between transparency and liquidity is monotonic in Markets 2, 3, and 4 (see Panels B, C, and D, respectively). In Market 1, liquidity improves as transparency improves only up to a certain level (line a, Panel A, displays a minimum). Thus market makers may have the incentive to reveal only a certain amount of information. This possibility is beyond the scope of previous models. In Chowdhry and Nanda (1991), for example, dealers must choose between revealing either all or none of their information.

Significant improvements in liquidity occur for the cross-listed security's domestic market if marginal improvements in transparency follow cross-listing. Indeed, the initial loss in liquidity due to order flow migration is

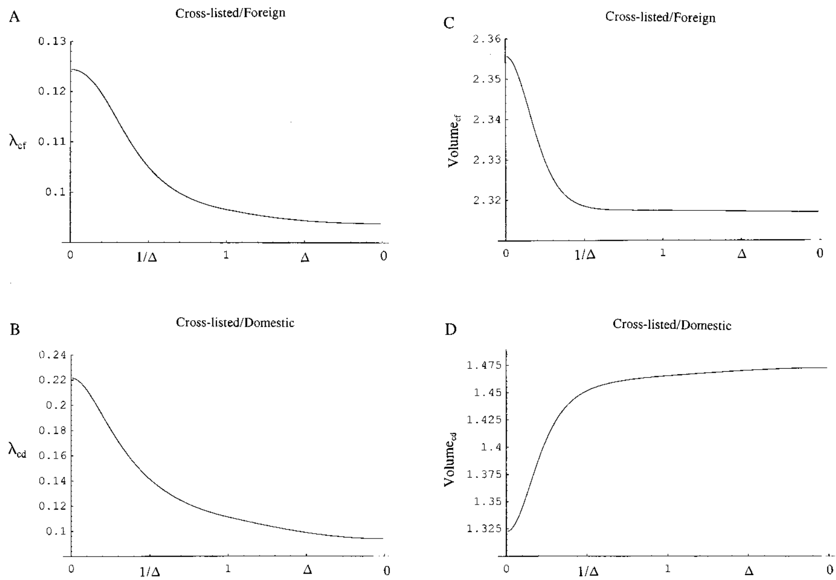

FIG. 5. Liquidity and volume in markets 1 and 2 for varying levels of symmetric information transparency and with endogenous entry of noise traders.

more than offset by liquidity gains resulting from increased transparency. This is evident from Panel B, where line a starts out marginally above the dashed line when markets are fragmented (i.e., when $1/\Delta$ equals zero), and ends up significantly below it when markets are integrated (i.e., when Δ equals 0). Market 1 also sees a considerable liquidity improvement although less than Market 2. In contrast, liquidity in Markets 3 and 4, even under perfect integration, never recovers to pre-cross-listing levels (line a lies above the dashed line in Panels C and D).

4.1.3. *Asymmetric Transparency.* Market makers have a stronger incentive to acquire information about the other market's order flow than to reveal order flow information about their own market. To see this, we examine line b (line c), which shows liquidity when the domestic (foreign) market maker observes the foreign (domestic) market's order flow but not the reverse. Liquidity in Market 1 (i.e., the cross-listed security's foreign market; see Panel A) improves significantly if the foreign market maker observes domestic order flow (line c) and only marginally if foreign order flow is revealed to the domestic market maker (line b). Indeed, Market 1's liquidity can actually worsen if the market maker reveals information with low precision (line b, Panel A, has an interior maximum). The asymmetric incentives regarding acquiring vs revealing information also hold for Market

2 (i.e, the cross-listed security's domestic market; see Panel B). Furthermore, for Market 2, liquidity improves beyond the pre-cross-listing level as transparency increases regardless of the type of informational asymmetry between markets (in Panel B, both lines b and c start out above the dashed line but end up below it as markets become integrated). Thus cross-listing benefits the security's domestic market under a wide range of information sharing assumptions.

Another interesting feature is one that contrasts Markets 1 and 2. First consider Market 1 (see Panel A). After the foreign market maker acquires information about the domestic market's order flow and liquidity improves (line c), there may or may not then be an incentive to reveal the foreign market's order flow to the domestic market maker. For the range of transparencies where line c lies above line a, subsequently revealing information will further improve Market 1's liquidity because it will move the market from a point on line c to a corresponding point vertically below on line a. Conversely, Market 1's liquidity will worsen by subsequently revealing information for the range of transparencies for which line c lies below line a. This dichotomy does not hold true for Market 2 (Panel B). Market 2's liquidity improves following acquisition of information about Market 1's order flow (line b), following which liquidity improves even further by revealing information (because line a lies below line b for all levels of transparency).

The contrasting results for Markets 1 and 2 can be attributed to the smaller size of 2 relative to 1 (in terms of noise-trading volume) and the competition between markets for institutional trades. We find that as the sizes of Markets 1 and 2 become comparable, both markets have the incentive to reveal information about their own order flow following the acquisition of information about the other markets order flow. In related work (Ramanlal *et al.*, 1997), a game-theoretic analysis is used to show that the interaction between markets results in three types of equilibria: (1) integrated, where both markets reveal information; (2) fragmented, where neither market reveals information; and (3) partially integrated, where the smaller market (i.e., Market 2) reveals and the larger market (i.e, Market 1) does not. The results suggest that despite competition, the larger market exerts a dominating influence on the smaller one, providing a more liquid trading environment for institutional investors. The smaller market nevertheless benefits from improved liquidity by cross listing, which is reflected in the cited empirical work that domestic market liquidity often improves even though the foreign market dominates in terms of trading volume (Hargis, 1997).

For the remaining Markets 3 and 4 (Panels C and D, respectively), asymmetric transparency results in correspondingly asymmetric liquidity spillover effects. While both markets respond in similar ways to the information asymmetry between market makers (i.e., the shape of lines b and c are similar in both Panels C and D), the positive impact of transparency on liquidity is larger when the larger market observes order flow (i.e., Market 1 observes order flow in Market 2, see Line c). Moreover, in both cases of information asymmetries, liquidity improves as transparency increases only up to a certain level beyond which liquidity worsens (both lines b and c display interior minimums). This has policy implications for the extent to which emerging markets will permit liberalization for some of their securities given the impact on others that remain traded in only the domestic market.

4.1.4. *Foreign Ownership Restrictions.* To see the postlisting effect of foreign ownership restrictions on liquidity in the domestic market, we reexamine the marginal impacts of order flow migration and increased transparency in Market 2 (Panel B). Cross-listing draws institutional trades from the security's domestic to foreign market. This lowers the domestic market's liquidity, which may in turn be offset by liquidity gains that accompany transparency improvements. With foreign ownership restriction in the domestic market, foreign institutional investors are absent in the domestic market prior to listing, and therefore post listing order flow migration is limited to domestic institutional investors. With reduced order flow migration, the net positive impact on liquidity due to improved transparency is greater in markets with prior restrictions.

4.2. *Trading Volume*

Following Domowitz *et al.* (1996), volume is measured as the expected absolute value of total order flow:

$$\text{Volume}_i = E[|\omega_i|] = \sqrt{2\,\text{Var}(\omega_i)/\pi}, \qquad i = \text{f, d, cf, and cd.} \tag{9}$$

In (9), ω_i is the total order flow in market I as defined in (5). The informed and liquidity trading components of ω_i, namely X_i and Y_i, are determined as part of the equilibrium as shown in the Appendix. The expression for this expected absolute value follows from normal distribution theory. The relation between volume (along the vertical axis) and transparency (along the horizontal axis) for Markets 1, 2, 3, and 4 is displayed in Fig. 3, Panels A, B, C, and D, respectively. The solid lines are labelled a, b, and c according to our previously defined transparency types, and the dashed lines signify pre-cross-listing volume levels.

4.2.1. *Impact of Order Flow Migration on Volume.* As before, we examine the marginal impact of order flow migration on volume in the absence of transparency effects by comparing the dashed lines to the solid lines in Panels B, C, and D when $1/\Delta$ equals zero. Volume is reduced in all three of Markets 2, 3, and 4. This occurs for two reasons. First, as noted previously, institutional trades are drawn to the newly created Market 1 because of the greater liquidity and diversification benefits it offers. Second, the migration of (uninformed) institutional trades away from Markets 2, 3, and 4 makes it more difficult for informed traders to effectively mask their trades in these markets, therefore informed trading decreases as well. Given that the intensity of noise training is fixed, overall volume is reduced in these three markets.

4.2.2. *Volume Changes Due to Symmetric Transparency.* We have seen that as transparency increases, liquidity improves in all four markets. However, volume decreases in Markets 1 and 2 and increases in Markets 3 and 4 (see line a, Panels A, B, C and D). The reason is as follows. As information is increasingly shared between Markets 1 and 2, it becomes more difficult for informed traders to profit in these markets (recall that informed trades are correlated across these markets and so sharing order flow information permits market makers to better identify these trades). Thus while Markets 1 and 2 continue to draw liquidity traders, informed traders are shut out. This has the potential to yield an ambiguous sign for volume changes as transparency improves. However, we find for the most part that volume decreases as symmetric transparency increases in Markets 1 and 2 (this result is later reversed when noise-trading intensity is endogenized).

In Markets 3 and 4, there is a marginal increase in volume as transparency increases (line a, Panels C and D, respectively). This volume increase is due primarily to the accompanying increase in liquidity that has the tendency to draw institutional trades. Since there is no benefit obtained from sharing information between market makers in Markets 3 and 4, informed trading remains unaffected in these markets. Thus as transparency and correspondingly liquidity improves, volume increases.

4.2.3. *Volume Changes Due to Asymmetric Transparency.* We first examine Markets 1 and 2 (Panels A and B) for the two types of asymmetries discussed earlier (corresponding to lines b and c). Recall, in order to improve liquidity, market makers have a greater incentive to acquire information than to reveal it. This finding is reaffirmed in the volume results. For example, volume in Market 1 (i.e., the cross-listed security's foreign market) increases if the foreign market maker observes the domestic market's order flow (line c in Panel A); if the foreign market's order flow is revealed to the domestic market maker, Market 1's volume decreases (line b in Panel A). This asymmetry in volume effects holds for Market 2 as well (Panel B). The reason is that since information acquisition has the greater potential to enhance market liquidity, a larger proportion of institutional trades can be attracted, resulting in greater volume.

More importantly for Market 2, acquiring information about order flow can increase its volume to beyond the pre-cross-listing level (line b in Panel B rises from below the dashed line to above it as transparency increases). Thus, cross listing benefits the security's domestic market in terms of increased volume under certain informational sharing assumptions, even in the absence of endogenous entry by retail traders into the market as local liquidity improves.

For the remaining Markets 3 and 4 (Panels C and D of Fig. 3), volume spillover effects are derived from liquidity spillover effects. Namely, as liquidity improves in these markets (shown in Panel C and D of Fig. 2), institutional traders are drawn, and correspondingly volume increases. Although, as in the case of liquidity, volume never reaches its pre-cross-listing level.

4.2.4. *Impact of Foreign Ownership Restrictions on Volume.* To see the post-listing effect of foreign ownership restrictions on volume in the cross-listed security's domestic market, we reexamine the marginal impacts of order flow migration and increased transparency on volume in Market 2 (Panel B). Recall that cross-listing results in order flow migration from the security's domestic to foreign market. This lowers the domestic market's volume. Volume will decrease even further as symmetric transparency improves. Conversely, it will increase if the domestic market maker acquires information about the foreign market's order flow. The net impact on volume is negative in the former case, but can be positive in the latter.

In the case of prior foreign ownership restrictions, order flow migration is reduced. Furthermore, since price discovery is likely to occur in the more liquid foreign market (Hasbrouck, 1995), more so because the domestic market is restricted, the benefit of cross-listing can be better realized if the domestic market maker acquires information about the foreign market's order flow. Because of the positive impact of information acquisition on volume together with the reduced order flow migration, markets with prior foreign ownership restrictions are likely to see a volume increase. Conversely, volume changes are ambiguous for markets without ownership restrictions (this result does not as yet consider the endogenous entry of retail traders into markets).

4.3. *Price Volatility and Informativeness*

We examine volatility and informativeness of prices for the cross-listed security's foreign and domestic markets only (i.e., Markets 1 and 2). Prices in these markets are given by Eqs. (7c) and (7d), respectively. The corresponding volatilities are

$$\mathrm{Var}(P_{\mathrm{cf}}) = (\lambda_{\mathrm{cf}})^2\,\mathrm{Var}(\omega_{\mathrm{cf}}) + (\lambda'_{\mathrm{cd}})^2\,\mathrm{Var}(\omega'_{\mathrm{cd}}) + 2(\lambda_{\mathrm{cf}})(\lambda'_{\mathrm{cd}})\,\mathrm{Cov}(\omega_{\mathrm{cf}}, \omega'_{\mathrm{cd}}) \tag{10a}$$

$$\mathrm{Var}(P_{\mathrm{cd}}) = (\lambda_{\mathrm{cd}})^2\,\mathrm{Var}(\omega_{\mathrm{cd}}) + (\lambda'_{\mathrm{cf}})^2\,\mathrm{Var}(\omega'_{\mathrm{cf}}) + 2(\lambda_{\mathrm{cd}})(\lambda'_{\mathrm{cf}})\,\mathrm{Cov}(\omega_{\mathrm{cd}}, \omega'_{\mathrm{cf}}). \tag{10b}$$

In (10), ω and ω' are defined in Eqs. (5) and (6). These expressions, together with the price coefficients (λs), optimal informed trades (X's), and allocation of liquidity trades (Y's), which are determined as part of the equilibrium (see Appendix), are sufficient to evaluate (10).

Price informativeness is defined as the precision with which price reveals the informed trader's private information (ν_{c}), which is given by the inverse of

$$\mathrm{Var}(\nu_{\mathrm{c}}|P_{\mathrm{cf}}) = N_{\mathrm{c}} - \mathrm{Cov}^2(\nu_{\mathrm{c}}, P_{\mathrm{cf}})/\mathrm{Var}(P_{\mathrm{cf}}) \tag{11a}$$

$$\mathrm{Var}(\nu_{\mathrm{c}}|P_{\mathrm{cd}}) = N_{\mathrm{c}} - \mathrm{Cov}^2(\nu_{\mathrm{c}}, P_{\mathrm{cd}})/\mathrm{Var}(P_{\mathrm{cd}}). \tag{11b}$$

These relations follow from normal distribution theory and are straightforward to evaluate given the pricing functions in (7c) and (7d) and their variances in (10a) and (10b). The measures in (10) and (11) are displayed in Fig. 4 for the three types of transparencies defined earlier.

Results for both Markets 1 and 2 can be summarized as follows: (1) acquiring information increases volatility as well as informativeness of prices; (2) revealing information decreases volatility and informativeness; (3) these results are monotonically dependent on transparency levels; and (4) relative to asymmetric transparency, increases in symmetric transparency does not significantly influence either volatility or informativeness of prices.[1]

4.4. *Expansion of Shareholder Base*

The cited empirical literature finds that expansion of shareholder base is an important factor that can influence market development (e.g., Hargis, 1997). International shareholder base may be expanded by cross-listing in a foreign market, and the increase in domestic shareholder base will depend on the potential to draw local investors as home market liquidity improves.

[1] In the absence of transparency (i.e., $1/\Delta = 0$), pre- and post-listing price volatility/informativeness of the cross-listed security in its domestic are equal. Thus, order flow migration alone does not influence volatility/informativeness, but the accompanying increase in transparency does. Neither order flow migration nor increased transparency influences volatility/informativeness of the securities in Markets 3 and 4.

The increase in international shareholder base will depend on the relative size of the foreign market. Exogenous noise-trading intensity is taken as the measure of market size (because informed and liquidity trading is endogenized). We have analyzed the equilibrium for ratios of foreign to domestic market size ranging from one to three. In general, smaller domestic markets benefit more in terms of improved liquidity as post-listing transparency increases. The same holds true for volume increases in those cases where the domestic market acquires information.

Analyzing the impact of increases in domestic shareholder base is more complicated. As domestic liquidity improves, additional retail traders enter the market. Within the framework of our model, this means that as liquidity increases (i.e., as λ_i decreases), so does noise trading intensity (i.e., Ω_i increases). The relation between them will depend on how responsive traders are to changes in liquidity. We choose the following simple relation consistent with rational behavior:

$$\frac{\partial \Omega_i / \Omega_i}{\partial \lambda_i / \lambda_i} = -\eta \lambda_i, \qquad i = \text{f, d, cf, and cd.} \tag{12}$$

In (12), noise-trading elasticity varies inversely with liquidity (η is a positive constant); i.e., for more liquid markets, noise traders are less responsive to changes in liquidity. Inelastic trading occurs only in perfectly liquid markets, i.e., when λ approaches zero. Both characteristics reasonably describe trading behavior. Solving (12) yields

$$\Omega_i = \Omega_i^0 \, \mathrm{Exp}[-\eta \lambda_i] \qquad i = \text{f, d, cf, and cd.} \tag{13}$$

In (13), Ω_i^0 is the maximum attainable noise-trading level; it measures the market's potential to attract retail customers as liquidity improves.

We solve the equilibrium assuming that maximum attainable noise-trading intensity in the domestic market is one-half that of the foreign market (i.e., $\Omega_{\text{cf}}^0 = \Omega_{\text{f}}^0 = 8$, $\Omega_{\text{cd}}^0 = \Omega_{\text{d}}^0 = 4$, and $\eta = 5$). Results for the cross-listed security's foreign and domestic markets are displayed in Fig. 5 for the case of symmetric transparency only (the analysis is limited because of the complicated numerical procedure to obtain equilibrium). Liquidity is shown in Panels A and B, and volume in Panels C and D, respectively, for the two markets, foreign and domestic.

As in the case when the intensity of retail trading is held fixed, liquidity improves with increased symmetric transparency in both markets (Panels A and B). More importantly, volume in the cross-listed security's domestic market now increases as transparency increases (Panel D), while volume in the foreign market continues to decrease (Panel C). Thus, volume increases accompany transparency increases in the domestic market for a wider range of information sharing assumptions when the potential to increase domestic shareholder base is considered.

5. CONCLUSIONS AND DISCUSSION

The expansion of cross-listings from emerging markets in Russia and China have followed the earlier surge from Latin America and have important implications for the development of domestic stock markets. We develop a model to determine when domestic markets are more likely to develop after cross-listing. The model incorporates factors such as the likelihood of postlisting order flow migration away from the domestic market to the foreign market and the domestic market's potential benefit from price discovery in the foreign market facilitated by information transparency. Foreign ownership restrictions will influence the net impact of these two factors on the domestic market's liquidity and volume, as will the potential to increase shareholder base both internationally and domestically. Furthermore, frictions and imperfections in emerging markets will result in varying degrees of information transparencies as well as asymmetric transparencies across markets. By modeling this multitude of factors, we can determine the conditions under which domestic market development is more or less likely to occur.

The primary conclusion of this paper, in agreement with the empirical literature, is that the overall impact of international cross-listing on domestic market liquidity and volume traded is positive. Testable implications of the model are that international cross-listings on larger more transparent markets, from smaller less liquid markets with greater foreign ownership restrictions should show the greatest improvement in domestic stock market quality. Our results also show that the potential to increase shareholder base is an important factor for market development, which is consistent with the empirical evidence in Hargis (1997). These results indicate that contrary to fears of policy makers, international cross-listings may enhance the development of domestic stock markets.

APPENDIX

Equilibrium is specified by the optimal informed trades (X_{f}, X_{d}, X_{cf}, and X_{cd}), the optimal allocation of liquidity trades (Y_{f}, Y_{d}, Y_{cf}, and Y_{cd}), and the price coefficients (λ_{f}, λ_{d}, λ_{cf}, λ_{cd}, λ'_{cf}, λ'_{cd}). We employ a four-step approach to solve for the equilibrium. First, we determine the X's as functions of the λ's. Second, we obtain the Y's as functions of the λ's. Third, the λs are written as functions of the X's and Y's. Finally, the entire system of relations is solved numerically for the X's, Y's, and λ's. The system of equations is nonlinear as well as complex, affording no closed-form analytic solution.

A. *Optimal Informed Trades.* Substitute the future values of the securities given in Eq. (1), the price functionals given in Eq. (7), and the order flows as well as signals of order flow given in Eqs. (5) and (6), respectively, into the informed traders' objective functions in Eq. (2). The expected values of the γ's, ν's, Y's, Z's and ε's are zero. Thus, the first-order conditions yield

$$\begin{aligned}
X_{\mathrm{f}} &= \left(\frac{1}{2\lambda_{\mathrm{f}}}\right)\nu_{\mathrm{f}} \equiv \alpha_{\mathrm{f}}\nu_{\mathrm{f}} \\
X_{\mathrm{d}} &= \left(\frac{1}{2\lambda_{\mathrm{d}}}\right)\nu_{\mathrm{d}} \equiv \alpha_{\mathrm{d}}\nu_{\mathrm{d}} \\
X_{\mathrm{cf}} &= \left(\frac{2\lambda_{\mathrm{cd}} - (\lambda'_{\mathrm{cf}} + \lambda'_{\mathrm{cd}})}{4\lambda_{\mathrm{cf}}\lambda_{\mathrm{cd}} - (\lambda'_{\mathrm{cf}} + \lambda'_{\mathrm{cd}})^2}\right)\nu_{\mathrm{c}} \equiv \alpha_{\mathrm{cf}}\nu_{\mathrm{c}} \\
X_{\mathrm{cd}} &= \left(\frac{2\lambda_{\mathrm{cd}} - (\lambda'_{\mathrm{cf}} + \lambda'_{\mathrm{cd}})}{4\lambda_{\mathrm{cf}}\lambda_{\mathrm{cd}} - (\lambda'_{\mathrm{cf}} + \lambda'_{\mathrm{cd}})^2}\right)\nu_{\mathrm{c}} \equiv \alpha_{\mathrm{cd}}\nu_{\mathrm{c}}.
\end{aligned} \tag{A1}$$

The second-order conditions for a maximum hold when λ_{f}, λ_{d}, λ_{cf}, and λ_{cd} are positive.

B. *Liquidity Trade Allocations.* The liquidity trader allocates the quantity Y across the four trading locations. Proportions traded at the various locations are denoted by β_{f}, β_{d}, β_{cf}, and β_{cd}; i.e.,

$$Y_{\mathrm{f}} = \beta_{\mathrm{f}}Y, \quad Y_{\mathrm{d}} = \beta_{\mathrm{d}}Y, \quad Y_{\mathrm{cf}} = \beta_{\mathrm{cf}}Y, \quad \text{and} \quad Y_{\mathrm{cd}} = \beta_{\mathrm{cd}}Y. \tag{A2}$$

The sum of the proportions equals unity. To determine the liquidity trader's optimal allocations, think of the four terms that have the form $(S\text{-}P)Y$ in the expression for the liquidity trader's time-1 portfolio value in (3) as a four-component vector, denoted by ϕ. Then, $E[W_1|Y]$ and $\mathrm{Var}[W_1|Y]$ in (4) can be written in terms of ϕ's conditional mean and covariance matrix. Substituting for the securities' future value and current price (using (1) and (7), respectively) and for the liquidity trader's allocations (using (A2)) in (3) and then evaluating ϕ's expected value conditional on Y yields

$$\begin{pmatrix} -\lambda_{\mathrm{f}}\beta_{\mathrm{f}}^2 \\ -\lambda_{\mathrm{d}}\beta_{\mathrm{d}}^2 \\ -\lambda_{\mathrm{cf}}\beta_{\mathrm{cf}}^2 - \lambda'_{\mathrm{cd}}\beta_{\mathrm{cf}}\beta_{\mathrm{cd}} \\ -\lambda_{\mathrm{cd}}\beta_{\mathrm{cd}}^2 - \lambda'_{\mathrm{cf}}\beta_{\mathrm{cf}}\beta_{\mathrm{cd}} \end{pmatrix}. \tag{A3}$$

The elements in (A3) have Y^2 as a common factor which is suppressed. The liquidity trader's allocation strategy is specified by the β's and does not depend on the realized value of Y.

To express ϕ's covariance matrix, we use the notation for the model's variance parameters given at the end of Section 3. With subscripts suppressed, $\Gamma = \mathrm{Var}(\gamma)$, $N = \mathrm{Var}(\nu)$, $\Theta = \mathrm{Var}(Y)$, $\Omega = \mathrm{Var}(Z)$, $\Delta = \mathrm{Var}(\varepsilon)$ and $\rho = \mathrm{Correlation}(\gamma_{\mathrm{f}}, \gamma_{\mathrm{d}})$. Then, ϕ's conditional covariance matrix is

$$\begin{bmatrix} (\Gamma_{\mathrm{f}} + (1-\lambda_{\mathrm{f}}\alpha_{\mathrm{f}})^2 N_{\mathrm{f}} + \lambda_{\mathrm{f}}^2\Omega_{\mathrm{f}})\beta_{\mathrm{f}}^2 & \cdot & \cdot & \cdot \\ (\rho\Gamma_{\mathrm{f}}^{1/2}\Gamma_{\mathrm{d}}^{1/2})\beta_{\mathrm{f}}\beta_{\mathrm{d}} & (\Gamma_{\mathrm{d}} + (1-\lambda_{\mathrm{d}}\alpha_{\mathrm{d}})^2 N_{\mathrm{d}} + \lambda_{\mathrm{d}}^2\Omega_{\mathrm{d}})\beta_{\mathrm{d}}^2 & \cdot & \cdot \\ (\rho\Gamma_{\mathrm{f}}^{1/2}\Gamma_{\mathrm{d}}^{1/2})\beta_{\mathrm{f}}\beta_{\mathrm{cf}} & (\Gamma_{\mathrm{d}})\beta_{\mathrm{d}}\beta_{\mathrm{cf}} & \begin{matrix}(\Gamma_{\mathrm{d}} + (1-\lambda_{\mathrm{cf}}\alpha_{\mathrm{cf}} - \lambda'_{\mathrm{cd}}\alpha_{\mathrm{cd}})^2 N_{\mathrm{c}} \\ + \lambda_{\mathrm{cf}}^2\Omega_{\mathrm{cf}} + (\lambda'_{\mathrm{cd}})^2(\Omega_{\mathrm{cd}} + \Delta_{\mathrm{cd}}))\beta_{\mathrm{cf}}^2\end{matrix} & \cdot \\ (\rho\Gamma_{\mathrm{f}}^{1/2}\Gamma_{\mathrm{d}}^{1/2})\beta_{\mathrm{f}}\beta_{\mathrm{cd}} & (\Gamma_{\mathrm{d}})\beta_{\mathrm{d}}\beta_{\mathrm{cd}} & \begin{matrix}(\Gamma_{\mathrm{d}} + (1-\lambda_{\mathrm{cf}}\alpha_{\mathrm{cf}} - \lambda'_{\mathrm{cd}}\alpha_{\mathrm{cd}}) \\ \cdot (1-\lambda_{\mathrm{cd}}\alpha_{\mathrm{cd}} - \lambda'_{\mathrm{cf}}\alpha_{\mathrm{cf}})N_{\mathrm{c}} \\ + \lambda_{\mathrm{cf}}\lambda'_{\mathrm{cf}}\Omega_{\mathrm{cf}} + \lambda_{\mathrm{cd}}\lambda'_{\mathrm{cd}}\Omega_{\mathrm{cd}})\beta_{\mathrm{cf}}\beta_{\mathrm{cd}}\end{matrix} & \begin{matrix}(\Gamma_{\mathrm{d}} + (1-\lambda_{\mathrm{cd}}\alpha_{\mathrm{cd}} - \lambda'_{\mathrm{cf}}\alpha_{\mathrm{cf}})^2 N_{\mathrm{c}} \\ + \lambda_{\mathrm{cd}}^2\Omega_{\mathrm{cd}} + (\lambda'_{\mathrm{cf}})^2(\Omega_{\mathrm{cf}} + \Delta_{\mathrm{cf}}))\beta_{\mathrm{cd}}^2\end{matrix} \end{bmatrix}.$$

The matrix is symmetric, and so the off-diagonal elements in the upper-triangle of the matrix are suppressed. Also, the matrix elements have Y^2 as a common factor and this is suppressed as well.

In (4), $E[W_1|Y]$ equals the sum of the elements in (A3) and $\mathrm{Var}[W_1|Y]$ equals the sum of the elements in the above matrix (including those suppressed). The constraint $\beta_{\mathrm{f}} + \beta_{\mathrm{d}} + \beta_{\mathrm{cf}} + \beta_{\mathrm{cd}} = 1$ is imposed by setting $\beta_{\mathrm{f}} = 1 - \beta_{\mathrm{d}} - \beta_{\mathrm{cf}} - \beta_{\mathrm{cd}}$ in the resulting expression for (4). The first-order conditions with respect to β_d, β_{cf}, and β_{cd} are then determined. It is apparent that these relations are linear in β_d, β_{cf}, and β_{cd}, thus a solution for them is assured (while simple to obtain, the solution is lengthy and therefore not provided). The following expresses the dependence of the β's on the λ's (i.e., the "unknowns") as well as on the Γ's, N's, Ω's, Δ's, and ρ (i.e., the model's "parameters"):

$$\beta_i(\lambda, \alpha(\lambda); \Gamma, N, \Omega, \Delta, \rho) \qquad i = \text{f, d, cf, and cd.} \tag{A4}$$

In (A4), the explicit relations between αs and λs are given in (A1). The model's parameters describe the following: Γ's characterize the risk of the market factors, N's convey the magnitude of the risk due to firm-specific reasons, Ω's depict the size as well as the relative intensity of noise trading across markets and securities, Δ's portray the degree of market transparency as well as the transparency asymmetry between markets, and ρ is the correlation between market factors whose size tells us the potential benefit from global diversification. The remaining parameter, Θ, measures liquidity trading intensity. Although it does not impact the β's explicitly as suggested by (A4), it does so implicitly through price.

Summarizing, given the model's parameters, the informed traders' optimal actions are specified by the α's (see (A1)), and the liquidity traders optimal allocations are specified by the β's (see (A2) and (A4)). Both sets in turn are functions of the λ's.

C. *Equilibrium Prices.* The next step toward obtaining equilibrium is to write down expressions for the market prices of securities, i.e., expressions for the λ's in terms of the α's and β's. These follow directly from applying normal distribution theory to Eqs. (7). To evaluate the conditional expectations in (7a), (7b), (7c), and (7d), we need the corresponding joint distributions of $\{S_f, \omega_f\}$, $\{S_d, \omega_d\}$, $\{S_c, \omega_{cf}, \omega'_{cd}\}$ and $\{S_c, \omega_{cd}, \omega'_{cf}\}$. These are multivariate normal based on the functional form of the optimal informed trades and the optimal allocation of liquidity trades and the linearity of (5) and (6). The means of these distributions are zero, and their respective covariance matrices are

$$\Sigma^f = \begin{pmatrix} \Gamma_f + N_f & \cdot \\ \alpha_f N_f & \alpha_f^2 N_f + \beta_f^2 \Theta + \Omega_f \end{pmatrix}$$

$$\Sigma^d = \begin{pmatrix} \Gamma_d + N_d & \cdot \\ \alpha_d N_d & \alpha_d^2 N_d + \beta_d^2 \Theta + \Omega_d \end{pmatrix}$$

$$\Sigma^{\mathrm{cf}} = \begin{pmatrix} \Gamma_{\mathrm{d}} + N_{\mathrm{c}} & \cdot & \cdot \\ \alpha_{\mathrm{cf}} N_{\mathrm{c}} & \alpha_{\mathrm{cf}}^2 N_{\mathrm{c}} + \beta_{\mathrm{cf}}^2 \Theta + \Omega_{\mathrm{cf}} & \cdot \\ \alpha_{\mathrm{cd}} N_{\mathrm{c}} & \alpha_{\mathrm{cf}} \alpha_{\mathrm{cd}} N_{\mathrm{c}} + \beta_{\mathrm{cf}} \beta_{\mathrm{cd}} \Theta & \alpha_{\mathrm{cd}}^2 N_{\mathrm{c}} + \beta_{\mathrm{cd}}^2 \Theta + \Omega_{\mathrm{cd}} + \Delta_{\mathrm{cd}} \end{pmatrix}$$

$$\Sigma^{\mathrm{cd}} = \begin{pmatrix} \Gamma_{\mathrm{d}} + N_{\mathrm{c}} & \cdot & \cdot \\ \alpha_{\mathrm{cd}} N_{\mathrm{c}} & \alpha_{\mathrm{cd}}^2 N_{\mathrm{c}} + \beta_{\mathrm{cd}}^2 \Theta + \Omega_{\mathrm{cd}} & \cdot \\ \alpha_{\mathrm{cf}} N_{\mathrm{c}} & \alpha_{\mathrm{cf}} \alpha_{\mathrm{cd}} N_{\mathrm{c}} + \beta_{\mathrm{cf}} \beta_{\mathrm{cd}} \Theta & \alpha_{\mathrm{cf}}^2 N_{\mathrm{c}} + \beta_{\mathrm{cf}}^2 \Theta + \Omega_{\mathrm{cf}} + \Delta_{\mathrm{cf}} \end{pmatrix}.$$

Given these matrices, the conditional expectations in Eq. (7) may be expressed as follows:

$$P_{\mathrm{f}} = 1 + \frac{\Sigma_{12}^{\mathrm{f}}}{\Sigma_{22}^{\mathrm{f}}} \omega_{\mathrm{f}}$$

$$p_{\mathrm{d}} = 1 + \frac{\Sigma_{12}^{\mathrm{d}}}{\Sigma_{22}^{\mathrm{d}}} \omega_{\mathrm{d}}$$

$$P_{\mathrm{cf}} = 1 + \frac{|\Sigma_{12}^{\mathrm{cf}}|}{|\Sigma_{11}^{\mathrm{cf}}|} \omega_{\mathrm{cf}} - \frac{|\Sigma_{13}^{\mathrm{cf}}|}{|\Sigma_{11}^{\mathrm{cf}}|} \omega'_{\mathrm{cd}}$$

$$P_{\mathrm{cd}} = 1 + \frac{|\Sigma_{12}^{\mathrm{cd}}|}{|\Sigma_{11}^{\mathrm{cd}}|} \omega_{\mathrm{cd}} - \frac{|\Sigma_{13}^{\mathrm{cd}}|}{|\Sigma_{11}^{\mathrm{cd}}|} \omega'_{\mathrm{cf}}.$$

In these relations, Σ_{ij} refers to the ijth matrix element, and $|\Sigma_{ij}|$ is the determinant of that matrix which is obtained by deleting row i and column j from the matrix Σ. Comparing these relations to (7) and equating coefficients, we get

$$\lambda_{\mathrm{f}} = \frac{\Sigma_{12}^{\mathrm{f}}}{\Sigma_{22}^{\mathrm{f}}}, \qquad \lambda_{\mathrm{d}} = \frac{\Sigma_{12}^{\mathrm{d}}}{\Sigma_{22}^{\mathrm{d}}}$$

$$\lambda_{\mathrm{cf}} = \frac{|\Sigma_{12}^{\mathrm{cf}}|}{|\Sigma_{11}^{\mathrm{cf}}|}, \quad \lambda'_{\mathrm{cd}} = -\frac{|\Sigma_{13}^{\mathrm{cf}}|}{|\Sigma_{1}^{\mathrm{cf}}|}$$

$$\lambda_{\mathrm{cd}} = \frac{|\Sigma_{12}^{\mathrm{cd}}|}{|\Sigma_{11}^{\mathrm{cd}}|}, \quad \lambda'_{\mathrm{cf}} = -\frac{|\Sigma_{13}^{\mathrm{cd}}|}{|\Sigma_{11}^{\mathrm{cd}}|}$$

From examining the Σ matrices, it is apparent that the above relations are expressions of the λ's in terms of α's and β's (as well as the parameters N, Θ, Ω, and Δ). Substituting the previously evaluated expressions for the α's and β's, we obtain six implicit expressions for the six λ's. Given the model's parameters Γ, N, Θ, ρ, Ω, and Δ, this simultaneous nonlinear system of equations for the λ's is solved numerically (using the software package Mathematica). The λ's thus obtained (i.e., the prices) are then used to evaluate the α's (i.e, the optimal informed trades) and the β's (i.e., the optimal allocation of liquidity trades).

D. *Parameter Values.* To solve for equilibrium numerically, values must be specified for the parameters Γ, N, Θ, ρ, Ω, and Δ. Our model focuses on explaining the impact of cross-listing domestic (e.g., Mexican) securities in foreign (e.g., U.S.) markets. Accordingly, we choose parameter values representative of these markets and the securities traded in them.

Γ and N describe the risk characteristics of the securities in the two markets. The historical long-run standard deviation of the U.S market portfolio is 20% (NYSE Factbook, 1995). Accordingly we set the volatility of the foreign market factor to $\Gamma_f = 0.20^2$. The average standard deviation of NYSE-listed decile portfolios is 30% (Ibbotson Associates, 1995). Thus we set the foreign firm-specific factor's volatility to $N_f = 0.30^2 - 0.20^2$. The corresponding volatilities in emerging markets are significantly larger (Emerging Markets Factbook, 1995). We assume $\Gamma_d = 0.30^2$ for the foreign market factor's volatility and $N_d = 0.60^2 - 0.30^2$ for the firm-specific factor volatility. These numbers make the diversifiable component of the domestic security's risk equal to 75% of its total risk (see Divecha *et al.* 1992). Since the cross-listed security is a domestic security (traded in both the foreign and domestic markets), we set $\Gamma_c = \Gamma_d$ and $N_c = N_d$.

For the 5-year period ending 1992, 13 of the 20 emerging markets tracked by the corporation had correlation coefficients less than the average value of 0.20 with the United States. Accordingly, we assume $\rho = 0.20$ for the correlation coefficient between the foreign and domestic market factors. The average correlation through 1992 is chosen to capture the state of emerging markets prior to investment liberalization. Our results are robust for a range of correlations.

The equilibrium depends on the relative intensities of liquidity (Θ) and noise (Ω) trading in the various markets/securities, and not on their absolute levels. Accordingly, we normalize the intensity of noise trading in the domestic market to unity (for both the domestic and the cross-listed securities), $\Omega_d = \Omega_{cd} = 1$. We assume that noise-trading intensity is larger in the foreign market, $\Omega_f = \Omega_{cf} = 3$, based on the fact that the traded value of Latin American securities in U.S. markets is three times the corresponding traded value in their home markets (Hargis, 1997). Since a significant proportion of trade in U.S. equity markets is initiated by institutional investors (in excess of 75%), we assume that the intensity of liquidity trading is $\Theta = 10$.

Since transparency is affected by many factors, transparency levels are not readily observable. Thus we analyze the equilibrium for a range of transparencies between perfect integration (Δ approaches zero) and perfect fragmentation (Δ approaches infinity). It cannot be assumed that each market maker observes the other's order flow with equal precision, so we permit Δ_{cf} and Δ_{cd} to be unequal. Hence a range of imperfect as well as asymmetric levels of transparency are analyzed.

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