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Bolsa or NYSE: price discovery for Mexican shares☆

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Abstract

Is price discovery and the calibration of news through American (A) or global (G) depositary receipts (DR) or depositary shares (DS), traded in central markets, superseding local discovery in peripheral markets? This question remains very much open as the evidence we present on the durability of price innovations in two major Mexican stocks provides little support for the view that the demise of local markets is inevitable. Rather it appears that such markets may have some advantage in information efficiency that may compensate for their extra costs.
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1. Introduction

As ADR/ADS, and GDR/GDS programs become increasingly available for more and more foreign issues, the question arises whether the weight of market-making has shifted away from their home stock market to a central market, as often claimed. The common presumption to that effect has been supported mostly by pointing to economic inefficiencies in peripheral stock exchanges and not by assessing the informational efficiency of the transactions conducted on them. Such an assessment will be attempted in this paper by comparing the durability of price innovations in two major Mexican stocks registered in different forms both on the New York Stock Exchange (NYSE) and the Bolsa Mexicana de Valores (BMV).

Section 2 provides basic information on the cross-listed shares whose price relations are the subject of a preliminary data analysis in Section 3. Section 4 models the price discovery and reconciliation process, and Section 5 estimates how that process of error correction is shared between the two stock exchanges. Section 6 discusses the significance of the most critical coefficient estimates, and Section 7 concludes.

2. Shares that are cross-listed in local and central markets

Considering only economic efficiency, it is natural to surmise that a local market will be at a competitive disadvantage in stock trading if it is small[1] and denominating its trades in a minor currency. And indeed, trading costs itemized in Section 1 of the Appendix available upon request are about twice as high on the BMV as on the NYSE. Thus equity markets in a number of developing countries have been presumed endangered or on the brink of extinction. The reasons commonly cited are illiquidity, high transaction costs, and falling volume as foreign acquisitions of leading domestic companies soon after they had gone public leave few securities to trade in such markets. A large part of trading in the remaining domestic shares may then be shifted to New York causing a further deterioration of the economics of local stock markets (Moel, 2001).

For instance, in the case of Teléfonos de México “L” (Telmex-L) shares, the most widely traded share on the Bolsa Mexicana de Valores, only 23% of total volume was traded in Mexico City on average for 1996–2000 (28% from February 2001 to February 2002) and all the rest as ADS on the New York Stock Exchange (NYSE). This volume percentage was derived by adjusting for an ADS ratio of 20 domestic shares per ADS and for the fact that the domestic shares were split 2:1 four trading days before the ADS were split at the start of trading 7 February 2000. Grupo Televisa S.A. de C.V. is the other major company considered that, like Telmex, is known to almost every Mexican individual and business from daily contact with its services. For “TV”, the percentage of the total volume of trading that occurred in Mexico was even smaller than for Telmex but rising from 13

[1] With regard to economic efficiency, economies of scale in effecting stock market transactions and the liquidity of deep markets may leave small exchanges disadvantaged on both the supply and demand sides. Hasan and Malkamäki (2001) have provided evidence of scale and scope economies for stock exchanges. See also the comments by S.A. Andersen, President and CEO of Oslo Børs (Andersen, 2002, pp. 5–8).

to 19% over the two periods. While there were 28 Mexican shares listed on the NYSE in 2000, Grupo Televisa (US$ 11 billion) and Telmex (US$ 35 billion) accounted for 85% of the total Mexican value listed (US$ 54 billion) that year according to statistics published by the New York Stock Exchange. Grupo Televisa was admitted to the NYSE on 12/14/1993 and Telmex on 5/14/1991.

Before dismissing the share of trading in these two shares that is retained in Mexico as "small" or "insignificant," some perspective is needed. Once markets become globally investable, the shares of those companies that are headquartered in small countries but large by capitalization are likely to end up being predominantly owned and traded by foreigners, preferably in central markets and in US dollar (or euro).[2] This however does not mean that price discovery must migrate along with volume from local to central markets. For the Toronto Stock Exchange (TSE) which, like the Mexican stock exchange, keeps the same trading hours as the NYSE, Eun and Sabherwal (2003) found that in a cross-section of cross-listed shares, a larger US share of trading adds to the informativeness of US over TSE trading. For the Mexican shares this could imply that US price discovery might be relatively more important for Televisa than for Telmex but not that US price discovery must be more important than Mexican price discovery for either share just because most trading in these shares occurs on the NYSE.[3]

The research issue thus is to determine whether price leadership over their own domestic shares has in fact slipped away from stock markets in emerging countries using their own currency. Error correction analysis may provide some power of discrimination. Successive processing of news as well as first news injection can affect the prices of cross-listed shares

[2] If actual and required rates of return on capital are higher for domestic than for internationally traded companies, as evidence from Mexican-firm data by Gelos (2003) suggests, ownership of the latter is likely to be dispersed away from the home country of operations. Doidge et al. (2001) have found that firms listed in the US have a Tobin's *q* ratio that exceeds the *q* ratio of firms from the same country that do not list in the US by 16.5% on average again indicating that a lower required rate of return applies to firms listed in the United States that have received recognition from international investors. However, it is not clear what this globalization of share ownership implies about price discovery, or when the fraction traded in the home country becomes "too small" for keeping discovery in its own stock market. Depending on the emerging market considered, less than half-a-dozen to two dozen shares tend to be actively traded internationally.

[3] As an example of why trading share and information share may not be highly correlated: If shares with special voting rights are traded infrequently in the local market, inside information may be communicated through order flow and limit orders to local broker/dealers in these special shares and be used for informed trading in other classes of shares of the same company, including ADS. Telmex has AA, A, and L shares outstanding. AA shares may be subscribed only by Mexican individuals and corporate entities and are not traded. Class A shares are rarely traded. For instance, trading occurred only at a single price of 15.71 peso between 12:00 and 12:30 p.m. on 26 March 2003 while L shares with limited voting rights, the "inferior voting sibling" (Pinegar and Ravichandran, 2002, p. 35), were trading down from 15.84 to 15.79 during that time interval. In the case of Grupo Televisa, its series L and series D (preferred) shares and half the number of series A shares outstanding are packaged, one of each to a unit, into Ordinary Participation Certificates (CPOs). Series L and series D shares have limited voting rights and non-Mexican holders of CPOs do not have voting rights with respect to the series A and D shares. On 26 March 2003, no "TV" shares other than CPOs were traded on the BMV. Domowitz et al. (1998, p. 2026) point out that ownership structure may be a factor in cross-listing the shares in the first place: if controlling ownership is concentrated in domestic A shares, "the costs associated with order flow migration (in terms of liquidity and price volatility) will largely accrue to other series where trading occurs, whereas the benefits (in terms of increased ability to access international capital markets) accrue to the firm as a whole."

in markets that do not open and close at the same time such as those analyzed by Kim et al. (2000). Our analysis of two markets that open and close at exactly the same time, the BMV and the NYSE, focuses instead on each market's contribution, not to price formation per se, but to the elimination of exchange-converted price discrepancies that may have arisen between them. We also match exchange rate quotations obtained from the Olsen Data Group as exactly as feasible to the 9:30 a.m. open and 4:00 p.m. close in New York corresponding to trading hours of 8:30 a.m. to 3:00 p.m. local time in Mexico City. Unlike the stock price data, the exchange-rate data do not represent actual transaction prices but live quotes that may or may not have been acted upon; details are provided in Section 4 of the Appendix available upon request.

If investors were completely indifferent to the form and currency in which their ownership of a given class of company shares was evidenced and in which market the shares of any particular form could be traded, the law of one price (LOP) should hold in all markets that are open at the same time. However, if different buyers are somewhat discriminating between dollar-denominated depositary shares (DS), and peso-denominated ordinaries, there may be exchange-converted price differences because arbitrage between the two forms of shares technically cannot be instantaneous. It then matters that the supply of ADS or GDS securities is fixed in the very short run and that some costs must be incurred to change it. Settlement periods and ADS-formation/dissolution periods can be bridged through forward-covered buying in one and selling in the other market. However, this arbitrage process requires the near-simultaneous execution of a number of transactions at some cost and execution risk and the straddling of different settlement periods in the two markets before the original position can be restored. Because the process is not costless, LOP does not hold for ADR or ADS in the precise way it would tend to hold for global (G) shares that are perfectly substitutable even when listed on different stock exchanges and traded in different currencies.

For instance, between Telmex-L shares and Grupo Televisa-CPO shares traded on the BMV[4] on the one hand and the corresponding ADS or GDS traded on the NYSE[5] on the other, exchange-converted price differences on a few occasions have exceeded 10%, mostly at open rather than close, during the estimation period. That period extends from 2 January 1996 through 2 January 2001 and continues through 1 February 2002 in a second sample.[6] It is the existence of these price discrepancies, and how they are resolved, that provides an opportunity to explore market leadership.[7] Deviations of several percentage points in

[4] Bloomberg source codes TELMXL MM MXP and TLEVICPO MM MXP.

[5] Bloomberg source codes TMX US and TV US.

[6] Starting after the most recent major Mexican crisis of 1994–1995, both sample periods are chosen to be free of financial crises in Mexico to achieve some homogeneity of the pricing regime. Estimating through periods containing such crises, Galati (2000) has found that relations among financial transactions volume and exchange-rate volatility in normal times and in periods of turbulence may be quite different so that estimating across crisis and normal periods yields "average" coefficient estimates fitting neither period.

[7] Asking how much each market contributes to the convergence of prices for the same asset in the long run, here defined as the next daily open or close, does not necessarily yield the complement of the information shares to be attributed to each market. Lehmann (2002, p. 268) provides a profound analysis and synthesis of the different concepts and measures of price discovery in models in which the cointegrating vector is specified a priori very much like the LOP vector [1, −1, 1] implied in Eq. (3). We attempt to shed some light ion Section 3 on how these concepts and distinctions apply in the present case.

almost simultaneously registered exchange-converted transactions prices recorded in the two locations at open and close do not appear as isolated outliers. They appear credible even though they far exceed the minimum price difference of around 0.9% that would have to exist for arbitrage to be profitable according to the information compiled in Appendix Sections 2 and 3. Presumably larger discrepancies can arise because exploiting them in appreciable volume through executions at non-matching prices is hampered by thin quotes that are fleeting.

3. Preliminary data analysis

Because of observable transitory price differences between the exchange-converted prices of each company's shares in Mexico City and New York, the question may be asked which quotation is more authoritative in the sense of being freer of self-correcting error when pricing discrepancies occur. It is conceivable that the prices of major corporates headquartered in the Western Hemisphere outside the United States are set decisively in New York and then translated back with some local addition of "noise" into local currency if home listing is maintained. "Market participants argue that for some prominent Latin American stocks price discovery is done in New York rather than in local markets" (IMF, 2002, p. 56). If true, this would mean that the calibration of news and the price-making function have shifted from the home base of operations to the foreign global financial center and from local currency to US dollars. Even the exchange risk could be thrown back on the originating home market. The variance of exchange-translated security prices in the local market would then be greater than that of the corresponding ADRs and this would discourage use of the local market and of its local-currency trading by foreign and domestic residents alike.

3.1. Variance of daily stock price changes in the two markets compared

The preliminary evidence presented in Table 1 for 1996–2000 does not support this common conjecture for the price behavior of Grupo Televisa and Telmex-L shares. For this fairly steady period of economic and financial recovery, 1202 rates of change were constructed from daily data for 01/02/1996–01/02/2001. Testing the Null hypothesis that the variances of the log price change in Mexico and in the United States represent independent estimates of the *same* variance leads to strong rejection. The data highlighted in Table 1 show that the ratio of the variance of the daily rate of stock price change in the US market, in position (2.2), to the variance of that rate in the Mexican market, in position (1.1), is commonly 1.2–1.3. This range is well above the critical value of about 1.15 (interpolated from Bennett and Franklin, 1963, p. 709) that applies at the 1% level with about 1200 numerator and denominator degrees of freedom.[8]

[8] Purely to caution against automatically inferring, that the market that appears noisier *before price conversion to the same currency* also has less pricing authority, Donald J. Mathieson (IMF) proposed the following thought experiment: What if the NYSE priced the two Mexican shares authoritatively but whenever their New York price rose (fell), "Mexico" was being upgraded (downgraded) and the peso appreciated (depreciated) though not by enough to prevent some sympathetic home-currency price movement in the two markets? Then percentage

Table 1
Variance–covariance matrix for rates of change in stock prices and FOREX rates

	1996–2000			2001–2002		
Grupo Televisa S.A.						
1a, Open-to-open						
Grupo-TV	**0.0945**			**0.0785**		
TV-GDS	0.0933	**0.1249**[a]		0.0709	**0.0842**	
MXP/USD	−0.0075	−0.0111	0.0046	−0.0025	−0.0045	0.0031
1b, Close-to-close						
Grupo-TV	**0.0963**			**0.0929**		
TV-GDS	0.0989	**0.1164**[a]		0.0915	**0.0982**	
MXP/USD	−0.0059	−0.0091	0.0031	−0.0031	−0.0049	0.0020
1c, Open-to-close						
Grupo-TV	**0.0680**			**0.0701**		
TV-GDS	0.0678	**0.0895**[a]		0.0606	**0.0657**	
MXP/USD	−0.0029	−0.0047	0.0020	−0.0003	−0.0015	0.0014
1d, Close-to-next open						
Grupo-TV	**0.0234**			**0.0183**		
TV-GDS	0.0162	**0.0259**		0.0136	**0.0206**	
MXP/USD	−0.0024	−0.0039	0.0020	−0.0009	−0.0017	0.0012
Telefonos de Mexico L						
2a, Open-to-open						
Telmex-L	**0.0561**			**0.0284**		
L-ADS	0.0586	**0.0772**[a]		0.0238	**0.0358**	
MXP/USD	−0.0060	−0.0102	0.0046	−0.0009	−0.0022	0.0028
2b, Close-to-close						
Telmex-L	**0.0560**			**0.0264**		
L-ADS	0.0564	**0.0665**[a]		0.0260	**0.0301**	
MXP/USD	−0.0046	−0.0075	0.0031	−0.0007	−0.0024	0.0019
2c, Open-to-close						
Telmex-L	**0.0449**			**0.0204**		
L-ADS	0.0411	**0.0484**		0.0171	**0.0233**	
MXP/USD	−0.0026	−0.0042	0.0020	0.0003	−0.0007	0.0012
2d, Close-to-next open						
Telmex-L	**0.0121**			**0.0083**		
L-ADS	0.0113	**0.0214**[a]		0.0043	**0.0086**	
MXP/USD	−0.0020	−0.0040	0.0020	−0.0007	−0.0009	0.0011

Note: variance is of the natural logarithm of daily (or within-day, in 1c and 2c) rates of change in the Mexican and US (GDS or ADS) share prices of the two companies and in the peso/dollar exchange rate, all reported after multiplying by 100.

[a] Variance of US log price changes significantly greater than of Mexican log price changes at the 1% level.

changes in the peso price in Mexico would be systematically lower than percentage changes in the USD price of the same shares in New York. Furthermore a depreciation of the peso would then be associated with some decline in peso prices registered on the BMV and a correspondingly larger decline in dollar prices registered on the NYSE as we found. For estimates and careful consideration of volatility differences between ADRs and the underlying securities between markets whose trading hours either do or do not overlap for a time after opening sequentially, but do not overlap at the close, see Howe and Ragan (2002).

The variance ratio is not significantly different from 1 at the 1% level for the smaller, supplementary sample for 2001–2002. In this subsample, 260 rates of change were constructed from daily data for 01/02/2001 to 02/01/2002 for Grupo Televisa. Only 235 rates of change were obtained for Telmex by dropping out all 2001 observations prior to 02/08/2001 in order to allow for the América Móvil spin-off. That action took out a high-risk line of business worth almost 40% of the old Telmex-L share capitalization, leaving a different company. Except in this instance, we eliminated stock price data equally for both companies when shares in either company were not trading or had no reported volume in Mexico (Telmex, 28 April 1998), when circuit-breaker rules applied by the NYSE (27 October 1997) kept stock markets from closing simultaneously in New York and Mexico City or when suspiciously transitory jumps in quoted exchange rates between close and opening were reported in our time-matched data source. Hence the data set is identical for the two companies in the basic period, and from 02/08/01 on.

The present study investigates the match-up of rates of change not only from open (O_t) to the next open (O_{t+1}) and from close (C_t) to the next close (C_{t+1}), but also from O_t to close C_t within a trading day and from C_t to O_{t+1} of the next trading day. The log (ln) rates of change from open to next open and close to next close are given by the identities:

$$\ln\left(\frac{O_{t+1}}{O_t}\right) \equiv \ln\left(\frac{O_{t+1}}{C_t}\right) + \ln\left(\frac{C_t}{O_t}\right) \tag{1}$$

$$\ln\left(\frac{C_{t+1}}{C_t}\right) \equiv \ln\left(\frac{O_{t+1}}{C_t}\right) + \ln\left(\frac{C_{t+1}}{O_{t+1}}\right) \tag{2}$$

The RHS of expressions (1) and (2) shows that the variances of $\ln(O_{t+1}/O_t)$ and $\ln(C_{t+1}/C_t)$ must be close in large samples as long as the covariances, which tend to be sensitive to temporal ordering, are small, as they are found to be in Table 1. All data in that table and this text are presented as 100 times their natural values to economize on places of decimals.

3.2. Investigating market leadership through temporary departures from LOP

If the law of one price (LOP) applied without fail to shares of Grupo Televisa or of Telmex no matter how these shares are bundled or where they are traded, we would have a tight arbitrage relation. In Eq. (3) below, LOP would imply that there is no residual and no constant ($a_0 = 0$), and that coefficients a_1 and a_2 both equal 1. That equation links the rate of change (or log change, DLN) in the US share price (P_{US}) to the rate of change in the corresponding Mexican share price DLN(P_{MX}) and in the peso/dollar exchange rate DLN(MXP/USD). Because the Mexican peso has tended to depreciate over the basic period, 1996–2000, in nominal, though not in real, terms, the peso price of a given share on the BMV has tended to rise faster than its dollar price on the NYSE.

$$\text{DLN}(P_{US}) = a_0 + a_1\text{DLN}(P_{MX}) - a_2\text{DLN}(\text{MXP/USD}) + \text{residual} \tag{3}$$

Hence if LOP held, the variance of the term on the LHS (0.1249 to illustrate with open-to-open statistics reported for Grupo Televisa for 1996–2000 in Table 1) would have to be equal to the sum of the variances of the two terms on the right ($0.0945 + 0.0046$) minus twice the (negative) covariance of DLN(P_{MX}) and DLN(MXP/USD) (-0.0075). But clearly 0.1249

is appreciably greater than $0.0945 + 0.0046 + 0.0150 = 0.1141$. Indeed the variance of the news-with-noise residual, practically uncorrelated with the other RHS variables in Eq. (3), accounts for almost 9% of the variance in the log price change of the GDS. Hence LOP does not fully assert itself in the very short run, and market leadership can be investigated by studying how prices for the same shares in the two markets respond to any recorded price discrepancy.

Conversely, if LOP is to hold *except* in the very short run, the level of integration of DLN(P_{US}), DLN(P_{MX}) − DLN(MXP/USD), and also of DLN(MXP/USD), which strongly influences both of these variables, must be the same. They must either all be I(1) or all not (quite) I(1) but I(0) for price arbitrage to function. The data satisfy this compatibility condition. For instance, in the ADF test for Telmex in the basic period, we regress the open-to-open rate of price change with constant on three successive lags of that variable and on the lagged level of the log stock price with 1199 observations. Then the coefficient on the lagged NYSE price level is −0.001894 (−1.06) and the coefficient on the lagged BMV price level converted to USD is −0.001811 (−1.04). The rate of change in the peso/dollar exchange rate from stock-market opening to next open, regressed in the same pattern, yields a coefficient on the lagged level of the exchange rate of −0.002175 (−1.15). Hence the Null of non-stationarity I(1) is not rejected for any of these variables, and the same holds for the corresponding close-to-close data and for Televisa in the basic data period. For the short follow-on sample for Telmex 2001–2002, all of the lagged level variables, estimated in the same way and reported in the same order, by contrast are significant at the 5% level (see Hamilton, 1994, case 3, p. 529). However, the negative level coefficients remain small. This indicates a high degree of persistence of any changes: −0.055878 (−2.20) for Telmex-NYSE, −0.052644 (−2.21) for Telmex-BMV in USD and −0.039674 (−2.37) for the 232 matching open-to-open exchange rate quotations.

Since LOP should hold rather closely *on average*, any short-run deviations from LOP that are reflected in the coefficients estimated for Eq. (3) must be consistent with that requirement. An error correction term, EC, identifying level deviations from LOP at the start of each daily-change period, needs to be added to the specification to account for the tendency of exchange-converted price differences to be eliminated. EC is simply the log (LN) difference between the exchange-converted US price of a particular class of shares and their Mexican price, $EC = \ln\{[(P_{US})(MXP/USD)]/P_{MX}\}$, at either the open (ECO) or close (ECC) of the market. The change (D) in the error, DEC, is equal to the residual deviation from LOP identified by setting $a_0 = 0$ and $a_1 = a_2 = 1$ in Eq. (3).

Regarding the persistence of nonzero values of EC, regressing ECO on its two lagged values did not yield statistical significance for the intercept at the 5% level for any of the two periods or companies, and statistically significant coefficients (of less than 0.1%) on ECO_{-1} and ECO_{-2} only for Telmex in the basic period. Proceeding in the same way with ECC yielded very small, but statistically significant, intercepts that—except for Televisa 2001–2002 with intercept of 0.001285 (3.23)—were negative (i.e., lower on NYSE than BMV) and less than 0.001 in absolute value. Because the coefficients on the two lagged values of ECC were still always rather small (at most 0.23 combined), these intercepts were not far below the respective averages of ECC.

We conclude that average price differences tended to be of the order of plus or minus one-tenth of 1% and that serial correlation was low enough to observe frequent sign change

in the price discrepancies between the two markets. Furthermore, there was little (0.1 or less) autocorrelation in values of ECO (open) or ECC (close) on successive days and little cross-correlation between ECO and ECC (open and close) on the same day. The only exception is the relation between ECC and ECO_{+1} on the next day that indicates that price discrepancies were not completely eliminated overnight but carried over to a degree from close to next open.[9] In general, however, we can expect that pricing discrepancies will essentially be eliminated within a single trading period. Indeed the extent to which the Mexican and US markets contribute to the price re-equalization tendency will be a central focus of the statistical analysis that follows.[10]

4. Modeling each market's news calibration and error correction

To model the processing of news and then of discrepancies that may result in pricing it, we start with the following assumption: When news arrives in both markets, more or less simultaneously, each market tries to calibrate it instantly without trying to factor in what the other market is doing in pricing that news. Because the calibrations initially are mutually independent, there may be temporary discrepancies between them. These may be due to differences in opinion (see Varian, 1989) about the event's equilibrium price implications and to the two markets being separated in the very short run on account of arbitrage being costly and time consuming as detailed in the Appendix. The task then is how optimally to correct these discrepancies in the "next" trade by correctly pricing the change in fundamentals affecting the equilibrium price of the shares.

Let the logarithm of price quotations p in markets i and j at time t be a function of imprecisely observed fundamentals, m, that follow a random walk and of market-specific, serially independent, noise, ε.

$$p_{it} = m_t + \varepsilon_{it}, \quad \varepsilon \sim N(0, \sigma_i^2) \tag{4}$$

$$p_{jt} = m_t + \varepsilon_{jt}, \quad \varepsilon \sim N(0, \sigma_j^2) \tag{5}$$

$$m_t = m_{t-1} + \mu_t, \quad \mu \sim N(0, \sigma_\mu^2). \tag{6}$$

According to this specification, even without triggering arbitrage, prices for the same shares in the two markets seek the same equilibrium.[11] Then the task for pricing the next trade is optimally to infer the innovation to fundamentals, μ_t, from the current price movements in the two markets for the same security. This is done by choosing market ith weight β, and hence market jth weight $(1 - \beta)$, so as to minimize the expected squared

[9] For instance, the coefficient of correlation between ECO and ECC_{-1} was 0.3044 for Grupo Televisa 1996–2000 and the variance of ECO was twice as high (0.0153, after multiplying by 100 as before) as that of ECC_{-1} and hence ECC (0.0071). For comparison, the correlation between ECO and ECC was only 0.0971.

[10] Effects on share prices in the two markets and on EC could arise from the changing size or distribution of trading volume over the two markets. However, no systematic associations were found except that when Mexico's share of total daily volume rises, so does the share price on the BMV and NYSE, even though NYSE volume tends to fall in such instances as if trades were simply diverted from one market to the other.

[11] The reason is analogous to Krugman's (1991) showing that capital-gains/capital loss expectations are best balanced at the central rate inside a fully credible exchange-rate band (Krugman, 2001).

error function,

$$\begin{aligned} S &= E[\beta(p_{it} - p_{it-1}) + (1-\beta)(p_{jt} - p_{jt-1}) - \mu_t]^2 \\ &= E[\beta(\varepsilon_{it} - \varepsilon_{it-1}) + (1-\beta)(\varepsilon_{jt} - \varepsilon_{jt-1})]^2 \\ &= 2\beta^2\sigma_i^2 + 2(1-\beta)^2\sigma_j^2 + 4\beta(1-\beta)\sigma_{ij}. \end{aligned} \tag{7}$$

Hence the optimal normalized weight to put on the rate of price change recorded in the *i*th market is:

$$\beta^* = \frac{(\sigma_j^2 - \sigma_{ij})}{(\sigma_j^2 + \sigma_i^2 - 2\sigma_{ij})} = \left[\frac{1 - \rho_{ij}(\sigma_i/\sigma_j)}{1 + (\sigma_i^2/\sigma_j^2) - 2\rho_{ij}(\sigma_i/\sigma_j)}\right]. \tag{8}$$

If we assume independence of prior beliefs between markets *i* and *j*, the optimal value of β, β^*, obtained so as to minimize *S*, is readily identified with the normalized precision of prior beliefs in pricing the security in market *i*. That Bayesian posterior precision for pricing the next trade is $\beta^* = \sigma_i^{-2}/(\sigma_i^{-2} + \sigma_j^{-2}) = \sigma_j^2/(\sigma_j^2 + \sigma_i^2)$: The greater the noise in pricing in market *j*, the more weight should be given to price change recorded in market *i*.

We note also that when σ_{ij} and the coefficient of correlation, ρ_{ij}, are *not* zero,

$$\frac{\mathrm{d}\beta^*}{\mathrm{d}\rho_{ij}} = \frac{(\sigma_i/\sigma_j)[1 - (\sigma_i/\sigma_j)^2]}{[1 + (\sigma_i^2/\sigma_j^2) - 2\rho_{ij}(\sigma_i/\sigma_j)]^2}. \tag{9}$$

Because the sign of this derivative is that of$1 - (\sigma_i/\sigma_j)^2$, when pricing errors in the two markets become more positively correlated, perhaps because common factors such as "irrational exuberance" affect both, weights β^* and hence $(1-\beta^*)$ will move simply in the direction of the market with the lowest error variance. In other words, if $\sigma_i^2 > \sigma_j^2$, β^* will fall as ρ_{ij} rises. This is to be expected because a higher ρ_{ij} means lower opportunities for diversification of the risk of pricing errors.

To derive the basic form of the error correction model to be estimated in this paper, we difference Eqs. (4) and (5) to obtain rates of change in stock prices over discrete intervals of time.

$$p_{it} - p_{it_{-1}} = \mu_t + \varepsilon_{it} - \varepsilon_{it-1} \tag{10}$$

$$p_{jt} - p_{jt-1} = \mu_t + \varepsilon_{jt} - \varepsilon_{jt-1}. \tag{11}$$

The logarithm of the ratio of a stock's $t-1$ prices in the two markets, which indicates their observed percentage deviation, is known at time *t* and considered for price setting in each market at time *t*. It contains information about ε_{it-1}, and analogously about ε_{jt-1}, since $p_{it-1} - p_{jt-1} = \varepsilon_{it-1} - \varepsilon_{jt-1}$ from Eqs. (4) and (5). Hence:

$$\varepsilon_{it-1} = \gamma(p_{it-1} - p_{jt-1}) + \eta_{it-1}, \quad \gamma = \frac{(\sigma_i^2 - \sigma_{ij})}{(\sigma_j^2 + \sigma_i^2 - 2\sigma_{ij})}. \tag{12}$$

Hence $\gamma = 1 - \beta^*$ and the coefficient subsequently estimated on the error correction term, EC, for market *i*, γ, can be identified as the information weight to be put on price quotations in market *j*. This justifies the subsequent interpretation that the more a market contributes

to error correction, the less authoritative its pricing in the first place. It also creates a firm link between the information shares introduced in Eq. (7) and the estimated error correction coefficients.

5. Statistical properties of residual stock price movements of cross-listed shares

We are now ready to specify four estimating equations that will help reveal the extent to which BMV and NYSE participate actively in stock price formation for the two companies considered. Estimation involves a two-stage process. The first two estimated equations are used to identify the residual stock price movement (RESID) in each market after taking account of current exchange rate movements DLN(MXP/USD) and any pre-existing deviation in the exchange-converted US value of shares from their Mexican value (EC). The stock price innovation RESID in the Eq. for the respective market below is attributable to some combination of news, represented by μ_t, and change in market-specific pricing noise, $\varepsilon_{it} - \varepsilon_{it-1}$, as shown in Eq. (10) of the previous section.

$$\mathrm{DLN}(P_{\mathrm{US}}) = a_0 + a_1\mathrm{DLN}(\mathrm{MXP/USD}) + a_2\mathrm{EC} + \mathrm{RESID}_{\mathrm{US}} \tag{13}$$

$$\mathrm{DLN}(P_{\mathrm{MX}}) = b_0 + b_1\mathrm{DLN}(\mathrm{MXP/USD}) + b_2\mathrm{EC} + \mathrm{RESID}_{\mathrm{MX}}. \tag{14}$$

The noisy innovation in one market is then entered into the equation for the rate of stock price change in the other market for a company's shares to help clarify the extent to which markets cue each other about the change in the equilibrium price attributable to μ_t. These alternative Cholesky decompositions leave a random error term, η_t, in each equation that is ordered last, i.e., Eq. (16) after (13) or Eq. (15) after (14). The decomposition substitutes ordering one market's price determination before the other's for the independent price discovery in the initial reaction to news that was envisioned in the previous section. There each of the two markets first had a go at pricing the news independently before moving to eliminate any resulting price discrepancy.

$$\mathrm{DLN}(P_{\mathrm{US}}) = a_0 + a_1\mathrm{DLN}(\mathrm{MXP/USD}) + a_2\mathrm{EC} + a_3\mathrm{RESID}_{\mathrm{MX}} + \eta_{\mathrm{US}} \tag{15}$$

$$\mathrm{DLN}(P_{\mathrm{MX}}) = b_0 + b_1\mathrm{DLN}(\mathrm{MXP/USD}) + b_2\mathrm{EC} + b_3\mathrm{RESID}_{\mathrm{US}} + \eta_{\mathrm{MX}} \tag{16}$$

Cross-equation coefficient expectations are:

- $a_1 - b_1 = -1$ so that exchange rate effects are fully reflected in the differences between in the peso (MXP) and dollar (USD) denominated price movements in the different markets;
- $a_2 - b_2 = -1$ so that correction of any exchange-converted price differences outstanding at the beginning of the period is completed by its end or by the beginning of the next trading period;
- a_3 and b_3 should be of similar size and approach 1 more closely from below the more the unobserved innovation to fundamentals, μ_t, that affects the equilibrium price, predominates over the market-specific change in pricing noise also contained in $\mathrm{RESID}_{\mathrm{MX}}$ and $\mathrm{RESID}_{\mathrm{US}}$.

Table 2
Regression results, open-to-open stock price change, Grupo Televisa 2001–2002

(4)$\mathrm{DLN}(P_{\mathrm{US}}) = -0.000239_{(-0.14)} - 1.471279_{(-4.73)}\,\mathrm{DLN}(\mathrm{MXP/USD}) - 0.161773_{(-0.96)}\,\mathrm{EC} + \mathrm{RESID}_{\mathrm{US}}$
Adjusted $R^2 = 0.074$. Equation yields $\mathrm{RESID}_{\mathrm{US}}$ and corresponds to Eq. (4) (*t*-statistics in parentheses)
(5)$\mathrm{DLN}(P_{\mathrm{MX}}) = -0.000689_{(-0.42)} - 0.677685_{(-2.29)}\,\mathrm{DLN}(\mathrm{MXP/USD}) + 0.780363_{(4.85)}\,\mathrm{EC} + \mathrm{RESID}_{\mathrm{MX}}$
Adjusted $R^2 = 0.100$. Equation yields $\mathrm{RESID}_{\mathrm{MX}}$ and corresponds to Eq. (5).
(6)$\mathrm{DLN}(P_{\mathrm{US}}) = -0.000239_{(-0.37)} - 1.471279_{(-12.90)}\,\mathrm{DLN}(\mathrm{MXP/USD}) - 0.161773_{(-2.61)}\,\mathrm{EC} + 0.977839_{(40.71)}\,\mathrm{RESID}_{\mathrm{MX}} + \eta_{\mathrm{US}}$
Adjusted $R^2 = 0.876$. Equation corresponds to Eq. (6).
(7)$\mathrm{DLN}(P_{\mathrm{MX}}) = -0.000689_{(-1.14)} - 0.677685_{(-6.25)}\,\mathrm{DLN}(\mathrm{MXP/USD}) + 0.780363_{(13.22)}\,\mathrm{EC} + 0.885819_{(40.71)}\,\mathrm{RESID}_{\mathrm{US}} + \eta_{\mathrm{MX}}$
Adjusted $R^2 = 0.879$. Equation corresponds to Eq. (7).

Note: Comparing coefficients on those explanatory variables that blocks (4) and (6), and (5) and (7) have in common shows that their size is unchanged but their significance level much higher in (6) than in (4) and in (7) than in (5) when the other country's RESID is added to the list of explanatory variables. The coefficient on $\mathrm{RESID}_{\mathrm{MX}}$ in (6) is $0.978 = 0.000686/0.000701$, and on $\mathrm{RESID}_{\mathrm{US}}$ in (7) $0.886 = 0.000686/0.000774$, with size differences in the coefficients on RESID fully explained by the differences in the size of their variances (in the denominator) and with significance levels identical (40.71).

Table 2 shows that addition of the respective variable RESID, obtained from Eq. (13) or (14), to Eq. (15) or (16) reduces the standard error of estimate of the earlier coefficients without affecting their size, thereby increasing the efficiency of estimation. $\mathrm{RESID}_{\mathrm{MX}}$ is uncorrelated with all other explanatory variables in the system except $\mathrm{RESID}_{\mathrm{US}}$ and vice versa. Hence a_3 and b_3 differ only (inversely) on account of differences in the variance of $\mathrm{RESID}_{\mathrm{MX}}$ and $\mathrm{RESID}_{\mathrm{US}}$ and not also on account of any difference in their covariance with the respective dependent variable.

5.1. *Independent variables*

DLN(MXP/USD) is the change in the natural logarithm of the Mexican peso/US dollar exchange rate from 9:30 a.m. 1 day to 9:30 a.m. the next trading day. EC is the logarithm of the ratio of the US (NYSE) price of Grupo Televisa at the open converted to peso to the corresponding Mexican (BMV) price. EC is entered with a lag to represent price discrepancies, if any, at the beginning of each daily period over which the stock price change is calculated. By construction, a ceteris paribus *increase* in $\mathrm{LN}(P_{\mathrm{MX}})$ and a *fall* in $\mathrm{LN}(P_{\mathrm{US}})$ would reduce EC. EC is positive (negative) if the US price converted to peso exceeds (is less than) the Mexican price of Grupo Televisa shares.

6. The critical coefficient estimates

Differences between coefficients a_1 and b_1 obtained from estimating Eqs. (15) and (16) are important for the question of information efficiency, and both the size of a_2 and b_2, and the difference between them, yield insights into exchange rate effects on stock prices quoted in different currencies. Coefficients a_3 and b_3 should not be much below 1 in each

Table 3
Regression coefficient on EC and DLN(MXP/USD) and R^2-adjusted

	Telefonos de Mexico				Grupo Televisa			
	1996–2000		2001–2002		1996–2000		2001–2002	
	NYSE	BMV	NYSE	BMV	NYSE	BMV	NYSE	BMV
Coefficient on EC								
(1) *O–O*	−0.3284	0.5693	−0.7575[a]	0.2077	−0.8040[a]	0.1762	−0.1618[a]	0.7804
Open-to-open	(−11.41)	(21.39)	(−12.16)	(3.43)	(−28.26)	(6.43)	(−2.61)	(13.22)
(2) *C–C*	−0.4168	0.4925	−0.7479[a]	0.0944	−0.3649	0.4646	−0.6353[a]	0.2590
Close-to-close	(−14.86)	(17.21)	(−11.70)	(1.47)	(−12.83)	(16.87)	(−10.37)	(4.16)
(3) *O–C*	−0.4073	0.5339	−0.6400	0.2631	−0.8144	0.1226	−0.2569[a]	0.7137
Open-to-close	(−19.53)	(25.26)	(−22.79)	(9.24)	(−41.72)	(6.54)	(−7.05)	(19.44)
(4) *C–O*	−0.2353	0.5347	−0.2834	0.3412	−0.0131	0.5375	−0.1870	0.4373
Close-next-open	(−6.17)	(16.87)	(−2.37)	(2.87)	(−0.36)	(14.81)	(−1.95)	(4.69)
Coefficient on Exchange Rate								
(1) *O–O*	−2.231[a]	−1.234	−0.874	−0.303	−2.449[a]	−1.618	−1.471[a]	−0.678
Open-to-open	(−63.7)	(−38.1)	(−8.0)	(−2.8)	(−47.2)	(−32.4)	(−12.9)	(−6.3)
(2) *C–C*	−2.436[a]	−1.428	−1.259[a]	−0.370	−2.909[a]	−1.893	−2.450[a]	−1.481
Close-to-close	(−78.8)	(−45.8)	(−20.4)	(−6.0)	(−67.9)	(−45.6)	(−29.7)	(−17.7)
(3) *O–C*	−2.161[a]	−1.185	−0.636[a]	0.271	−2.417[a]	−1.439	−1.270[a]	−0.234
Open-to-close	(−56.6)	(−30.6)	(−8.5)	(3.6)	(−45.1)	(−28.0)	(−13.2)	(−2.4)
(4) *C–O*	−2.034[a]	−0.994	−0.820	−0.682	−1.993	−1.225	−1.404	−0.817
Close-next-open	(−38.7)	(−22.8)	(−5.4)	(−4.5)	(28.9)	(−17.7)	(−8.3)	(−5.0)
RESID *O–O*	1.011	0.865	0.882	0.836	0.947	0.878	0.978	−0.886
	(91.5)	(91.5)	(25.4)	(25.4)	(76.7)	(76.7)	(40.7)	(40.7)
R^2-adjusted								
O–O	0.9122	0.8967	0.7824	0.7396	0.8803	0.8532	0.8756	0.8791
C–C	0.9461	0.9350	0.9453	0.9371	0.9408	0.9329	0.9636	0.9602
O–C	0.9271	0.9189	0.9311	0.9197	0.9221	0.9048	0.9455	0.9475
C–O	0.6971	0.6313	0.3296	0.3112	0.5695	0.5196	0.5756	0.5505

Note: EC, the natural logarithm of the ratio of the NYSE price converted to peso to the BMV price of the respective share, refers to conditions at the beginning of the trading period that call for pricing error correction (EC) jointly in the two markets.

[a] First coefficient minus the second coefficient of respective pair is not significantly different from −1. The *t*-values of regression coefficients are shown in parentheses.

price change equation, with the value of each coefficient lowered by the extent of pricing noise in the other market.

6.1. EC

If the price discrepancies calling for error correction are substantially eliminated within one trading period, though not from close to next open, then the first minus the second market's coefficient on EC in Table 3 should not differ significantly from −1 in rows (1) through (3) of each bloc.[12] A value of −1 would imply complete elimination of what pricing

[12] We use the property that $[\text{aNYSE} - \text{aBMV} + 1]/S \sim t$, where $S = [S^2_{\text{aNYSE}} + S^2_{\text{aBMV}}]^{0.5}$ (ignoring covariance, see Kmenta, 1971, p. 372) to test the hypothesis that the difference between two coefficients (a) is −1.

discrepancy was observed at the beginning of the period over which the daily price change is measured. At a 5% level of significance, this expectation is met in 6 out of 12, or half the number of pairs of estimates shown in the first three rows of Table 3. Furthermore, the difference is always close to −1 (between −0.8 and −1). Hence an important result is that, except in overnight trades, pricing errors tend to be at least 80% corrected within the ensuing trading period, and the hypothesis that correction is complete cannot be rejected in half the number of cases.[13]

Which market then contributes most to achieving this correction by the NYSE moving down and the BMV up whenever a positive EC has occurred? Here the evidence for Telmex is not supportive of the judgment, quoted in Section 3, that the price making function has shifted from the small domestic market. Rather, the trend has gone the other way: The NYSE bore a consistently higher share of the burden of adjustment in the second sample period, 2001–2002, than the first, 1996–2000. In the most recent period the NYSE had to correct 64–76% of the price discrepancy outstanding at the beginning of the trading period in rows (1) through (3). This made BMV pricing, in the case of Telmex, more efficient over time so as to overtake the NYSE in the latest period.

The pattern for Grupo Televisa is consistent with that for Telmex only from close-to-close. Unlike with Telmex, for Grupo Televisa the quality of the open on the BMV appears to have deteriorated relative to the NYSE; the NYSE had to correct about 80% of any pricing errors in 1996–2000 while having to correct only about 20% in 2001–2002 in rows (1) and (3). For both Telmex and Grupo Televisa, row 4 shows that about half the error at the close was corrected by the next opening of the BMV overnight. The NYSE contributed considerably less to overnight error correction in both periods and for both shares thus maintaining more confidence in its close overnight until the next open.

6.2. DLN(MXP/USD)

A second efficient-markets hypothesis derived from LOP as the equilibrium of the system is that the difference between the NYSE and BMV coefficients on the exchange rate change should be −1. At the 5% level this hypothesis cannot be rejected in all but 1 of the 12 pairs of cases in rows (1) through (3) of the bottom panel of Table 3. An important additional finding is that exchange rate change is hardly ever neutral, as it would be if $b_2 = 0$ for the Mexican market.

Elsewhere in the world a pattern has been found of depreciation of the local currency lifting the local-currency price of shares on account of the aid that an orderly depreciation may provide to the export business. In that case local-currency returns and exchange-converted returns may correlate negatively. However we find that with only one exception—the intraday price movement of Telmex from open-to-close—and even without a currency crisis in

[13] Since EC is the error outstanding at the beginning of the period over which any stock price change is measured, its value is the same in the open-to-close (O–C) as in the open-to-next open (O–O_{+1}) regression equations. Because correction occurs predominantly from O to C, ECO tends to be more significant in that regression than in the run for changes over O–O_{+1} that covers periods O–C and C–O_{+1} combined. The value of ECC is also the same in the C–O_{+1} and C–C_{+1}runs, but comparatively little error correction is achieved overnight. Hence here the ECC coefficient tends to be more significant over the longer period, C–$C_{+1,}$than over its first part alone, C–O_{+1}.

the sample, depreciation of the peso is bad news for Mexican shares on the BMV and doubly bad news for the dollar price of these shares on the NYSE. In other words, $b_2 = 0$ is decisively rejected in favor of b_2 being negative. Hence, unlike Zhang and Johnson (1998), we find a *positive* correlation between "local returns" and "currency returns" for Mexico, with exchange-rate changes affecting currency returns more than local returns and contributing to their higher variance. A possible explanation could lie in the two Mexican companies having large amounts of dollar-denominated debt that could give a peso depreciation an adverse balance-sheet effect.[14] A reduction in operating income could follow if dollar receivables are less than payables, including debt service, for the two companies and a real depreciation is involved.

6.3. RESID

As the US market for Mexican shares tends to be noisier than their Mexican home market, the coefficient on $RESID_{MX}$, unlike that on $RESID_{US}$, is not significantly below 1 in Table 2. Just before reporting the R^2, Table 3 presents results showing that the Mexican residual is always more informative for the New York market than vice versa from open-to-open; results for other trading intervals are more mixed.

7. Conclusion

Stock exchanges in developing countries often lack the economies of scale and scope enjoyed by much larger markets, in particular those quoting and settling in a major currency. But even if these exchanges are economically inefficient, they need not be informationally inefficient as often assumed. Rather, there is evidence that the BMV provides efficient information services in the cross-listed Mexican shares to the NYSE. This finding casts doubt on the common assertion (IMF, 2001, pp. 137–138) that price discovery for some of the major emerging-market stocks, in particular Mexican stocks that have more ADR listings than any other emerging market, is done in New York.

This paper considered price discovery as a matter of degree of accuracy: If one market registers prices that stick to a greater extent than those recorded in another market when deviations from LOP occur, then the first market is more effective in price discovery than the second. Market leadership thus means that when price discrepancies occur, the *other* market is being led to adjust. This has implications for stock trading. We found that when deviations from LOP occur that call for error correction, usually within the next trading session, much of the correction gets made during the ensuing trading in New York rather than in Mexico City. Yet this pattern is not entirely consistent over the two subperiods or shares. This very

[14] As of 31 December 2001, 75% of the debt of Telmex (see its *Annual Report*, 2001, pp. 30, 39), an amount equal to 33% of its total assets, was in US dollars. The corresponding percentages for Grupo Televisa (see its *Estados Financieros*, 2001, pp. 4, 19) are 68 and 19%, with "TV" holding a large stake in the US Spanish-language network, Univision. Telmex obtains dollar receivables for instance from its international long-distance service. The adverse effects of exchange depreciation on countries with widespread liability dollarization are detailed by Calvo et al. (2004).

lack of consistency over time and across shares cautions against wholesale judgments about the utility of a particular local stock exchange. For leadership of the New York market to be affirmed, price innovations in that market would have to be more persistent and not the preferred object of error correction. They would more accurately have to reveal changes in the equilibrium price level due to new developments than innovations in the Mexican market.

The addition of noise in the New York market may contribute to the variance of (exchange-converted) price changes for the shares of Telmex and Grupo Televisa generally being greater on the NYSE than the BMV. In addition, shares listed on the NYSE are exposed to a double whammy of exchange-rate effects that contribute to their volatility. Even in the absence of any major currency or financial crisis, depreciation of the peso against the dollar is associated with *falling* peso prices of the Mexican shares, with the plunge in the corresponding ADS and GDS dollar prices in New York compounded by the decline in the dollar value of the peso.

Overall, assertions about price discovery for major Latin American stocks, a category certainly including Telmex and Grupo Televisa, being done either predominantly or exclusively in New York are not supported by our limited data.[15] The balance of the evidence presented in this paper tilts against these assertions in spite of their superficial plausibility. Geography or place of business, to paraphrase Pagano et al. (2000), has not become irrelevant for generating informationally efficient prices so that superior economic efficiencies offered by central world exchanges, such as the NYSE, need not be decisive. Hence the fate of securities exchanges like the BMV may not be sealed by the forces of global consolidation but remains in their own hands.

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