THE DYNAMIC RELATIONSHIP BETWEEN ADRS, INTEREST RATES, EXCHANGE RATES AND THEIR SPILLOVER EFFECTS

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ABSTRACT

We examine the price and volatility spillovers from interest rates and exchange rates to American Depository Receipts (ADRs) originating from Mexico, Brazil, and Chile. Using the multivariate EGARCH model, we also examine the asymmetries in volatility transmission from interest rate and exchange rate changes on ADRs. Overall, our results suggest that there is information flow between these markets and that the markets have linear and nonlinear relationships in the short-run and are linked through the second moment. The implication of our results for investors and portfolio managers is that time-varying portfolio inputs are more informative than standard portfolio inputs.

JEL classification: C32; G12; G15

Keywords: ADR; Interest rate; Exchange rate; EGARCH

I. INTRODUCTION

Recent research on international portfolio diversification suggests that investors can reduce their portfolio risk by diversifying internationally, since returns are less

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correlated across different stock markets than within markets (Eun and Resnick, 1994). Researchers interpret the relatively low correlation between the major world stock markets as indicative of significant potential gains from diversification (Levy and Sarnat, 1970). Current literature on international portfolio diversification also focuses attention on American Depository Receipts (ADRs) (e.g., Jiang, 1998; Kim et al., 2000; Alaganar and Bhar, 2002) since ADRs are often used for international diversification. Furthermore, with globalization there has been an increase in the integration of international financial markets.

Many firms engage in international financing strategies. As a result, working capital management is often affected by changes in both interest rates and exchange rates. These rates also play a fundamental role in the pricing of various assets. Consequently, the issue of interest rate risk and exchange rate risk has increasingly concerned investors, portfolio managers, banking authorities, academicians and policy makers.

These concerns, in turn, have prompted a substantial amount of research. Several studies examine the impact of interest rate movements on stock market performance or ADR pricing (Chen at. al. 1986; Giliberto, 1985; Sweeney and Warga, 1986; Bin et al., 2003), the effect of monetary policy on stock or ADR returns (Wong, 1990; Lombra and Torto, 1977; Bonomo et al., 1993), and the effects of real interest rate differentials and risk premium (Fenton and Paquet, 1998). Other research examines the effect of exchange rate changes on firm value, stock returns, or ADR pricing.[3]

The extant literature focuses on the long-term relationships (i) between interest rates and stock or ADR returns, and (ii) between exchange rates and stock or ADR returns, while essentially ignoring short-term relationships. Notwithstanding the fact that the simultaneous effects of interest rates and exchange rates on ADR returns have not been fully explored, little attempt has been made to analyze the possibility of spillover effects that may exist from interest rates and exchange rates to ADRs. It is important to analyze any potential spillover effects, since the recent globalization and integration of world financial markets has increased international transmission of returns and volatilities among the financial markets. The short-term impact from interest rates and exchange rates on ADRs is important to bankers, individual investors, and portfolio managers, since movements in these rates affect the cost of capital and profitability, as well as current assets and liabilities of firms. Thus, the impact of interest rates and exchanges rates on ADRs ultimately influence the returns of both ADRs and their underlying stock.

In addition to examining price changes, it is important to analyze volatility measures such as variance, which also provide information (Ross, 1989). Volatility

[3] See, for example, Bodnar and Gentry, 1993; Bartov amd Bodnar, 1994; Choi and Prasad, 1995; He and Ng, 1998; Bodart and Reding, 2001; Liang and Mougoue, 1996; Jiang, 1998; Kim et al., 2000; Bin et al., 2003.

spillover is a process by which volatility in one market is transmitted to another market. Volatility spillovers between stock markets of different countries are well documented.[4] Hence, we focus our research on examining volatility spillovers between interest rates and exchange rates to ADRs, in an effort to enhance our understanding of information transmission between markets.

The purpose of this paper is to examine the short-term effect of interest rate and exchange rate movements and their volatilities on ADRs originating from Mexico, Brazil, and Chile. In particular, this paper builds on Bin et al., (2003) and attempts to fill the gap in the literature by investigating how information is transmitted from interest rates and exchange rates to ADRs through short-term price interactions and asymmetric volatility spillovers.

We contribute to the literature in three distinct ways. First, we investigate the short-term dynamic relationship between interest rates and exchange rates and their volatilities on the conditional mean and variance of ADRs. We also account for the time-varying nature of risk premiums, which enables us to explore the linear and nonlinear relationships of interest rates and exchange rates on ADRs. Second, we simultaneously examine the effect of interest rate and exchange rate innovations on ADRs in a one-step procedure. This gives a more comprehensive picture of the relationships of interest rates and exchange rates on ADRs, as these relationships are not necessarily linear. Third, we investigate the asymmetric impact of negative and positive innovations on the volatility transmission of interest rates and exchange rates to ADRs. Current literature documents that negative innovations have bigger impacts on volatility than positive innovations (Cheung and Ng, 1992; Koutmos, 1992; Bae and Karolyi, 1994; Koutmos and Booth, 1995). However, previous studies investigate negative and positive rate changes separately. By investigating and comparing the effect of negative and positive changes simultaneously, we provide additional insights about how information is transmitted from interest rates and exchange rates to ADRs.

Using the multivariate extension of Nelson's (1991) Exponential Generalized Autoregressive Conditionally Heteroscedastic (EGARCH) model on ADRs from Mexico, Brazil, and Chile, we find strong price and volatility spillovers. In terms of price spillovers, we find that interest rates and exchange rates spillover to Mexican and Chilean ADRs, whereas only exchange rates spillover to Brazilian ADRs. In terms of volatility spillovers, both interest rates and exchange rates spillover to Brazilian and Chilean ADRs, whereas only exchange rate spillovers to Mexican ADRs. With regard to asymmetry, negative interest rate changes in Mexico, Brazil and Chile and negative exchange rate changes in Chile increase volatility more than positive changes. These

[4] See, for example, Eun and Shim, 1989; Hamao, Masulis and Ng, 1990; Lin, Engle and Ito, 1994; Theodossiou and Lee, 1993; Koutmos, 1996; Ng, 2000

findings suggest that these markets are more sensitive to negative innovations originating from other markets than to positive innovations.

The remainder of the paper is organized as follows: Section 2 discusses the empirical framework while Section 3 highlights the data and Section 4 the econometric methodology. Section 5 discusses the empirical results and is followed by our concluding remarks in Section 6.

II. EMPIRICAL FRAMEWORK

Several studies document the effect of interest rate changes on the pricing of assets. For example, Chen et al., (1986), Gilberto (1985) and Sweeney and Warga (1986) examine the relationship between interest rate changes and stock market performance in the U.S. and find significant correlation. Wong (1990) analyzes the effect of monetary policy on stock returns for the U.S., U.K., Canada, Japan, Germany and Italy and finds that monetary policy significantly influences stock returns.

A broad set of literature examines the impact of Federal Reserve discount rate changes on the U.S. stock markets with varying results. For example, Lombra and Torto (1977) find linkages between discount rate changes and the U.S. stock market during 1968 to 1974. Fenton and Paquet (1998) find that real interest rate differentials between the U.S. and Canada reflect the risk premium that is a result of economic growth differentials between the two countries.

These findings suggest that ADRs, which are backed by foreign securities, could also be affected by movements in both foreign and U.S. interest rates. However, Bonomo, Ferris, and Noronha (1993) examine the effect of U.S. interest rate changes on ADRs and find that ADRs do not react to changes in U.S. interest rates. Notwithstanding this finding, we know that interest rates affect a firm's cash flow position since it influences the cost of capital. However, the home-country money market is usually the main source of current liabilities for foreign firms. Also, changes in short-term interest rates in foreign countries are often affected by changes in U.S. interest rates (Bin et. al., 2003). Thus, when U.S. interest rates change, the foreign country interest rates also change, which in turn affects the operations and profitability of the ADR-originating foreign firm. This impact is transmitted to the value of the underlying stock and ultimately to the ADRs. Furthermore, since ADRs are quoted in dollars, the price of the ADR reflects not only the changes in the value of the underlying stock but also the exchange rate movements against the dollar. Kim et al. (2000, p. 1362) note, "Although ADRs, being dollar-denominated, do not bear explicit exchange-rate risk, there is an implicit risk in their price due to the convertibility between ADRs and the underlying shares. Even if the price of the underlying share remains unchanged for a period, changes in the exchange rate against the U.S. dollar would make the price of ADRs adjust to avoid arbitrage profits".

There are a few studies that examine the impact of exchange rate fluctuations on ADRs. For example, Liang and Mougoue (1996) examine the ADRs from the U.K., Japan, and South Africa, and find that these ADR returns are sensitive to fluctuations in exchange rates. Jiang (1998) examines the pricing factors for ADRs from Australia, France, the Netherlands, South Africa, Spain, Sweden and the U.K. and finds the exchange rate to be an influential factor in the pricing of ADRs. Kim et al. (2000) analyze ADRs from Japan, U.K., Sweden, the Netherlands, and Australia and document that exchange rates have an impact on ADR prices. Lastly, Bin et al. (2003) analyze select Australian, European, Asian, and Latin American ADRs, and find that not only exchange rates but also interest rates impact ADR returns.

We have three objectives in using an EGARCH model to examine the effects of changes in interest rates and exchange rates on ADR returns. Our first objective is to determine the price and volatility spillover effect of interest rates and exchange rates on ADR returns. It is important to estimate interest rates and exchange rates within the same system of equations, since a change in either exogenous variable is expected to influence the other. Second, we examine whether the spillover effect persists over time. Third, we analyze whether the interest rate and exchange rate innovations have an asymmetric impact on ADR returns.

Our review of the literature indicates that research focuses on the long-term relationships between interest rates or exchange rates and ADRs, while generally ignoring short-term relationships. In addition, the effects of interest rates and exchange rates on ADRs have been analyzed separately. We therefore contribute to the literature by simultaneously examining the effect of interest rate and exchange rate changes on ADRs in the short-run. Additionally, we examine the relationship between the higher moments of the two markets on ADRs, i.e., volatility spillover. This framework discards the restrictive assumption of linearity and constant conditional variance. We further extend the literature by investigating the effect of changes in interest rate volatility and exchange rate volatility on the return generating process, thereby delineating the nature of risk varying time premiums. To date, these effects have not been considered in the ADR literature.

III. DATA

American Depository Receipts (ADRs) are U.S. dollar-denominated negotiable receipts that represent equity shares of foreign-based companies. This arrangement allows foreign companies to be listed and traded in U.S. equity markets without the inconvenience of currency conversions and foreign settlement procedures. ADRs are popular in the U.S., as they are an alternate way of achieving international diversification. Additionally, the ADR market has been rapidly expanding to meet the growing demand of U.S. investors in their quest for international diversification. At the end of 2004, the trading volume of ADRs on the New York Stock Exchange (NYSE), American Stock Exchange (AMEX), and Nasdaq reached a record high of 39.1 billion shares (an increase of 18% over 2003) valued at $885 billion (an increase of 40% over 2003).[5]

Our research focuses on ADRs originating from Mexico, Brazil, and Chile, three Latin American countries that have exhibited strong economic growth in the past two decades. Brazil, Mexico, and Chile are placed among the top 40 developing and emerging markets in the world and are ranked 18th, 25th, and 31st, respectively, by the International Finance Corporation (IFC, 1999).

The data used in this study are the daily closing equity prices of the ADR country indexes provided by the Bank of New York.[6] The Bank of New York indexes track all the ADRs traded on the NYSE, AMEX and Nasdaq and are calculated on a continuous basis throughout the trading day. All these indexes are value-weighted and are adjusted for free-float using the same method used in calculating the Dow Jones indices. We use the 30-day Commercial Paper average returns (middle rates) for Mexico and the 30-day Certificate of Deposit middle rates for Brazil and Chile. The exchange rates used are the bilateral spot rates expressed in terms of local currency per unit of U.S. dollar for the three countries. We use the Mexico IPC (BOLSA) price index for Mexico, Brazil Bovespa price index for Brazil, and the Chile general (IGPA) price index for Chile as control variables.

All data are obtained from the *DataStream* database. The dataset, which covers the period from January 1, 1999 to October 31, 2004, contains 1,521 observations. Daily percentage returns are calculated for all variables (except interest rates) as 100 (log P_t – log P_{t-1}), where P_t is the value of the index at time t in terms of the local currency. We use the daily data series for this study since weekly returns may be too long to examine the rapid interactions between stock markets (Eun and Shim, 1989; Chowdhry, 1994).

Table 1 provides the summary statistics for the returns of the Mexican ADR index (M_ADR), Mexican interest rates (M_INT), Mexican exchange rates (M_XR) and Mexican equity index (M_IND). Table 2 provides the summary statistics for the returns of the Brazilian ADR index (B_ADR), Brazilian interest rates (B_INT), Brazilian exchange rates (B_XR) and Brazilian equity index (B_IND). Table 3 provides the summary statistics for the returns of the Chilean ADR index (C_ADR), Chilean interest rates (C_INT), Chilean exchange rates (C_XR), and Chilean equity index (C_IND). The

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5 See http://www.bankofny.com/adr

6 See http://www.adrbny.com/adr_index_landing.jsp

distribution of returns for the ADR indexes, interest rates, exchange rates, and equity index variables of Mexico and Brazil are positively skewed, while the returns of the ADR index and equity index of Chile are negatively skewed. The returns of each variable for all three countries are leptokurtotic. The significant values of the Ljung-Box test statistics (LB) for the returns and the square of returns suggest the presence of autocorrelation and heteroscedasticity in these series. Also, the Jarque-Bera normality test rejects the null hypothesis of normality. Clearly, these descriptive statistics indicate that these data fit the ARCH type modeling approach employed in this study.

Table 1
Descriptive Statistics of Returns for Mexico

Statistics	M_ADR	M_INT	M_XR	M_IND
Mean	0.00047	0.12918	0.00010	0.00071
Standard Deviation	0.01775	0.06989	0.00536	0.01525
Skewness	0.22517	1.09504	0.45541	0.10507
Kurtosis	6.92156	3.95212	6.93928	5.56051
LB(12) for $R_{i,t}$	47.72	17225.00	14.08	40.58
	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
LB(12) for $R^2_{i,t}$	123.53	16516.00	176.82	176.60
	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
Jarque-Bera	987.47	361.42	1036.02	418.29
	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
Correlation Coefficients				
	M_ADR	M_INT	M_XR	M_IND
M_ADR	1.0000	0.0333	-0.2790	0.8596
M_INT		1.0000	-0.0479	0.0256
M_XR			1.0000	-0.2071
M_IND				1.0000

This table displays the descriptive statistics of returns for Mexico. The variables in the EGARCH model are returns on Mexican ADRs (M_ADR), Mexican interest rates (M_INT), Mexican exchange rates (M_XR) and returns on Mexican equity index (M_IND). The sample spans the period from January 1, 1998 to October 31, 2004 and contains 1,521 observations. Daily percentage returns ($R_{i,t}$) are calculated as 100 (log P_t – log P_{t-1}), where P_t is the value of the index at time t in terms of the local currency. LB(12) for $R_{i,t}$ is the Ljung-Box statistic, which tests for the presence of autocorrelation, while LB(12) for $R^2_{i,t}$ is the statistic that tests for the presence of heteroscedasticity. The Jarque-Bera statistic tests the null hypothesis of normality. Lastly, ***, **, and * denote statistical significance at the 1%, 5% and 10% levels respectively.

Table 2
Descriptive Statistics for Returns for Brazil

Statistics	B_ADR	B_INT	B_XR	B_IND
Mean	0.00032	0.20471	0.00057	0.00080
Standard Deviation	0.02478	0.05408	0.01224	0.02104
Skewness	0.85984	2.38632	0.33154	1.48386
Kurtosis	34.60792	9.76161	21.34480	26.53713
LB(12) for $R_{i,t}$	9.81	16195.00	68.93	24.29
	(0.0000)***	(0.0000)***	(0.0000)***	(0.019)***
LB(12) for $R^2_{i,t}$	265.20	15612.00	927.47	75.05
	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
Jarque-Bera	63502.89	4341.02	21355.56	35667.69
	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***

Correlation Coefficients

	B_ADR	B_INT	B_XR	B_IND
B_ADR	1.0000	0.0397	-0.3188	0.7625
B_INT		1.0000	0.0412	0.0818
B_XR			1.0000	-0.1089
B_IND				1.0000

This table displays the descriptive statistics of returns for Brazil. The variables in the EGARCH model are returns on Brazilian ADRs (B_ADR), Brazilian interest rates (B_INT), Brazilian exchange rates (B_XR), and returns on Brazilian equity index (B_IND). The sample spans the period from January 1, 1998 to October 31, 2004 and contains 1,521 observations. Daily percentage returns ($R_{i,t}$) are calculated as 100 (log P_t – log P_{t-1}), where P_t is the value of the index at time t in terms of the local currency. LB(12) for $R_{i,t}$ is the Ljung-Box statistic, which tests for the presence of autocorrelation, while LB(12) for $R^2_{i,t}$ is the statistic that tests for the presence of heteroscedasticity. The Jarque-Bera statistic tests the null hypothesis of normality. Lastly, ***, **, and * denote statistical significance at the 1%, 5% and 10% levels respectively.

Table 3
Descriptive Statistics for Chile

Statistics	C_ADR	C_INT	C_XR	C_IND
Mean	0.00019	0.00382	0.00017	0.00059
Standard Deviation	0.01116	0.00168	0.00558	0.00605
Skewness	-0.31964	0.18968	0.19977	-0.00659
Kurtosis	8.75448	1.68952	5.79685	5.08945
LB(12) for $R_{i,t}$	116.40	17482.00	35.98	216.37
	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
LB(12) for $R^2_{i,t}$	42.69	17017.00	160.10	255.95
	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
Jarque-Bera	2124.50	117.95	505.85	276.69
	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
Correlation Coefficients				
	C_ADR	C_INT	C_XR	C_IND
C_ADR	1.0000	-0.0265	-0.3723	0.6917
C_INT		1.0000	0.0303	-0.0196
C_XR			1.0000	-0.1408
C_IND				1.0000

This table displays the descriptive statistics of returns for Chile. The variables in the model are returns on Chilean ADRs (C_ADR), Chilean interest rates (C_INT), Chilean exchange rates (C_XR), and returns on the Chilean equity index (C_IND). The sample spans the period from January 1, 1998 to October 31, 2004 and contains 1,521 observations. Daily percentage returns ($R_{i,t}$) are calculated as 100 (log P_t – log P_{t-1}), where P_t is the value of the index at time t in terms of the local currency. LB(12) for $R_{i,t}$ is the Ljung-Box statistic, which tests for the presence of autocorrelation, while LB(12) for $R^2_{i,t}$ is the statistic that tests for the presence of heteroscedasticity. The Jarque-Bera statistic tests the null hypothesis of normality. Lastly, ***, **, and * denote statistical significance at the 1%, 5% and 10% levels respectively.

IV. ECONOMETRIC METHODOLOGY

The price and volatility spillovers from interest rates and exchange rates to ADRs are analyzed using a multivariate extension of the EGARCH developed by Nelson (1991). Following Nelson (1991), researchers such as Koutmos (1996) and Koutmos and Booth (1995) use a multivariate EGARCH to test their hypothesis. Our analysis of the volatility linkages from interest rates and exchange rates to the ADR returns has the following important feature: the interactions are investigated in a one-step estimation procedure, therefore eliminating the need to use estimated regressors.

The multivariate EGARCH is written as follows:

$$R_{i,t} = \beta_{i,0} + \sum_{j=1}^{4} \beta_{i,j} R_{j,t-1} + \varepsilon_{i,t} \qquad (1)$$

Where,

i = 1,2,3, 4 and $\varepsilon_{i,t} \sim N(0, \sigma^2_{i,t})$

The daily returns are expressed as:

$R_{i,t} = \mu_{i,t} + \varepsilon_{i,t}$ for market i,

Where:

$\mu_{i,t} = E(R_{i,t} / \Omega_{t-1})$ is the conditional mean of returns at time t, based on information available at time t-1,

$\varepsilon_{i,t}$ is the innovation at time t and i = 1,…4 (where 1 = ADR index, 2 = interest rates, 3 = exchange rates and 4 = stock index).

The above equation describes returns as a Vector Autoregressive (VAR) model where the conditional mean in each market is a function of its own past returns and cross-market past returns. A significant $\beta_{i,j}$, $i = j$, implies that the ADR returns, interest rates, exchange rates and stock indexes are dependent on their past values. Coefficients $\beta_{i,j}$, $i \neq j$ measure the extent of price spillover between the variables. A significant $\beta_{i,j}$

would imply that market *j* leads market *i*, or equivalently, that current returns in market *j* can be used to predict future returns in market *i*.

The conditional variance between the markets, given by equation (2), is an exponential function of past own innovations as well as cross-market standardized innovations (Koutmos and Booth 1995, Koutmos, 1998).

$$\sigma_{i,t}^2 = \exp[\alpha_{i,0} + \sum_{j=1}^{4} \alpha_{i,j} f_j(z_{j,t-1}) + \gamma_i \ln(\sigma_{i,t-1}^2)], \text{ for } i = 1,2,3,4 \tag{2}$$

Where:

$\sigma_{i,t}^2$ is the conditional variance,

$Z_{j,t-1}$ is the standardized innovation at time *t*-1 (i.e., $Z_{i,t-1} = \varepsilon_{i,t-1} / \sigma_{i,t-1}$)

In the above equation, the coefficient $\alpha_{i,j}$ captures the effect of innovations from portfolio *j* to portfolio *i*. Significant parameter values of $\alpha_{i,j}$, *i*=*j*, indicate that volatilities in each market are dependent on their past innovations. Coefficients $\alpha_{i,j}$ □ $i \neq j$ measure the extent of volatility spillover between the markets.

The particular functional form $f_j(Z_{j,t-1})$ given in equation (3) is an asymmetric function of past standardized innovations.

$$f_j(Z_{j,t-1}) = (|Z_{j,t-1}| - E(|Z_{j,t-1}|) + \delta_j(Z_{j,t-1}) \quad \text{for } j = 1,\ldots 4 \tag{3}$$

The coefficient γ_i measures the persistence in volatility. A high value suggests that an information shock tends to persist for some time into the future. Asymmetry in volatility transmission is modeled by equation (3) and can be examined using its derivatives:

$$\partial f_j(z_{jt}) / \partial z_{jt} = \left\{ 1 + \delta_j, \textit{ for } \quad z_j \succ 0 \right\}$$

$$\partial f_j(z_{jt}) / \partial z_{jt} = \left\{ -1 + \delta_j, \textit{ for } \quad z_j \prec 0 \right\} \tag{4}$$

The term $(|Z_{j,t-1}| - E(|Z_{j,t-1}|)$ measures the magnitude effect while the term $\delta_j(Z_{j,t-1})$ measures the sign effect. In the event that market advances and market declines impact volatility symmetrically, then the coefficient of δ_i would not be expected to be significant. However, if declines in market j ($Z_{j,t} < 0$) are followed by higher (lower) volatility than the advances in market ($Z_{j,t} > 0$) then δ_j would be expected to be negative (positive) and significant. In summary, a significant positive $\alpha_{i,j}$ coupled with a negative δ_i implies that negative innovations in market *j* have a higher impact on the volatility of market *i*, than positive innovations, i.e. the volatility transmission is asymmetric.

Equation (5) provides the conditional covariance that captures the contemporaneous relationship between returns of the two markets.

$$\sigma_{i,j,t} = \rho_{i,j}\sigma_{i,t}\sigma_{j,t} \quad \text{for } i, j = 1,\ldots 4 \;\; i \neq j; \qquad (5)$$

Where:

$\sigma_{i,j,t}$ is the conditional covariance between markets *i* and *j* at time t.

This specification implies that the covariance is proportional to the product of the standard deviations (Bollerslev, 1990). The coefficient $\rho_{i,j}$ is the cross-market correlation coefficient between the volatilities of the two markets. Statistically significant estimates of $\rho_{i,j}$ indicate that time-varying volatilities across markets *i* and *j* are correlated over time (Racine and Ackert, 1998). This assumption greatly simplifies the estimation of the model (Bollerslev and Wooldridge, 1992). We use the Berndt, Hall, Hall, and Hausman (BHHH) (1974) approach to maximize the log-likelihood function.

V. RESULTS

The maximum likelihood estimates of the multivariate EGARCH model for Mexican, Brazilian and Chilean ADRs are reported in Tables 4, 5,and 6. The results show substantial evidence of multidirectional lead-lag relationships from interest rates and exchange rates to ADRs.

A. Mexican ADRs

In terms of price spillovers, Table 4 presents evidence that both Mexican interest rates and exchange rates spillover to Mexican ADRs. This shows that changes in both Mexican interest rates and exchange rates significantly influence Mexican ADRs. Price spillovers also exist from the Mexican equity index to Mexican ADRs. Furthermore, there is feedback of price spillovers from interest rates to Mexican ADRs, and from the Mexican equity index to ADRs.

In terms of volatility spillovers, we find that only Mexican interest rates do not spillover to Mexican ADRs. Also, there is evidence of volatility spillovers from the

Mexican equity index to Mexican ADRs. Further, a feedback effect exists from the Mexican equity index to Mexican ADRs. Lastly, Table 4 also shows that all four variables are strongly influenced by their own past innovations in the first and second moments.

Table 4-Maximum Likelihood Estimates of the EGARCH model for Mexico

	M_ADR			M_INT			M_XR			M_IND	
Price spillover parameters											
β_{10}	0.0193	(0.0009)***	β_{20}	0.0001	(0.0000)***	β_{30}	0.0071	(0.0006)***	β_{40}	0.0098	(0.0001)***
β_{11}	0.0507	(0.0026)***	β_{21}	0.0020	(0.0001)***	β_{31}	0.0147	(0.0130)	β_{41}	0.0483	(0.0008)***
β_{12}	0.0284	(-0.005)***	β_{22}	0.0011	(0.0011)***	β_{32}	0.0381	(0.0030)***	β_{42}	0.0461	(0.0008)***
β_{13}	0.6569	(0.0579)***	β_{23}	0.0000	(0.0000)***	β_{33}	0.106	(0.0428)***	β_{43}	0.0442	(0.0008)***
β_{14}	0.4671	(0.0243)***	β_{24}	0.0024	(0.0023)***	β_{34}	0.0283	(0.0155)***	β_{44}	-0.0074	(0.0004)***
Volatility spillover parameters											
α_{10}	-5.2603	(0.3598)***	α_{20}	-11.8464	(0.5318)***	α_{30}	-8.5939	(0.3504)***	α_{40}	-1.0350	(0.0484)***
α_{11}	2.1028	(0.2412)***	α_{21}	-3.8585	(0.2748)***	α_{31}	0.0286	(0.1833)	α_{41}	0.2924	(0.082)***
α_{12}	-0.0215	(0.0234)	α_{22}	0.2346	(0.0328)***	α_{32}	-0.4364	(0.0311)	α_{42}	0.0983	(0.0095)***
α_{13}	0.2513	(0.0516)***	α_{23}	0.8444	(0.1145)***	α_{33}	1.5683	(0.1331)***	α_{43}	0.0079	(0.0035)***
α_{14}	0.6011	(0.1081)***	α_{24}	-0.0396	(0.0874)	α_{34}	-0.0156	(0.0332)	α_{44}	6.6683	(0.0795)***
Other parameters											
γ_1	-0.2108	(0.0400)***	γ_2	-0.0553	(0.0499)	γ_3	-0.0990	(0.0406)***	γ_4	0.0941	(0.0085)***
δ_1	0.7350	(0.0124)***	δ_2	-0.3471	(0.0103)***	δ_3	-0.0915	(0.0759)	δ_4	0.0917	(0.0115)***
Correlation Matrix											
	M_ADR			M_INT			M_XR			M_IND	
M_ADR	1.0000			0.1839	(0.0233)***		0.3990	(0.0870)***		0.9528	(0.0148)***
M_INT				1.0000			0.3947	(0.0859)***		0.2055	(0.0507)***
M_XR							1.0000			0.4065	(0.0731)***
M_IND										1.0000	

This table displays the maximum likelihood estimates of the EGARCH model for Mexico. The variables in the model are returns on Mexican ADRs (M_ADR), Mexican interest rates (M_INT), Mexican exchange rates (M_XR) and returns on Mexican equity index (M_IND). The EGARCH model is estimated based on Eqs. (1)-(3): $R_{i,t} = \beta_{i,0} + \sum_{j=1}^{4} \beta_{i,j} R_{j,t-1} + \varepsilon_{i,t}$; $\sigma_{i,t}^2 = \exp[\alpha_{i,0} + \sum_{j=1}^{4} \alpha_{i,j} f_j(z_{j,t-1}) + \gamma_i \ln(\sigma_{i,t-1}^2)$ and $f_j(Z_{j,t-1}) = (|Z_{j,t-1}| - E(|Z_{j,t-1}|) + \delta_j(Z_{j,t-1})$ for *i*, *j*=1,2,3,4 and where $R_{i,t}$ is the daily percentage return for market *i* at time *t*, $R_{j,t-1}$ is the daily percentage return for market *j* at time *t-1* and $z_{j,t-1}$ is the standardized innovation at time *t*-1. The parameters $\beta_{i,j}$ reflect the extent of price spillovers, $\alpha_{i,j}$ captures volatility spillovers, γ_i measures the persistence of volatility and δ_i captures the asymmetric impact of volatility. ***, **, and * denotes statistical significance at the 1%, 5% and 10% levels respectively. Numbers in parenthesis are robust standard error.

B. Brazilian ADRs

From Table 5 we can see that, in terms of price spillovers, both Brazilian exchange rates and Brazilian equity index spillover to Brazilian ADRs, while Brazilian interest rates do not. Also significant is the feedback effect from Brazilian exchange rates and the Brazilian equity index to Brazilian ADRs.

In terms of volatility spillovers, both Brazilian interest rates and exchange rates spillover to Brazilian ADRs. This shows that volatilities in both Brazilian interest rates and exchange rates significantly influence Brazilian ADRs. Also, the Brazilian stock index affects Brazilian ADRs, and there is a feedback effect from Brazilian exchange rates and the Brazilian stock index to Brazilian ADRs. Lastly, similar to Mexican ADRs, all four variables are strongly influenced by their own past innovations in the first and second moments.

Table 5-Maximum Likelihood Estimates of the EGARCH model for Brazil

B_ADR			B_INT			B_XR			B_IND		
Price spillover parameters											
β_{10}	0.0104	(0.0052)**	β_{20}	0.0411	(0.0030)***	β_{30}	0.0102	(0.0030)***	β_{40}	0.0124	(0.0013)***
β_{11}	-0.4155	(0.0404)***	β_{21}	0.0188	(0.0286)	β_{31}	-0.0488	(0.0051)***	β_{41}	-0.0216	(0.0019)***
β_{12}	0.0189	(0.0193)	β_{22}	0.8606	(0.0143)***	β_{32}	-0.0124	(0.0145)	β_{42}	0.0345	(0.0054)***
β_{13}	-0.1566	(0.0594)***	β_{23}	0.0959	(0.0027)***	β_{33}	0.0775	(0.0231)***	β_{43}	0.1041	(0.0078)***
β_{14}	0.4211	(0.0000)***	β_{24}	-0.0048	(0.0392)	β_{34}	0.0707	(0.0253)***	β_{44}	0.0453	(0.0170)***
Volatility spillover parameters											
α_{10}	-3.8589	(0.0915)***	α_{20}	-2.9290	(0.4945)***	α_{30}	-4.7344	(0.3478)***	α_{40}	-2.8864	(0.1968)***
α_{11}	-0.7888	(0.0739)***	α_{21}	0.0144	(0.0787)	α_{31}	0.4147	(0.0000)***	α_{41}	-0.0751	(0.0431)*
α_{12}	0.6570	(0.0000)***	α_{22}	-0.2468	(0.0464)***	α_{32}	-0.5888	(0.0789)***	α_{42}	-0.0217	(0.0359)
α_{13}	0.1979	(0.0000)***	α_{23}	-0.2739	(0.0650)***	α_{33}	1.2559	(0.0000)***	α_{43}	-0.3401	(0.0433)***
α_{14}	2.6228	(0.3438)***	α_{24}	0.2214	(0.0000)***	α_{34}	-0.1663	(0.0409)***	α_{44}	4.3947	(0.1567)***
Other parameters											
γ_1	0.1058	(0.0434)***	γ_2	0.5840	(0.0716)***	γ_3	0.2462	(0.0421)***	γ_4	0.0817	(0.0311)***
δ_1	0.7825	(0.0453)***	δ_2	-1.0259	(0.0000)***	δ_3	-0.0056	(0.0655)	δ_4	0.1200	(0.0439)***

Correlation Matrix

	B_ADR	B_INT		B_XR		B_IND	
M_ADR	1.0000	-0.2451	(0.0581)***	-0.2527	(0.0441)***	0.8297	(0.0000)***
M_INT		1.0000		0.4315	(0.0000)***	0.0977	(0.0401)***
M_XR				1.0000		0.0437	(0.0000)***
M_IND						1.0000	

This table displays the maximum likelihood estimates of the EGARCH model for Brazil. The variables in the model are returns on Brazilian ADRs (B_ADR), Brazilian interest rates (B_INT), Brazilian exchange rates (B_XR) and returns on Brazilian equity index (B_IND). The EGARCH model is estimated based on Eqs. (1)-(3): $R_{i,t} = \beta_{i,0} + \sum_{j=1}^{4} \beta_{i,j} R_{j,t-1} + \varepsilon_{i,t}$; $\sigma_{i,t}^2 = \exp[\alpha_{i,0} + \sum_{j=1}^{4} \alpha_{i,j} f_j(z_{j,t-1}) + \gamma_i \ln(\sigma_{i,t-1}^2)$ and $f_j(Z_{j,t-1}) = (|Z_{j,t-1}| - E(|Z_{j,t-1}|) + \delta_j(Z_{j,t-1})$ for *i, j*=1,2,3,4 and where $R_{i,t}$ is the daily percentage return for market *i* at time *t*, $R_{j,t-1}$ is the daily percentage return for market *j* at time *t-1* and $z_{j,t-1}$ is the standardized innovation at time *t*-1. The parameters $\beta_{i,j}$ reflect the extent of price spillovers, $\alpha_{i,j}$ captures volatility spillovers, γ_i measures the persistence of volatility and δ_i captures the asymmetric impact of volatility. ***, **, and * denotes statistical significance at the 1%, 5% and 10% levels respectively. Numbers in parenthesis are robust standard errors.

C. Chilean ADRs

In terms of both price and volatility spillovers, we can see from Table 6 that Chilean interest rates and exchange rates both spillover to Chilean ADRs. This implies that not only does the levels of Chilean interest rates and exchange rates, but also their volatilities, significantly influence Chilean ADRs. Furthermore, the Chilean equity index significantly influences Chilean ADRs. We also find evidence of a feedback effect between the Chilean interest rates, exchanges rates, and the equity index to Chilean ADRs. Lastly, similar to Mexican and Brazilian ADRs, all four variables are strongly influenced by their own past innovations in the first and second moments.

Table 6-Maximum Likelihood Estimates of the EGARCH model for Chile

	C_ADR			C_INT			C_XR			C_IND	
Price spillover parameters											
β_{10}	0.0094	(0.0003)***	β_{20}	0.0002	(0.0000)***	β_{30}	0.0001	(0.0000)***	β_{40}	0.0090	(0.0000)***
β_{11}	-0.1137	(0.0000)***	β_{21}	-0.0039	(0.0000)***	β_{31}	0.0373	(0.0000)***	β_{41}	0.0450	(0.0000)***
β_{12}	0.4817	(0.0000)***	β_{22}	0.9559	(0.0000)***	β_{32}	0.0430	(0.0000)***	β_{42}	0.0436	(0.0000)***
β_{13}	-0.1119	(0.0000)***	β_{23}	-0.0057	(0.0000)***	β_{33}	-0.0938	(0.0000)***	β_{43}	0.0482	(0.0000)***
β_{14}	0.7422	(0.0000)***	β_{24}	0.0011	(0.0000)***	β_{34}	-0.2425	(0.0000)***	β_{44}	0.0126	(0.0000)***
Volatility spillover parameters											
α_{10}	-5.5026	(0.0332)***	α_{20}	-13.2126	(0.0000)***	α_{30}	-4.8532	(0.0546)***	α_{40}	-0.1079	(0.0139)***
α_{11}	-2.2243	(0.0166)***	α_{21}	1.6580	(0.0000)***	α_{31}	0.2430	(0.0000)***	α_{41}	0.0309	(0.0000)***
α_{12}	-0.0516	(0.0000)***	α_{22}	0.0904	(0.0000)***	α_{32}	-0.0596	(0.0000)***	α_{42}	0.0229	(0.0000)***
α_{13}	-1.0852	(0.0000)***	α_{23}	0.5127	(0.0000)***	α_{33}	0.1925	(0.0000)***	α_{43}	0.1513	(0.0000)***
α_{14}	1.9272	(0.0000)***	α_{24}	-2.2370	(0.0000)***	α_{34}	0.3476	(0.0000)***	α_{44}	7.6180	(0.0000)***
Other parameters											
γ_1	0.0998	(0.0000)***	γ_2	0.0748	(0.0000)***	γ_3	0.2869	(0.0000)***	γ_4	0.1167	(0.0000)***
δ_1	0.2126	(0.0000)***	δ_2	-2.7883	(0.0000)***	δ_3	-0.7629	(0.0000)***	δ_4	0.0950	(0.0000)***
Correlation Matrix											
	C_ADR			C_INT			C_XR			C_IND	
M_ADR	1.0000			-0.0228	(0.0000)***		-0.6403	(0.0280)***		0.9090	(0.0000)***
M_INT				1.0000			0.0530	(0.0000)***		0.1042	(0.0000)***
M_XR							1.0000			-0.3157	(0.0000)***
M_IND										1.0000	

This table displays the maximum likelihood estimates of the EGARCH model for Chile. The variables in the model are returns on Chilean ADRs (C_ADR), Chilean interest rates (C_INT), Chilean exchange rates (C_XR) and returns on Chilean equity index (C_IND). The GARCH model is estimated based on Eqs. (1)-(3):

$$R_{i,t} = \beta_{i,0} + \sum_{j=1}^{4} \beta_{i,j} R_{j,t-1} + \varepsilon_{i,t}\,;\ \sigma_{i,t}^{2} = \exp[\alpha_{i,0} + \sum_{j=1}^{4} \alpha_{i,j} f_j(z_{j,t-1}) + \gamma_i \ln(\sigma_{i,t-1}^{2}) \text{ and } f_j(Z_{j,t-1}) = (|Z_{j,t-1}| - E(|Z_{j,t-1}|) + \delta_j (Z_{j,t-1}) \text{ for } i,$$

j=1,2,3,4 and where $R_{i,t}$ is the daily percentage return for market *i* at time *t*, $R_{j,t-1}$ is the daily percentage return for market *j* at time *t-1* and $z_{j,t-1}$ is the standardized innovation at time *t*-1. The parameters $\beta_{i,j}$ reflect the extent of price spillovers, $\alpha_{i,j}$ captures volatility spillovers, γ_i measures the persistence of volatility and δ_i captures the asymmetric impact of volatility. ***, **, and * denotes statistical significance at the 1%, 5% and 10% levels respectively. Numbers in parenthesis are robust standard errors.

D. Volatility persistence and asymmetric volatility spillover effect

The values of volatility persistence in Tables 4, 5 and 6, measured by γ_i, indicate that persistence is significant and less than one. This is a necessary condition for the unconditional variance to be finite. For Mexico, persistence is strongest for ADRs, followed by interest rates, equity index, and exchange rates. For Brazil, persistence is strongest for interest rates, followed by exchange rates, ADRs, and the equity index. For Chile, persistence is strongest in exchange rates, followed by equity index, ADRs, and interest rates.

Recall that asymmetry in volatility transmission is modeled by equation (3). Table 6 indicates that the coefficients of asymmetry, δ_j, are negative and significant for interest rates of Mexico, Brazil, and Chile, and negative and significant for exchange rates of Chile. This implies that for interest rates of Mexico, Brazil, and Chile, as well as exchange rates for Chile, negative innovations increase volatility more than positive innovations. These findings suggest that these markets are more sensitive to negative innovations originating from other markets than to positive innovations. Furthermore, the coefficients of asymmetry for ADRs and equity indexes are positive and significant suggesting that these markets do not react differently to negative and positive innovations originating from other markets.

E. Diagnostics tests

Table 7 reports the residual based diagnostics tests developed by Engle and Ng (1993) to check whether the model is correctly specified. The asymmetry tests statistics - the sign bias, negative size, positive size, and joint tests - show that there is no serial correlation in the standardized residuals. Thus we conclude that our model is correctly specified.

Table 7
P-Values for Model Diagnostics

	ADR	INT	XR	IND
Mexico				
Sign bias test	0.8911	0.5420	0.0615	0.4232
Negative size bias test	0.0000	0.5382	0.0000	0.0000
Positive size bias test	0.1671	0.7567	0.0000	0.0625
Joint test	0.0000	0.6993	0.0000	0.0000
Brazil				
Sign bias test	0.0410	0.0039	0.1828	0.0012
Negative size bias test	0.0000	0.0000	0.0002	0.0891
Positive size bias test	0.0000	0.0808	0.0003	0.9494
Joint test	0.0000	0.0000	0.0000	0.0000
Chile				
Sign bias test	0.1501	0.0881	0.0015	0.8429
Negative size bias test	0.0000	0.0000	0.1996	0.0000
Positive size bias test	0.0061	0.0000	0.8070	0.7673
Joint test	0.0000	0.0000	0.0013	0.0000

This table presents the results of the Engle and Ng (1993) tests for the asymmetric effect using the squared standardized residuals $(\varepsilon_{j,t}/\sigma_{j,t})^2$. These tests as specified as follows:

sign bias ($z^2_{j,t} \equiv (\varepsilon_{j,t}/\sigma_{j,t})^2 = \alpha + \beta S_{j,t} + \varepsilon_{j,t}$);

negative size bias ($z^2_{j,t} \equiv (\varepsilon_{j,t}/\sigma_{j,t})^2 = \alpha + \beta S_{j,t}\varepsilon_{j,t-1} + e_{j,t}$);

positive sign bias ($z^2_{j,t} \equiv (\varepsilon_{j,t}/\sigma_{j,t})^2 = \alpha + \beta(1 - S_{j,t})\varepsilon_{j,t-1} + e_{j,t}$) and

joint test ($z^2_{j,t} \equiv (\varepsilon_{j,t}/\sigma_{j,t})^2 = \alpha + \beta_1 S_{j,t} + \beta_2 S_{j,t}\varepsilon_{j,t-1} + \beta_3(1 - S_{j,t})\varepsilon_{j,t-1} + e_{j,t}$)

where $\varepsilon_{j,t}$ is the error from the conditional mean equation of the jth country at t, $S_{j,t}$ is the dummy variable that is equal to 1 if $\varepsilon_{j,t-1}$ and zero otherwise.

VI. CONCLUDING REMARKS

The purpose of this paper is to examine the short-term effect of interest rate and exchange rate movements and their associated volatilities on prices of ADRs from Mexico, Brazil and Chile. This study also investigates the asymmetric impact of positive and negative innovations on the volatility transmission between these markets. We use the multivariate extension of Nelson's (1991) exponential generalized autoregressive conditionally heteroscedastic (EGARCH) model to analyze the price and volatility spillovers.

The results of our study indicate that all three markets have strong price spillovers and volatility spillovers. In terms of price spillovers, interest rates and exchange rates spillover to Mexican and Chilean ADRs, whereas only exchange rates spillover to Brazilian ADRs. In terms of volatility spillovers, both interest rates and exchange rates spillover to Brazilian and Chilean ADRs, whereas only exchange rates spillover to Mexican ADRs. With regard to asymmetry, the interest rates of Mexico, Brazil, and Chile, as well as the exchange rates of Chile, indicate that negative innovations increase volatility more than positive innovations. These findings suggest that these markets are more sensitive to negative innovations originating from other markets than to positive innovations.

The implication of our results for investors and portfolio managers is that time-varying portfolio inputs are more informative than standard portfolio inputs. This further implies that time-varying portfolio inputs are better able to capture the systematic risks embedded in the Latin American ADR markets (see Bekaert and Harvey, 1995). For policy makers, our findings suggest that they need to be sensitive to the cascading effect of volatility in these markets.

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