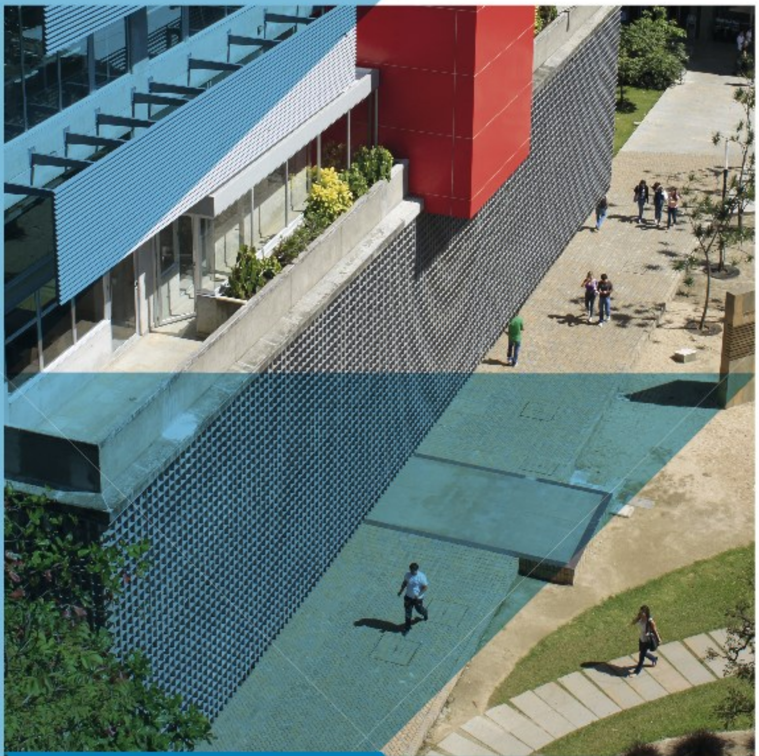

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Volatility transmission between US and Latin American Stock Markets: testing the decoupling hypothesis.

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Volatility transmission between US and Latin American Stock Markets: testing the decoupling hypothesis.

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Abstract

We test for volatility transmission between US and the six largest Latin American stock markets (Argentina, Brazil, Chile, Colombia, Mexico and Peru) using MGARCH-BEKK models in daily frequency from March 1993 to March 2013. As expected, we find strong evidence of volatility transmission from US to the Latin American markets but not so in the opposite direction. Testing the hypothesis of decoupling between US and Brazil and Mexico the evidence goes against it: the conditional correlations between US and the two emerging markets have steadily increased over the sample period and the volatility transmission have become more significant from 2003 onwards. We also find some evidence on the leadership of Brazil in the region, being the only Latin American stock market consistently transmitting volatility to US.

Keywords: Volatility transmission, MGARCH, decoupling hypothesis, emerging markets, conditional correlation

JEL: G15, F36, C32

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1. Introduction

The study of volatility transmission between international financial markets has made a comeback after the Subprime crisis, leading to the Great recession from 2007 to 2009, and the Eurozone sovereign debt crisis, starting from 2010 to the present. Unlike the period of 1997 to 1999 that witnessed the emerging market crises of Southeast Asia, Russia and Brazil, recent worldwide financial instability has mainly come from developed markets. Besides after the late 90´s crises, most emerging countries have advanced in terms of economic and financial stability, allegedly altering the pattern of volatility transmission from developed markets. In this context, the controversial idea of a "decoupling" between emerging and developed stock markets have gained popularity since the 2000's decade (The Economist, 2008, Dooley and Hutchison, 2009, Bekiros, 2014).

To understand volatility transmission from and to emerging markets is important for portfolio management. International volatility transmission and the contemporaneous increase in correlation worsen portfolio losses in globally diversified portfolios. Besides, it is a well-established fact that low correlation disappears in worldwide bear markets, precisely when needed the most (Soriano and Climent, 2005).

In this paper we test for volatility transmission between the US and the main six Latin American stock markets, in the period June 2007- March 2013, using bivariate MGARCH models. We use the MGARCH-BEKK specification (Engle and Krone, 1995) that estimates volatility transmission in a very general setting, provides estimations of time-varying conditional correlations and has become the standard approach to test volatility transmission, as discussed below. Besides, with trivariate MGARCH models, we test for the role of leadership of Brazil stock markets in the region. Finally, we test for the decoupling hypothesis by estimating volatility transmission between US and both Brazil and Mexico, the largest markets of the region, in three additional periods, starting on March 1993. Those results describe the evolution of volatility transmission and conditional correlation in a large span of time, that includes two periods of bullish international stock markets (Mar.1993- Jun. 1997 and Nov. 2003-May 2007), and two convulsed periods, the first including crises originating mostly from emerging markets (Jul.1997-Oct. 2003), and the second, from developed markets (Jun. 2007- Mar. 2013).

US and Latin America offer an interesting case to study volatility transmission from developed to emerging markets. First, the Latin American countries are strongly linked to US by trade and capital flows, cultural proximity, time zone, and macroeconomic effects. For example, Canova (2005) reports strong transmissions of US monetary shocks to Latin American countries. Second, Latin American stock markets have become more important for worldwide portfolio investments. Market capitalization of the region has increased from an average of 28% of GDP to 42% in 2011 (OECD, 2013). Foreign investment allocations in Latin American stock exchanges have increased by 14,5 times from 1996 to 2011 as reported the Emerging Portfolio database. Third, Latin American markets offer variety in terms of size, development and economic links with US. Brazil holds by far the largest and deepest stock market in the region, a hallmark among emerging markets, especially since 2001 when classified as a one of the BRIC economies. Mexico, the second largest, is deeply interconnected with US economy, especially since the NAFTA Free trade agreement in the middle of the 90's. The stock markets of Chile, Colombia, and Peru, of medium to small size among emerging markets, have gained visibility among foreign investors in the last decade for their growing economies and improving sovereign credit rankings, and are working towards a unified securities market, named MILA (*Mercado Integrado Latinoamericano*)[1]. On the other hand, Argentina, some time ago an obliged reference of emerging markets, has been mostly shunned by foreign portfolio investors since the "Corralito" crisis in 2001, to the point that was excluded from the emerging market classifications of MSCI and SP DowJones.

A wide set of studies have explored volatility transmission between stock markets. For example, Lin, Engle and Ito (1994) in the stock exchanges of Tokyo and New York, Chancharoenchai and Dibooglu (2006) in six southeast Asian stock markets and Japan and US during the Asian Crisis, Sakthivel, Bodkhe, and Kamaiah (2012) between developed markets and India, and Fayyad and Daly (2011), from US, UK and a group of Arab oil exporting countries and the oil prices.

However, previous studies on volatility transmission focused on Latin American stock markets are scarce. The more closely related to this paper are: Christofi and Pericli (1999), who report volatility spillovers between five major Latin American markets; Edwards and Susmel (2001), that use a bivariate switching volatility model finding strong co-movements between four Latin-American markets during the 90's; Weber (2012) that models stochastic volatility transmissions between American equity markets, finding volatility spillovers from the US stock markets to Mexico and Brazil from 1989 to 2008; Andreou, Matsi, and Savvides (2013) who identify bidirectional volatility spillovers between stock and foreign exchange markets for a sample of emerging Asian and Latin-American markets; and finally, Rejeb and Arfaoui, (2015), who study interdependence between the stock markets of US and Japan and a set of emerging stock markets,

[1] Chile, Colombia and Peru were the founding partners of MILA on 2011, Mexico has joined on 2015.

including five of Latin America, interpreting their results as an indirect evidence of volatility transmission.

The contribution of this article to the emerging markets literature is twofold. On the one hand, by running the model in a long span of time, 1993-2013, we are able to test the decoupling hypothesis, measuring the evolution of volatility transmission and conditional correlation between US and Mexico and Brazil, the two largest markets in the region. On the other hand, to our knowledge, this is the first study that tests volatility transmissions between US and Latin American stock markets using the MGARCH-BEKK model, unlike previous studies (Christofi and Pericli, 1999; Edwards and Susmel, 2001; Weber, 2012; Rejeb and Arfaoui, 2015). The MGARCH-BEKK model is currently deemed as the standard methodology for detecting volatility spillovers amongst financial markets (Gannon and Au-Yeung 2004; Caporale, Pittis and Spagnolo, 2006; Koulakiotis, Dasilas and Papasyriopoulos, 2009; Hammoudeh, Yuan, McAleer and Thompson, 2010; Fayyad and Daly, 2011; Arouri, Jouini and Nguyen, 2011; Andreou, Matsi, and Savvides, 2013).

As for the results, we find evidence of volatility transmission from US to each of the six Latin American stock markets, for the period Jun. 2007-Mar. 2013. Only in two cases, Mexico and Peru, there is evidence of some volatility transmission to the US stock market, but it is explained away when including Brazil in trivariate MGARCH models. We also find some evidence consistent with the leading role of Brazil in the region: Brazil transmits volatility not only to four out of the other five Latin American countries, but also to US in four out of five models. Interestingly, Brazil receives volatility transmission by four Latin American countries. Finally, bivariate MGARCH models between US and Brazil and US and Mexico for four periods from 1993 to 2013 provide strong evidence of an increasing integration of Latin American stock markets with those of US, contrary to the decoupling hypothesis. The evidence is twofold: First, volatility transmission from

US is statistically significant for Mexico in the last two periods and for Brazil in the last three. Second, the conditional correlations with US show a strong upward trend in the whole period 1993 -2013, with important increases upon the Asian Crisis (1998), and along the period 2003 to 2007 that corresponds to a bullish stock market in all the Americas. We find this rise on the conditional correlations as highly statistically significant in a non-parametric test.

This paper is organized as follows. Section 2 briefly discusses the relevant literature and presents the working hypotheses of the study. Section 3 and 4 presents the data and discusses the MGARCH methodology, respectively. Section 5 presents and discusses the results, and finally section 6 concludes.

2. Background and Hypotheses

The October 1987 crisis, originated in US financial markets, sparked interest in understanding the spread of financial crises across international markets. The seminal work of Engle, Ito and Lin (1990) offer two alternative hypotheses. The hypothesis of "Heat waves" posit that most volatility sources are specific of a country or region and do not transmit to other markets in contrast with the "Meteor Shower" hypothesis. Modeling the Yen/US Dollar exchange rate in different markets they find evidence consistent with the second hypothesis. Interestingly, studies in stock markets have presented mixed results. For example, Fayyad & Daly (2011); Melvin & Melvin (2003) report that most of the volatility transmission occurs among markets of the same region, whereas Corradi, Distaso, & Fernandes (2012); Lee et al. (2004) and Lin et al. (1994) report strong interdependencies on distant markets. Koulakiotis et al. (2009), in turn, test volatility transmission among European countries grouped in three regions: Scandinavian, Germanic and French areas. They find strong evidence of volatility transmission between stock markets of the same region, identifying the leading markets.

Some studies have focused on volatility transmission between developed and emerging market, for the most part reporting volatility transmission only from developed to emerging markets. Lee et al. (2004) finds transmission from Nasdaq to a group of Asian second-board stock markets, but not conversely. Li and Majerowska (2008) find volatility transmission from US and Frankfurt stock exchanges to the ones of Warsaw and Budapest, but not the other way around. Studying a group of stock markets from Arab oil exporting countries, Fayyad and Daly (2011), find that while most of the volatility transmission comes within the group, some come from US and UK stock markets. Finally, Weber (2012), modeling stochastic volatility transmission between US, Canada, Mexico and Brazil, only finds evidence of volatility transmission from US to the other three markets. An exception is Carporale et al. (2006), who study volatility transmission with bivariate GARCH-BEKK models in a sample of developed and South East Asian stock markets, in the time of the Asian Crisis (1997). They find bidirectional effects in normal periods, but volatility spillover from the markets in turmoil to the others in crisis times.

The research on volatility transmission has followed the development of econometric models that capture the complexity on interactions between markets. Early works based their tests on univariate volatility models (Lin et al, 1994; Christofi and Pericli, 1999; Melvin and Melvin 2003; Lee et al 2004; Abraham and Seyyed, 2006). Some other studies used bivariate switching volatility models (Edward and Susmel, 2001) or stochastic volatility models (Lopes and Migon, 2003; Weber, 2012). Some other studies have used restricted bivariate GARCH models that impose assumptions on the dynamic behavior of the conditional correlation (Giovannini et al 2006; Lean and Teng, 2013; Dimitriou, Kenourgios and Simos, 2013). Recently, Multivariate GARCH-BEKK model proposed by Engle and Kroner (1995), have been gained acceptation to model volatility spillovers, since it allows for more general interactions between the conditional volatility and disturbances across series (Gannon and Au-Yeung, 2004; Li and Majerowska, 2008; Koulakiotis et al, 2009; Fayyad and Daly, 2011; Andreou, Matsi, and Savvides 2013).

This paper is different from previous literature in at least two aspects. First, we study both interregional volatility transmission in Latin America, as well as transmission to and from US markets for a long period of time, 1993 to 2013, that encompasses two different eras of financial crises, alternated with periods of high growth and moderate volatility. Thus, we provide evidence of the changing nature of volatility spillovers between stock markets over time. Second, unlike previous papers that study volatility in Latin America (Christofi and Pericli, 1999, Edward and Susmsel, 2001; Ortiz and Arjona 2001; Weber, 2012), we explicitly model and test for volatility spillover effects using the MGARCH-BEKK, widely used by the recent literature as the standard model to estimate the cross-interactions effects of volatilities and perturbations between financial markets .

Taking into consideration the previous literature we propose the following four working hypothesis for this study:

H1. US Stock markets transmit volatility to Latin American markets, based on the evidence of unidirectional volatility transmission from developed to emerging markets (Lee et al, 2004; Li and Majerowska, 2008; Fayyad and Daly, 2011; Weber, 2012). Nevertheless, volatility transmission from Latin American markets to US might occur, presumably in times of crises originated in that region, as reported for South Asian Markets amid the Asian Crisis

(1997) both by Caporale, Pittis and Spagnolo (2006) and Chancharoenchai and Dibooglu (2006).

H2. Brazil, the largest stock market in the region, transmits volatility to the other Latin American stock markets, based on its perceived role of leadership in the region (Fondo Monetario Internacional, 2011), and on the evidence that volatility transmission goes mostly from large to small stock markets (Lee et al., 2004; Soriano and Climent, 2005; Weber, 2012).

H3. Volatility transmission from US to Latin American stock markets have decreased after the 2008 subprime crisis, when compared to the emerging market crises of 1998-1999. This is based on the perceived autonomy and stability of Latin-American economies and markets in the recent past (Fondo Monetario Internacional, 2011), in what has been called the "decoupling" hypothesis (Dooley and Hutchison, 2009; Bekiros, 2014).

H4. Conditional correlations between Latin American Markets and US should increase on crises periods as in Giovannini et al.(2006), Sakthivel et al., (2012). However, by the decoupling Hypothesis, correlations in relatively calm periods might have decreased over time.

Nevertheless, some recent evidence contradicts H3 and H4 and the decoupling hypothesis. Dimitriou et al (2013), studying Contagion from US stock markets to the BRICs for the period 1997-2012, find that whereas some decoupling might have occuren on the early stage of the Subprime crises, it dissapeared upon the Lehman Brother´s bankrupcty, and the correlation of emerging markets with US has increased onwards. Similar results are reported by Dooley and

Hutchinson (2009) in an event study that included 14 emerging markets, and Bekiros (2014) studying the BRIC from 1999 to 2011.

3. Data

We computed daily logarithmic returns for stock market indexes of each of the six Latin American countries and US, starting on March 1993 until March 2013. From Datastream we obtained daily index values for Merval (Argentina), Bovespa (Brazil), IGPA (Chile), IPC (Mexico) and IGBVL (Peru). For US, we took the SP500 composite index. For Colombia, we retrieved the MSCI Index, available for the entire period, since the main indexes, IGBC and COLCAP, started only on 2001 and 2008 respectively.

A proper modeling for those daily series requires to split the 20-year span in four periods. For that purpose, we took into consideration the results of ICSS structural break tests on the stock indexes (Inclan and Tiao, 1994) and the evolution of worldwide stock market volatility, as given by the VIX index. As a result we divide the sample in four periods. The first period, from March 1993 to June 1997, is a bull market period for Latin America and US, a few years after their financial liberalization, as indicated in Figure 1. The official liberalizations of five of the LA markets (Peru is not covered) took place between 1989 and 1992, and the estimated structural breaks in US Capital inflows occurred between 1988 and 1993, as reported by Bekaert, Harvey and Lundblad (2003). The major international event on that period, the Mexican Peso devaluation in December 1994, can be clearly associated with volatile markets in Mexico, Brazil and Peru, but with only a minor increase in the volatility of the US market as given by the VIX.

The second period, July 1997 to October 2003, includes four major worldwide financial crises: The Asian crisis, starting in July 1997 with the floating of the Thai baht, the Russian crisis, starting on August 1998 with the sovereign debt default, the Brazilian crisis starting on January 1999 with the devaluation of the real, and the Nasdaq crash on April 2000 (Forbes and Rigobon, 2001). Fig. 1 shows several peaks of volatility of the VIX and the erratic behavior of Latin American indexes during that period. The third period, November 2003 to May 2007, can be viewed as another bull period with moderate volatility for international stock markets, as evident in Fig. 1 in the drop in the VIX index and the upsurge of the Latin America and US stock markets since the beginning of 2003. The fourth and last period, signed by peaks and a permanent rise of volatility, runs from June 2007 to March 2013 and starts with the bail-out of two CDOs mutual funds of Bear Stearns, considered as the trigger point of the US subprime crises, culminating in the Lehman's Brother Bankruptcy in October of 2008, taking the VIX to unprecedented levels. The period also includes the crisis of the Euro Zone, starting on April 2010.

4. Methodology

Multivariate GARCH models are a generalization of the univariate volatility ones that allow to estimate simultaneously the conditional variance of several time-series variables and their cross-effects. The specialized literature has proposed variants of multivariate GARCH that are computationally viable and yield positive definite variance-covariance matrices. These include the diagonal VEC Model (Bollerslev, Engle and Wooldridge, 1988), the BEKK model (Engle and Kroner, 1995), and the bivariate models for returns, including the constant conditional correlation (CCC) (Bollerslev, 1990), the dynamic conditional correlation (DCC) (Engle, 2002), and the varying conditional correlation (Tse and Tsui, 2002). We select the BEKK model for being the one that explicitly estimates cross effects of volatilities and perturbations across different markets, and yields an estimation of the conditional correlations between series without imposing structure on them. Besides, MGARCH-BEKK model allows for dynamic dependence between conditional volatility series and guarantees a variance-covariance matrix positive semidefinite (Tsay, 2010, pp. 451). However, the number of parameters increases rapidly with $\boldsymbol{K}$, the number of series, so estimating the model with more than three is not recommended (Lütkepohl, 2005, p. 567).

As a first step, the MGARCH-BEKK requires to estimate a VAR (p) model on the returns (Lütkepohl, 2005), as follows:

$$\boldsymbol{r}_t = \boldsymbol{\alpha} + \Pi_1 \boldsymbol{r}_{t-1} + \ldots + \Pi_p \boldsymbol{r}_{t-p} + \boldsymbol{\varepsilon}_t,\ \boldsymbol{\varepsilon}_t \mid \Omega_{\text{t-1}} \sim (0, \Sigma_{t|t-1})$$

Where $\boldsymbol{r}_t = (\boldsymbol{r}_{1t}, \ldots, \boldsymbol{r}_{Kt})'$ stands for $\boldsymbol{K}$ index returns on day $\boldsymbol{t}$, $\boldsymbol{\varepsilon}_t = (\boldsymbol{\varepsilon}_{1t}, \ldots, \boldsymbol{\varepsilon}_{Kt})'$ is the perturbation term, Π_i is the coefficient matrix for the lag i and $\Omega_{\text{t-1}}$ is the conditional past information matrix, including the p lags of $\boldsymbol{r}_t$. The conditional variance is given by:

$$\Sigma_t = \boldsymbol{C}'\boldsymbol{C} + \sum_{i=1}^{m} \boldsymbol{A}'_i \boldsymbol{\varepsilon}_{t-i} \boldsymbol{\varepsilon}'_{t-i} \boldsymbol{A}_i + \sum_{j=1}^{s} \boldsymbol{B}'_j \Sigma_{t-j} \boldsymbol{B}_j$$

Where C is a lower triangle constant matrix and $\boldsymbol{A}_i$ ($\boldsymbol{B}_j$) is the matrix of coefficients of effects on the conditional variance from past perturbation terms (past conditional variance). MGARCH-BEKK, models can be estimated maximizing the log-likelihood function on the matrix of parameters θ, assuming normality and with T observations, as follows:

$$L(\theta) = -T \ln(2\pi) - \frac{1}{2} \sum_{t=1}^{T} \left(\ln |\Sigma_t| + \varepsilon_t' \Sigma_t^{-1'} \varepsilon_t \right)$$

Where T is the number of observation and θ is the vector of parameters to be estimated. This nonlinear function has to be estimated with numerical methods. In this case, we used the simplex method to get initial values and then apply the quasi-Newton BFGS method to optimize the function. Standard errors are estimated robust to heteroskedasticity and variance-covariance matrices are estimated in a daily basis (Malik and Ewing, 2009; Lütkephol, 2005). We follow the standard procedure to estimate a MGARCH-BEKK by Lütkepohl (2005 pag. 571), as follows:

- The return series are checked for stationarity by using the Dickey-Fuller, Phillips-Perron and KPSS tests.
- The ***K*** series of returns are modelled by using a vector autoregressive model (VAR). Optimal lag is selected using the Akaike, Hanna-Quinn and Shwarz-Bayes criteria.
- An ARCH effect test is performed on the residuals of the VAR model to identify heteroskedasticiy.
- A MGARCH-BEKK model is jointly estimated with a VAR model on the mean returns. Appropiate lags are found starting with m= 1 and s= 1 and increasing if required to assure whithe noise in the residuals.
- Univariate and multivariate Q-tests and ARCH-LM and ARCH-Portmanteau Tests are performed on the residual to test for residual serial correlation and for any standing heteroskedaticity, respectively.

5. Results

Summary statistics (Table 1) report annualized volatilities of the Latin American stock markets, as well as correlations with the SP500, in the study periods. We note that volatility is higher for Mexico, Brazil and US in the two periods of major international crises: 1997-2003 and 2007-2013. Besides, correlation between those two countries and US has seemingly increased over time. Multivariate GARCH modelling will help us to understand the dynamic of volatility transmission among Latin American countries and between them and US.

We first run bivariate MGARCH models between each of the six Latin American markets and US for the period June 2007 to March 2013. The results will help us to test the hypothesis H1 of unidirectional volatility transmission from US to the Latin American markets. Second, we run trivariate MGARCH models between US, Brazil and each of the other five Latin American markets. This will test whether Brazil transmits volatility to any of the other stock markets in Latin America when simultaneously modelling volatility transmission from and to US (H2). Third, we run bivariate MGARCH models of Brazil and Mexico with US, in each of the four periods, to test if volatility transmission has decreased over time (H3). Finally, from those bivariate MGARCH models, we estimate the conditional correlation between US and Brazil and US and Mexico, to test whether correlations have decreased over time, consistent with the "decoupling" hypothesis and if correlations increase in crisis times relative to calm periods (H4). Although in many cases, econometric tests call for a two lag MGARCH model, we restrict the analysis to the first-lag effects on volatility.

5.1 Volatility transmission between Latin American stock markets and US.

A bivariate MGARCH -BEKK model is estimated between US stock market returns and those of the six Latin American countries, Argentina, Brazil, Chile, Colombia, Mexico and Peru for the period 2007 to 2013. Following the procedure outlined in the previous section we find that in all six cases, a MGARCH(2,2) model is the best specification. The resulting squared coefficients of the $\boldsymbol{A}_i$ and $\boldsymbol{B}_j$ matrices, for the first lag, are presented in Table 2. As expected there are significant own effects of perturbation and volatility in all series, but are omitted for the sake of simplicity.

Most importantly, there is evidence of significant volatility transmission at the 5% level from US perturbations to Argentina, Brazil, Chile and Peru, as well as from US volatilities to Colombia and Mexico. At the 5% level of significance, only Mexico (from perturbations) and Peru (from volatility) have apparently a effect on US volatility. In particular, the size of the perturbation effect of Peru on US Volatility, although highly significant, is of very small magnitude comparted with the opposite effect of US on Peru (0,0030 vs 0,0832). In contrast, the volatility effect of Mexico on US is somewhat larger than the opposite effect (0,0164 vs 0,0109). Those results support largely H1.

We investigate how Brazil mediates the volatility transmission between US and the remaining Latin American stock markets by running a trivariate MGARCH, for the fourth period, as presented in Table 3. Proper specification of the errors require a MGARCH(2,2) in all cases. At the 10% of significance, we find volatility transmission from Brazil to all the other countries, except Argentina: significant coefficient of the perturbation effect for Chile, Peru and Mexico, and of the volatility effect for Colombia and Peru. In spite of including Brazil, the volatility transmission from US perturbations still appears in four of the five countries, Colombia being the only exception. Besides, perturbation effects from US to Brazil volatility appears significant in four of the models. In the models of Chile, Mexico and Peru there are significant effects of Brazil perturbation on the US volatility. Other than that, there is no volatility transmission from any other Latin American Market on US Volatility, and the volatility transmission of Peru on US reported in Table 2 disappears once including Brazil in the model. To note, there are also significant volatility effects from Chile, Colombia, Peru and Mexico on Brazil volatility.

Taking these results together, we find some mixed evidence of Brazil being the leader stock market of the region as posed by H2. On the one hand, the interaction of Brazil with US and Latin

American markets explains away the apparent transmission of Mexico and Peru towards US presented in Table 2. Moreover, Brazil appears as the only Latin American market transmitting volatility to US, in three out of five models. On the other hand, while Brazil transmits volatility to four countries, it receives volatility transmission from four of them. Furthermore, by comparing results of Table 2 and Table 3, we observe that including Brazil doesn´t weaken the volatility transmission from US to Latin America for the most part.

5.2 Evolution of volatility transmission between Latin American markets and US

We investigate the evolution of volatility transmission estimating bivariate MGARCH models for US-Mexico and US-Brazil for the four periods of the sample. Specification tests require a MGARCH-BEKK (2,2) for both pairs in the fourth period and for US-Brazil in the second period, but a MGARCH-BEKK(1,1) in all the five remaining cases. As before, we focus our analysis in the first lag effects. The results are presented in Table 4, where last column repeats the corresponding figures from Table 2. The results of the first period, March 1993 – June 1997, present no volatility transmission, significant at the 5% level, between US and the two Latin American Markets in either direction. This is consequent with a period of early integration of the Emerging Markets in the worldwide financial markets (Bekaert, Harvey and Lundblad, 2003).

On the contrary, the results for the second period, July 1997 October -2003 present volatility transmission between US and Brazil, but not between US and Mexico. Indeed, there is significant bidirectional volatility transmission both from the perturbation and in the volatility coefficient between US and Brazil in both directions. This result seems consistent with a period that includes worldwide financial crises originated not only in Emerging Markets including Brazil (1999) but also in US (Nasdaq crash, 2001). Chancharoenchai and Dibooglu (2006) similarly, report volatility transmission from six Southeast Asian emerging markets to both Japan and US in the midst of the 1997 Asian Crisis.

The third period, 2003-2007, is characterized by an important worldwide expansion of emerging stock markets, fueled by high commodities prices and a soaring demand by China, along with decreasing segmentation of emerging stock markets, including Latin America (Bekaert, Harvey, Lundblad and Siegel, 2011). Consistent with increasing financial integration, we find volatility transmission from US to both countries, significant at the 1% level. Moreover, both Mexico and Brazil appear to transmit perturbation effects to US volatility in that period, significant at the 5% level, but of lower magnitude that the reverse effect (15 times lower for Mexico, 6 times lower for Brazil).

Finally, in the fourth period 2007-2013, as discussed above, we find significant volatility transmission form US to both Latin American countries, and from Mexico to US, significant at the 5% level. This result might be explained by the negative shocks originated in US and Europe and transmitted worldwide, especially the US subprime crisis between 2007-2008.

Taken together, the evidence in Table 4 suggest that volatility transmission patterns between US and Latin American stock markets have changed over time reflecting the dynamic of financial integration and the origin of financial crises. On the other hand, the volatility transmission did not receded in the last period, contradicting the decoupling hypothesis (H3).

Volatility transmission from Brazil to US in the second and third periods still could be explained as originated in European markets, since in any given day they close before the American markets, and Brazil usually closes before USA. To test for this, as an additional robustness test we run a trivariate MGARCH-BEKK model with the daily stock returns of Brazil, US and the Eurozone, represented by the Eurostoxx 50 index. In unreported results we find that after including the Eurozone returns in the model, there is still strongly significant volatility transmission from

Brazil to US, along with some perturbation and volatility transmission from the Eurozone to the two American markets.

5.3 Evolution of conditional correlation between Latin American markets and US.

. Finally, we examine the evolution of the conditional correlation between Mexico and US and Brazil and US. As mentioned above, the estimation of bivariate MGARCH BEKK models for Mexico-US and Brazil-US at each of the four periods yields a conditional variance-covariance matrix, which in turn allows to estimate the conditional correlation between the returns of the markets at daily frequency[2]. Next, grouping the correlations in each of the four periods, we perform a non-parametric Mann-Whitney U test for the null hypothesis that the correlations for each pair of periods belong to the same distribution.

Table 5 presents the result of the Mann-Whitney U test for the correlation between Brazil and US daily returns, along with the respective median and average range in a joint distribution, whereas Table 6 do the same for the correlations between Mexico and US. In each of the six cases, the test renders a very low p value indicating a strong rejection of the null hypothesis that the correlation of the two periods comes from the same distribution. The average range and the median consistently indicate that later periods tend to have larger correlations. Thus, the results of both Tables indicate that the correlations between the two leading Latin American stock markets and US have increased over time. These results go against the decoupling hypothesis of the last period (H4) and support the results of Dooley and Hutchison(2009), Dimitriou et al (2013) and Bekiros (2014) obtained with different sample data.

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[2] Conditional correlation is estimated as: $\rho_{1,2,t}=\frac{E_{t-1}(r_{1,t}r_{2,t})}{\sqrt{E_{t-1}(r_{1,t}^2)E_{t-1}(r_{2,t}^2)}}$

In turn, Figures 2 and 3 present the time series plot of the conditional correlation between the two markets and US. In both cases, the correlation with US has clearly increased over time, particularly by the end of the first period (first half of 1997) and progressively over the third period (2003-2007). On the other hand, the daily conditional correlations are very volatile themselves, especially during crises, as in the second period with the emerging market crises and the Nasdaq meltdown, and in the fourth period, with the subprime and Euro Zone crises.

6. Conclusions

This study presents evidence of volatility transmission from the US stock markets to the six largest Latin American stock markets. This transmission originates mostly from perturbations of US market returns, and to a less extent from US volatility. Unexpectedly, we find evidence of volatility transmission from the two largest markets Mexico and Brazil to US, particularly from 1997 to 2007.

There is some evidence of the leadership role of Brazil on the region, since it transmits volatility to most of the other markets. Besides, there is also evidence of Brazil strongly transmitting volatility to US, in the second and third period, and weakly in the fourth period. This is consistent with the perceive role of Brazil as the main reference in the region for its sheer size[3] and large flows of foreign portfolio investment.

The results of the Brazil and Mexico volatility transmission with US along the four periods can be framed in the worldwide financial and economic context. From March 1993 to June 1997,

[3] Brazil is the fourth largest emerging market according to World Federation of exchanges (2010).

the relative isolation of Latin American markets, just after few years of their initial financial liberalization is consistent with both the reported absence of volatility transmission from or to US markets and the low correlation with US market returns. The period from July 1997 to October 2003, marked by several worldwide financial crises, explains both the significant bidirectional volatility transmission between Brazil and US and the increasing correlation of US returns with those of Brazil and Mexico. The third period, from November 2003 to May 2007, witnessed an important worldwide expansion and integration of stock markets, which corresponds with the reported volatility transmission from both Mexico and Brazil to and from US, and the still increasing correlation between US and the two Latin American markets. Finally, the fourth period, from June 2007 to March 2013, that includes different crises originated in US and the Euro Zone, sees volatility transmission mostly from US to Brazil and Mexico, and even higher correlations.

The results don´t provide support to the financial decoupling hypothesis, which poses that in recent times emerging markets have become less affected by events on developed markets. On the contrary, two set of results contradict this hypothesis. On one hand, each Latin American stock markets received volatility transmission from US in the fourth period. On the other hand, the correlation between Brazil and Mexico returns and US have significantly increased in the last period of the sample.

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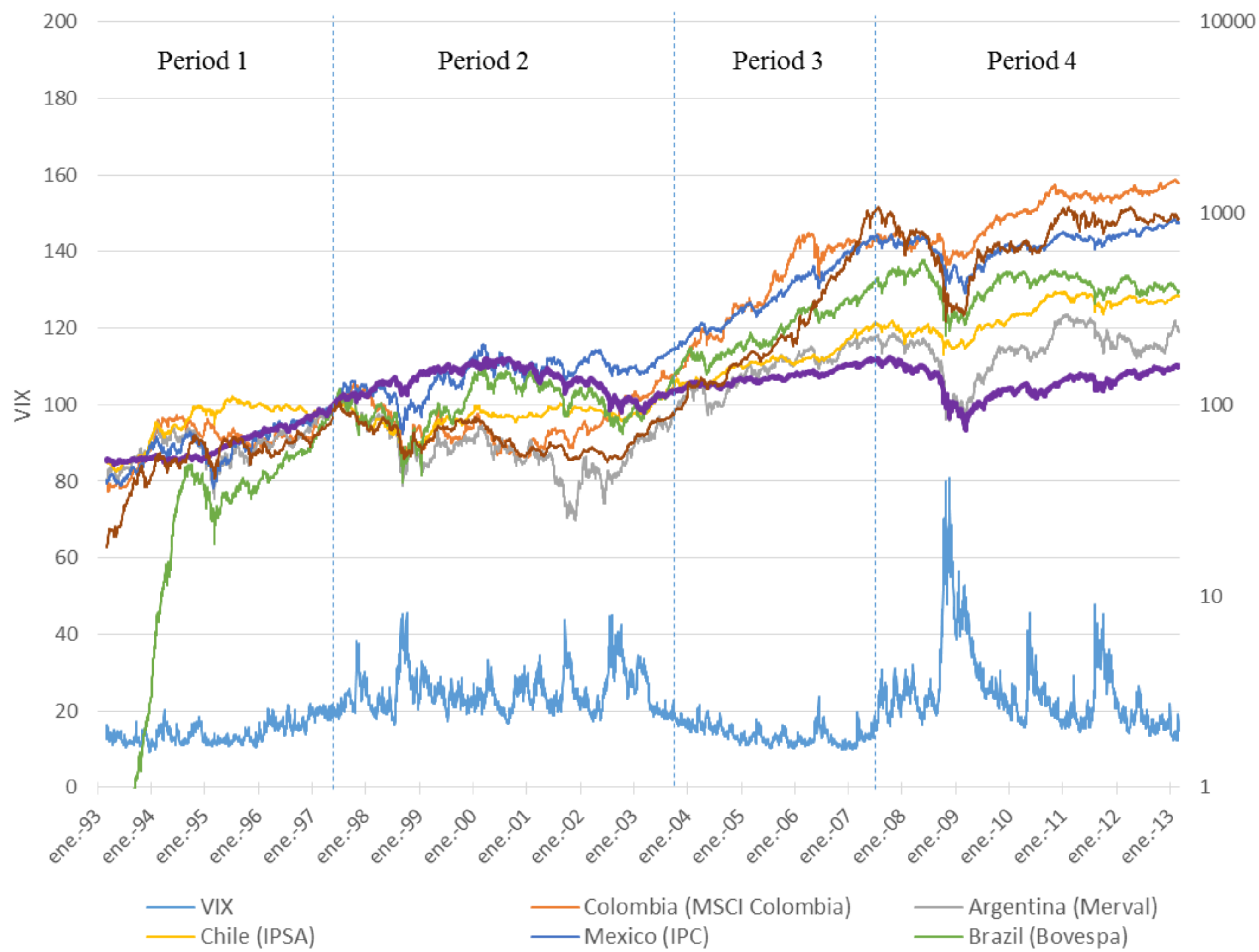
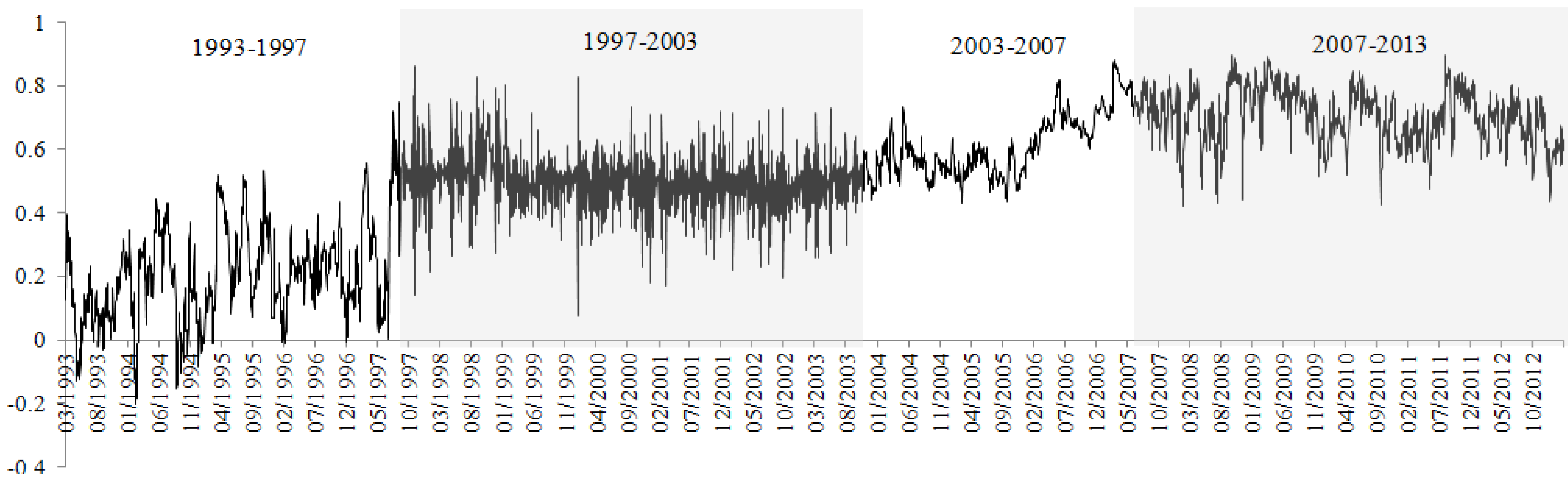
Figure 1 Evolution of Stock Market index for US and six Latin American Markets and the VIX stock returns, Mar 1993-Mar 2013.



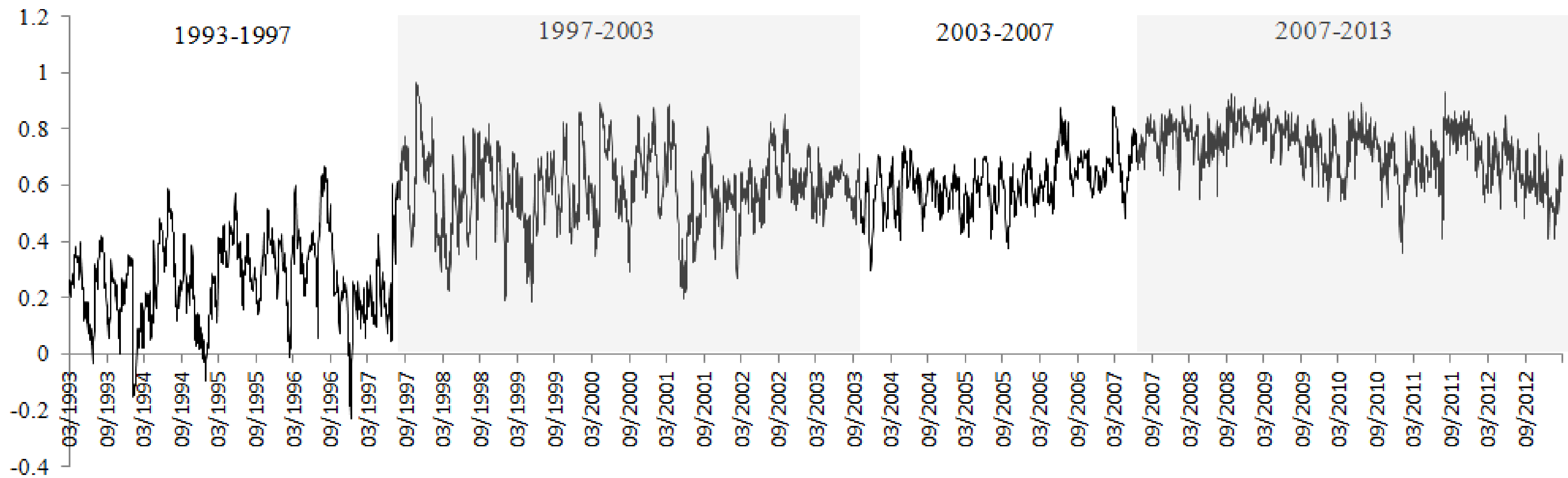
This figure plots the time series of the main stock market indexes for six Latin American countries and US (right axis) along with the VIX Index (left axis), from March 1993 to March 2013. Daily index values in local monetary units are taken from Bloomberg and normalized in 100 in 2-June 1997. Vertical dashed lines separate the four studied periods.

Figure 2. Conditional correlation between Brazil and US stock returns, Mar 1993-Mar 2013.



This figure plots the daily conditional correlations between Brazil (Bovespa) and US (SP500) returns for the four periods of the sample. The conditional correlations are based on estimated MGARCH-BEKK models of volatility transmission between US and Brazil. The MGARCH model is estimated by Maximum Likelihood on the residuals of a VAR model on daily returns of SP500 and Bovespa indexes, with a conditional variance $\Sigma_t = C'C + \sum_{i=1}^{m} A'_i \varepsilon_t \varepsilon'_t A_i + \sum_{j=1}^{s} B'_j \Sigma_{t-j} B_j$ with *m*=*s*=1 for periods 1 and 3, and *m*= *s*= 2 for periods 2 and 4.

Figure 3. Conditional correlation between Mexico and US stock returns, Mar 1993-Mar 2013.



This figure plots the daily conditional correlations between Mexico (IPC) and US (SP500) returns for the four periods of the sample. The conditional correlations are based on the estimated MGARCH-BEKK models of volatility transmission between US and Mexico. The MGARCH model is estimated by Maximum Likelihood on the residuals of a VAR model on daily returns of the SP500 and IPC indexes, with a conditional variance $\Sigma_t = C'C + \sum_{i=1}^{m} A'_i \varepsilon_t \varepsilon'_t A_i + \sum_{j=1}^{s} B'_j \Sigma_{t-j} B_j$ with and m=s=1 for the periods 1 to 3 and m= s= 2 for period 4.

Table 1. Annualized Volatility and Correlation with US for six Latin American Stock Markets.

	Period 1: Mar. 1993- Jun. 1997		Period 2: Jul. 1997-Oct. 2003		Period 3: Nov. 2003- May 2007		Period 4: Jun. 2007- Mar. 2013	
	Annualized Volatility	Correlation with US	Annualized Volatility	Correlation with US	Annualized Volatility	Correlation with US	Annualized Volatility	Correlation with US
Brazil	47.7%	0.166	41.1%	0.486	25.0%	0.597	30.8%	0.733
Mexico	25.3%	0.239	28.4%	0.593	18.2%	0.607	22.7%	0.765
US	10.2%		20.9%		10.3%	-	24.9%	-
Argentina							31.2%	0.636
Chile							15.1%	0.544
Colombia							19.6%	0.367
Peru							29.4%	0.473
No. observations		1,112		1,622		918		1,475

This table reports the annualized volatility and correlation with the SP500 returns of the returns of six Latin American Stock Markets in local monetary units. Daily logarithm returns are calculated from daily prices of the following indexes from Bloomberg: Merval Index (Argentina), Bovespa (Brazil), IGPA (Chile), (MSCI Colombia) Colombia, IPC (Mexico) and IGBVL (Peru).

Table 2. Volatility transmission in bivariate MGARCH models between Latin American stock market and US.

Period 4: June 2007- March 2013

Mexico - US	-	Chile - US	
Perturbation from Mexico to US	0,0048	Perturbation from Chile to US	0,0024
Perturbation from US to Mexico	0,0240*	Perturbation from US to Chile	0,0030**
Volatility from Mexico to US	0,0164***	Volatility from Chile to US	0,0012
Volatility from US to Mexico	0,0109**	Volatility from US to Chile	0,0007
Brazil - US		Peru - US	
Perturbation from Brazil to US	0,0036	Perturbation from Peru to US	0,0030***
Perturbation from US to Brazil	0,1186**	Perturbation from US to Peru	0,0832***
Volatility from Brazil to US	0,0015	Volatility from Peru to US	0,0004
Volatility from US to Brazil	0,0142	Volatility from US to Peru	0,0112
Argentina - US		Colombia - US	
Perturbation from Argentina to US	0,0008	Perturbation from Colombia to US	0,0011
Perturbation from US to Argentina	0,1612***	Perturbation from US to Colombia	0,0001
Volatility from Argentina to US	0,0022	Volatility from Colombia to US	0,0006
Volatility from US to Argentina	0,0015	Volatility from US to Colombia	0,0167*

This table reports the results of six bivariate MGARCH-BEKK models of volatility transmission between US and Latin American stock markets. The MGARCH model is estimated by Maximum Likelihood on the residuals of a VAR model on daily index returns of each of the six Latin American and US, with a conditional variance $\Sigma_t = C´C + \sum_{i=1}^{m} A´_i \varepsilon_t \varepsilon´_t A_i + \sum_{j=1}^{s} B´_j \Sigma_{t-j} B_j$ with *m*= *s*= 2 in each of the six models. Squared coefficients in matrices A_i and B_j are reported for the first-lag cross effects of perturbations and volatility from a stock market on another market´s volatility. *, **, ***: Statistical significant at the 10%, 5% and 1%, respectively, based on standard errors robust to heteroskedasticity.

Table 3. Volatility transmission in trivariate MGARCH models between Brazil, US and other Latin American stock market. Period 4: June 2007- March 2013

Colombia - Brazil -US	-	Argentina - Brazil -US	-	Mexico - Brazil -US	
Perturbation from Colombia to Brazil	0,0057	Perturbation from Argentina to Brazil	0,0191***	Perturbation from Mexico to Brazil	0,0015
Perturbation from Colombia to US	0,0009	Perturbation from Argentina to US	0,0008	Perturbation from Mexico to US	0,0000
Perturbation from Brazil to Colombia	0,0259	Perturbation from Brazil to Argentina	0,0011	Perturbation from Brazil to Mexico	0,0173***
Perturbation from Brazil to US	0,0000	Perturbation from Brazil to US	0,0020	Perturbation from Brazil to US	0,0137**
Perturbation from US to Colombia	0,0102	Perturbation from US to Argentina	0,1519***	Perturbation from US to Mexico	0,1002***
Perturbation from US to Brazil	0,0005	Perturbation from US to Brazil	0,1231**	Perturbation from US to Brazil	0,1763***
Volatility from Colombia to Brazil	0,0368***	Volatility from Argentina to Brazil	0,1662***	Volatility from Mexico to Brazil	0,1953***
Volatility from Colombia to US	0,0007	Volatility from Argentina to US	0,0001	Volatility from Mexico to US	0,0003
Volatility from Brazil to Colombia	0,0026**	Volatility from Brazil to Argentina	0,0259	Volatility from Brazil to Mexico	0,0008
Volatility from Brazil to US	0,0022	Volatility from Brazil to US	0,0290**	Volatility from Brazil to US	0,0000
Volatility from US to Colombia	0,0004	Volatility from US to Argentina	0,0560	Volatility from US to Mexico	0,0033
Volatility from US to Brazil	0,0190**	Volatility from US to Brazil	0,0707*	Volatility from US to Brazil	0,0389**
Chile - Brazil -US		Peru - Brazil -US			
Perturbation from Chile to Brazil	0,0005	Perturbation from Peru to Brazil	0,0022*		
Perturbation from Chile to US	0,0002	Perturbation from Peru to US	0,0008		
Perturbation from Brazil to Chile	0,0047*	Perturbation from Brazil to Peru	0,0107**		
Perturbation from Brazil to US	0,0106*	Perturbation from Brazil to US	0,0069*		
Perturbation from US to Chile	0,0075**	Perturbation from US to Peru	0,1236***		
Perturbation from US to Brazil	0,1089**	Perturbation from US to Brazil	0,0613**		
Volatility from Chile to Brazil	0,0998	Volatility from Peru to Brazil	0,0135**		
Volatility from Chile to US	0,0201	Volatility from Peru to US	0,0000		
Volatility from Brazil to Chile	0,0001	Volatility from Brazil to Peru	0,0553***		
Volatility from Brazil to US	0,0087*	Volatility from Brazil to US	0,0053		
Volatility from US to Chile	0,0092	Volatility from US to Peru	0,0051		
Volatility from US to Brazil	0,0277	Volatility from US to Brazil	0,0919**		

This table reports the results of five trivariate MGARCH-BEKK models of volatility transmission between US, Brazil and Latin American markets. The MGARCH model is estimated by Maximum Likelihood on the residuals of VAR models on daily index returns of US, Brazil and each of the other five Latin American countries, with a conditional variance $\Sigma_t = C\acute{}C + \sum_{i=1}^{m} A\acute{}_i \varepsilon_t \varepsilon\acute{}_t A_i + \sum_{j=1}^{s} B\acute{}_j \Sigma_{t-j} B_j$ with *m*= *s*= 2 in each of the five models. Squared coefficients in matrices A_i and B_j are reported for the first-lag cross effects of perturbations and volatility from a stock market on another market´s volatility. *, **, ***: Statistical significant at the 10%, 5% and 1%, respectively, based on standard errors robust to heteroskedasticity.

Table 4. Volatility transmission in bivariate MGARCH models between Brazil and Mexico with US.

	Period 1. Mar. 1993 - Jun. 1997	Period 2. Jul. 1997 -Oct. 2003	Period 3. Nov. 2003 - May 2007	Period 4. Jun. 2007 - Mar. 2013
Mexico - US				
Perturbation from Mexico to US	0,0000	0,0025	0,0083**	0,0048
Perturbation from US to Mexico	0,0007	0,0016	0,1260***	0,0240*
Volatility from Mexico to US	0,0000	0,0001	0,0010**	0,0164***
Volatility from US to Mexico	0,0000	0,0008	0,0057	0,0109**
Brazil - US				
Perturbation from Brazil to US	0,0000	0,0013***	0,0020***	0,0036
Perturbation from US to Brazil	0,0064	0,0785***	0,0122**	0,1186**
Volatility from Brazil to US	0,0000	0,0000***	0,0001***	0,0015
Volatility from US to Brazil	0,0000	0,0000***	0,0015***	0,0142

This table reports the results of ten bivariate MGARCH-BEKK models of volatility transmission between US and Mexico and Brazil. The MGARCH model is estimated by Maximum Likelihood on the residuals of VAR models on daily index returns of US and Brazil, and US and Mexico, with a conditional variance $\Sigma_t = C'C + \sum_{i=1}^{m} A'_i \varepsilon_t \varepsilon'_t A_i + \sum_{j=1}^{s} B'_j \Sigma_{t-j} B_j$ with *m*= *s*= 2 for the two models on Period 4 and the Brazilian model in Period 2, and *m*=*s*=1 in all the remaining models. Squared coefficients in matrices A_i and B_j are reported for the first-lag cross effects of perturbations and volatility from a stock market on another market´s volatility. *, **, ***: Statistical significant at the 10%, 5% and 1%, respectively, based on standard errors robust to heteroskedasticity.

Table 5. Mann-Whitney tests of conditional correlations between Brazil and US.

		Period 2. Jul. 1997 -Oct. 2003	Period 3. Nov. 2003 - May 2007	Period 4. Jun. 2007 - Mar. 2013
Period 1. Mar. 1993 - Jun. 1997	Medians	0.194-0.502	0.194-0.589	0.194-0.712
	p-value	0.0000	0.0000	0.0000
Period 2. Jul. 1997 -Oct. 2003	Medians		0.502-0.589	0.502-0.712
	p-value		0.0000	0.0000
Period 3. Nov. 2003 - May 2007	Medians			0.589-0.712
	p-value			0.0000

This table reports the results of Mann-Whitney tests comparing the average daily conditional correlations between Brazil and US returns for the four periods of the sample. The conditional correlations are based on the estimated MGARCH-BEKK models of volatility transmission between US and Brazil. The MGARCH model is estimated by Maximum Likelihood on the residuals of a VAR model on daily index returns of US and Brazil stock market returns, with a conditional variance $\Sigma_t = C'C + \sum_{i=1}^{m} A'_i \varepsilon_t \varepsilon'_t A_i + \sum_{j=1}^{s} B'_j \Sigma_{t-j} B_j$ with *m*=*s*=1 for periods 1 and 3, and *m*= *s*= 2 for the periods 2 and 4. For each pair of periods, the two medians of the conditional correlation are reported, first the median correlation of the period in the row. p-values of the Man Whitney tests on the null hypothesis of equal medians are reported.

Table 6. Mann-Whitney tests of conditional correlations between Mexico and US.

		Period 2. Jul. 1997 -Oct. 2003	Period 3. Nov. 2003 - May 2007	Period 4. Jun. 2007 - Mar. 2013
Period 1. Mar. 1993 - Jun. 1997	Medians	0.252-0.585	0.252-0.610	0.252-0.739
	p-value	0.0000	0.0000	0.0000
Period 2. Jul. 1997 -Oct. 2003	Medians		0.585-0.610	0.585-0.739
	p-value		0.0000	0.0000
Period 3. Nov. 2003 - May 2007	Medians			0.610-0.739
	p-value			0.0000

This table reports the results of Mann-Whitney tests comparing the average daily conditional correlations between Mexico and US returns for the four periods of the sample. The conditional correlations are based on the estimated MGARCH-BEKK models of volatility transmission between US and Mexico. The MGARCH model is estimated by Maximum Likelihood on the residuals of a VAR model on daily returns of US and Mexico stock market returns, with a conditional variance $\Sigma_t = C´C + \sum_{i=1}^{m} A´_i \varepsilon_t \varepsilon´_t A_i + \sum_{j=1}^{s} B´_j \Sigma_{t-j} B_j$ with m=s=1 for periods 1 to 3 and m= s= 2 for period 4. For each pair of periods, the two medians of the conditional correlation are reported, first the median correlation of the period in the row. p-values of the Man Whitney tests on the null hypothesis of equal medians are reported.