M.Sc. thesis

in financial economics

Volatility spillovers between stock markets and exchange rates

Evidence from North- and South America

Daníel Kristinsson

Advisor: Hossein Asgharian

School of Economics and Management

LUND UNIVERSITY
School of Economics and Management

October 2014

Volatility spillovers between stock markets and exchange rates

Evidence from North – and South America

Daníel Kristinsson

A thesis towards a M.Sc. degree in financial economics

Advisor: Hossein Asgharian

School of Economics and Management

Lund University

October 2014

Volatility spillovers between stock markets and exchange rates

This thesis is a 15 ETCS credit equivalent towards a M.Sc. degree from the School of Economics and Management in Lund University.

Lund, Sweden, 2014

Foreword

This is a 15 ECTS credit equivalent thesis towards a M.Sc. degree in financial economics from the School of Economics and Management in Lund University. The advisor of this thesis is Professor Hossein Asgharian. I would like to thank Mr. Asgharian for being readily available and for invaluable advice throughout writing of the thesis.

I would also like to thank Ásta Brá Hafsteinsdóttir for her moral support and helpful comments throughout the process of writing the thesis.

Abstract

The aim of this thesis is to look at volatility spillovers between the exchange rate changes and the stock market returns. The theoretical relationship between the exchange rate and stock market is covered with focus on two basic models, the stock oriented model and the flow oriented model. The relationship between the two variables is positive in the stock oriented model while it is negative in the flow oriented model. An empirical study is done on Brazil, Canada, Mexico and the United States from 1999-2014 using a GARCH-BEKK model. Three results from the model are obtained, the whole sample and before and after the financial crisis in 2008. According to the study there are significant spillovers between the exchange rate and stock market for some periods and countries but it is not consistent throughout. In general the spillovers are strongest after the crisis in 2008 for all countries. In the United States and Canada the spillovers are stronger from the stock market to the exchange rate while the spillover for Mexico and Brazil are stronger from the exchange rate to the stock market.

Keywords: GARCH-BEKK model, Volatility spillovers, Stock returns, Exchange rates, North American countries.

Table of contents

Table of figures

1 Introduction

At the end of World War II a deal was struck between the big economies of the world, fixing currency rates against the US dollar (which served as a backbone of the agreement). US officials in return guaranteed a fixed rate against the gold (35$/ounce). The agreement was called the Bretton-Woods system and it was a fixed exchange rate regime. At the end of the sixth decade cracks started to form in the Bretton-Woods system and the United States were forced to leave the gold leg. One by one countries left the fixed exchange rate regime and currencies were allowed to float freely. The floating currencies introduced greater uncertainty in international trade then before as the exchange rates varied from day to day.

With a floating currency, firms and other market participants are to a larger extent exposed to exchange rate risk as many firms are dependent on exports and imports. These firms represent a large part of stock markets in any given country. Stock markets can be thought of as a proxy for the state of the economy as stock prices generally reflect investor's future expectations of earnings, where earnings are usually low in downswings and higher in upswings.

The theoretical relationship between the stock market and the exchange rate is not conclusive among academics. Considering two basic models that try to explain the relationship, the "stock oriented" and the "flow oriented", a fundamental difference can be found. In "stock oriented" models the exchange rate is an intermediary in balancing the supply and demand of domestic and foreign assets in an internationally diversified portfolio. The stock market affects the wealth of market participants which can cause changes in the interest rate and shift demand for bonds, as market participants have a preference for domestic assets. In these models the exchange rate responds to changes in the stock market and the there is a positive relation between the stock market and the exchange rate (Branson, 1983 and Frankel, 1983).

In "flow oriented" models the exchange rate is the causation, affecting international competitiveness of firms and thereby affecting real income and output and eventually stock prices (Dornbusch and Fischer, 1980). Stock prices in general are believed to reflect the present value of future cash flow. In the “flow” models the relationship between the exchange rate and the stock market is negative.

Zapatero (1995) also showed that in fully integrated financial markets there is an explicit linkage between the volatility of stock prices and the volatility of exchange rate where the volatility of the exchange rate is affected by volatility of stock prices.

Empirical research results on volatility spillover between the stock market and exchange rate in the last couple of decades are not harmonious in terms of result. Some of them point to a unidirectional relationship from the exchange rate to the stock market (Federova and Saleem, 2010) while others indicate the opposite (Kanas, 2000). Some literature also suggest that the relationship is bidirectional, indicating that some truth may be found in both the “stock” and “flow” models in terms of the second moment (Morales, 2008).

The aim of the thesis is to establish whether there are significant volatility spillovers between the exchange rate and stock market. The result from the research may be of special interest to investors, pension funds and in general everyone who diversify their portfolio through international equity investments and large corporation that will need to manage their stock market risk and exchange rate exposure.

The volatility spillovers between the stock market and the exchange rate will be estimated empirically using a bivariate GARCH – BEKK model which incorporates a maximum likelihood function to estimate the coefficients of the model where The United States, Canada, Mexico and Brazil will be examined. The United States is chosen because of its size and importance in the world economy. The other three countries are chosen because of their close proximity and strong business relationship with the United States. The results from the model will be estimated and interpreted.

While there are plentiful of evidence on the first moment relationship between the stock market returns and the exchange rate there is limited body of work on the second moment (volatility) relationship of the two series. Previous studies on the subject have in general been limited in looking at a single exchange rate and one stock market while this research looks at four stock markets and additionally looks at the volatility spillover between the S&P 500 and three bilateral exchange rate giving a more robust results than comparing it only to one exchange rate.

2 Stock markets and exchange rates

Several theoretical models have been developed in the last decades trying to explain the interaction of the exchange rate and stock market. Two basic approaches that explain the relationship between stock prices and the exchange rates are "flow oriented" and "stock oriented" models.

The flow oriented model assume that the exchange rate is largely determined by the current account and trade balance performance, and through that effect competitiveness of the economy (Dornbusch and Fischer, 1980). The stock oriented model, assumes that the exchange rate responds to changes in the stock market (Branson, 1983, and Frankel 1983). Both model have certain features that are convenient for the purposes of this thesis and indicate different causation (between the markets) so they will both be introduced.

2.1 The stock oriented model

The model considers a small open economy where residents hold internationally diversified portfolio where the exchange rate works as an intermediary in balancing supply and demand of the domestic and foreign assets. It is assumed that domestic residents are the only one holding domestic bonds because foreign investors will not be interested in holding bonds in the small economy. Another assumption is that there are no international barriers segmenting domestic and foreign markets, but the foreign and domestic bonds are not perfect substitutes. There are numerous reasons why assets (domestic and foreign) are imperfect substitutes: liquidity, exchange rate risk, tax implications, political and default risk are all factors that affect the decision making of investors.

Under the assumption of perfect international markets the exchange rate risk will become the only risk of concern in the model. Foreign and domestic bonds will only differ in their currency denomination and investors will diversify their portfolios in foreign and domestic bonds to limit the exchange rate risk.

The initial equation of demand for each investor is given by:

$$\frac{B_j}{EF_j} = \beta_j(i - i^* - \delta\Delta e)$$

B_j are domestic and F_j are foreign held bonds by investor j and E is the exchange rate. β_j is a positive valued function which controls the assed demand function of investors (we assume that it is: exp[$\alpha_j + \beta_j(i - i^* - \delta\Delta e]$). The domestic interest rate is given by i, the foreign interest rate is i*and δΔe is the expected depreciation of the exchange rate. Investors will balance their portfolio between domestic and foreign assets depending on the expected relative rate of return. An increase in the domestic interest rate or a fall in the expected rate of depreciation induces investors to shift their portfolios to domestic bonds. (Investors can hold negative amount of B_j and F_j if they are debtors).

When the assumption is that all market participants have the same preferences it is possible to sum up all the individual demand functions into one aggregate demand function:

$$\frac{B}{EF} = \beta(i - i^* - \delta\Delta e)$$

$$B \equiv \sum_{j=1} B_j \text{ and } F \equiv \sum_{j=1} F_j$$

B and F are now net supplies of domestic and foreign bonds in the market.

The simplest version of this model assumes static expectation, $\delta\Delta e = 0$. When the expectations are static the exchange rate is given by (logarithmic form):

$$e = -\alpha + \beta(i - i^*) + b - f$$

The exchange rate is simply determined by relative bond supplies and interest rate differential.

The assumption of the small economy is not always realistic, especially when the two countries are big and it is safe to assume that investors will be interested in holding assets issued by both countries.

It is possible to divide the equation into two equations. The assumption of same preferences are relaxed and residents are now assumed to have preference for domestic bonds as they wish to hold a greater proportion of their own domestic bonds then foreign bonds, the same holds for foreign residents. This is quite logical as most individual have to do their daily business in their home currency. Individuals have their debts in the home currency so it reduces their exchange rate risk by having a larger sum of savings in the home currency. In general individuals are risk averse and investing in foreign bonds or stocks introduces greater uncertainty and requires greater expected rate of return than holding domestic.

Equation (*) are bonds owned by home residents and equation (**) are bonds owned by foreign residents:

$$\frac{B_H}{EF_H} = \beta_H(i - i^* - \delta\Delta e) \qquad (*)$$

$$\frac{B_F}{EF_F} = \beta_F(i - i^* - \delta\Delta e) \qquad (**)$$

The wealth of the domestic and foreign residents can be split up:

$$W_H \equiv B_H + EF_H \text{ and } W_F \equiv B_F + EF_F$$

B_H is the sum of all domestic bonds held by home residents and F_H is the sum of all foreign bonds held by home residents, and β_H is now the asset demand function for all home residents. The same argument holds for equation (**) for foreigners. As before it is possible to solve for the exchange rate, but it becomes a little more cumbersome now when both foreign and domestic individual hold both kind of bonds but the same logic as before still holds.

To sum up, it is the exchange rate that responds to changes in the demand for financial assets such as bond and stocks. A prosperous stock market will signal good domestic economic prospects, inducing capital inflows and an appreciation of the exchange rate. The total effect of an increase in stock prices can be summed up in couple of steps. Increase in the stock prices causes the wealth of domestic investors to soar and thereby increasing their demand for domestic assets. In order to buy the domestic asset they must sell of their foreign assets in order to obtain domestic currency needed in the transaction. The increased domestic asset price causes growth in wealth which in turn increases the demand for money, which causes interest rate to increases, which fuels capital inflows. That contributes to the increase in demand for domestic currency causing it to appreciate.

2.2 The flow oriented model

In the “flow oriented” model developed by Dornbusch and Fischer (1980) we have a small open economy that trades goods and securities with rest of the world. The demand for domestic products depends on the relative price (the terms of trade). The world price of imports is given in the terms of the foreign exchange. Domestic individuals can hold domestic money or foreign interest earning bonds but can't hold foreign money. The world interest rate is given.

The assumption of perfect international markets holds in the model and domestic and foreign bonds are perfect substitutes in the investment demand function. So there is effectively only one bond in the world. Domestic and foreign goods are as well perfect substitutes in the consumer demand function.

When the goods market clears, the current account will equal the excess of income over spending. In the model, absent of public sectors, taxes and investment, the surplus of income over spending is equal to savings. Saving is an increasing function of the labour income:

$$S = S(w)$$

The current account surplus is equal to the rate that the domestic economy acquires claims on the rest of the world:

$$\dot{a}/\, r^{*} = S(w)/\lambda$$

The r^* is the foreign interest rate, $\dot{a}$ is the income stream from external assets and λ is the terms of trade of the domestic economy relative to the foreign economy ($\lambda \equiv eP^{*}/P$).

The equilibrium of the purchasing power of individuals (real balances) is an increasing function of the value of external assets:

$$m = m(\lambda \mathrm{a})$$

Where an increase in the value of external assets raises real income, real money demand and via a decline in the price level, the equilibrium real money stock.

Before we turn our heads to the exchange rate determination, we look at how the terms of trade are determined. An increase in external assets raises wealth directly and via the change in the purchasing power. There is therefore an increased demand for domestic output. To get back to the equilibrium the terms of trade must improve (λ) (the relative value of imports must decline). The decline in the terms of trade falls relatively short of the increase in assets.

Now the focus is turned to the exchange rate movements in the adjustment process, and particularly to the relationship between the exchange rate and the current account. The exchange rate is determined alongside the general equilibrium in the goods and asset markets. The analysis starts by looking at the terms of trade:

$$e = \lambda \mathrm{P}/P^{*} \equiv [\lambda/(\mathrm{M}/\mathrm{P})]\ [\mathrm{M}/P^{*}]$$

λ is only determined by *a* and the equilibrium M/P is a function of *a* and λ. Since λ is a function of *a*, M/P is effectively just a function of only *a*. It is therefore possible to write the equilibrium exchange rate as a function of *a*:

$$e = \frac{\lambda(\mathrm{a})}{\frac{M}{P(\lambda, \mathrm{a})}} \left(\frac{M}{P^{*}}\right) = J(a)\left(\frac{M}{P^{*}}\right)$$

By expanding this equation around the long run equilibrium gives the following equation:

$$e = \bar{e} + \gamma(a - \bar{a});\ \gamma \equiv J_{a}\left(\frac{M}{P^{*}}\right) < 0$$

The bar denotes long-run equilibrium values. The equilibrium exchange rate is therefore equal to the long run exchange rate, but in the short run deviation of the external assets from their steady state level causes the exchange rate as well to deviate from the the long run equilibrium.

When the external assets are below the steady state level $\bar{a}$ the exchange rate is also above its steady state level, $\bar{e}$. Assets are accumulated while *a* moves up to $\bar{a}$, and at the same time as e appreciates to $\bar{e}$. Because the asset accumulation takes place through a

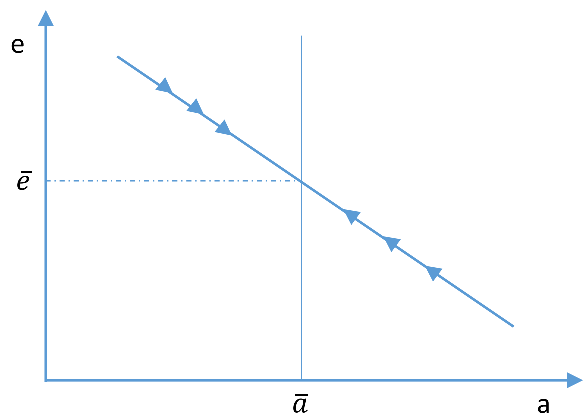


Figure 1: Adjustment process of the exchange rate (Dornbusch and Fischer, 1980)

current account surplus, the current account surplus is accompanied by an appreciating exchange rate in the adjustment process. This points to the relation between the exchange rate and the current account.

In short the model, opposite of the stock oriented approach, assumes that causality runs from the exchange rate to the stock market. A depreciation in the exchange rate will increase a country's competiveness and stimulate the economy through increased profitability and stock market prices. However domestic firms that rely on imported inputs to produce their goods will have to face increased costs, and subsequently decrease in sales and profits. That will cause their stock prices to decrease. So the overall effect is ambiguous but in general it is believed that the increased competiveness will dominate so the overall relationship is negative (depreciation – higher stock prices and appreciation – lower stock prices).

3 Previous empirical research

There have been numerous empirical studies in the last few years that focus on the volatility spillovers between the stock market and the exchange rate. Based on the results of earlier studies on this topic there seems to be a significant relationship between the two markets, exchange rate and stock market. However the direction and the significance of these effects differ between countries and exchange rates and it seems that the volatility relationship is not universal and depends largely on the market and time period at hand.

There are three main results from empirical research on the volatility spillovers: A unidirectional spillover from the exchange rate to the stock market, a unidirectional spillover from the stock market to the exchange rate and finally a bidirectional relationship where both markets effect each other with different degree.

3.1 Spillovers from the exchange rate to the stock market

The "flow oriented" model supports the theory of exchange rate affecting the stock market prices, and the relationship is considered to be negative (appreciation in the exchange rate decreases stock market prices). The model doesn't explicitly explain how the effects of the second moments are. A couple of studies have supported that the model also holds in the second moment, with exchange rate volatility spilling over to the stock market.

Dark and Raghavan (2008) look at the return and volatility spillover between the stock market in Australia (AOI) and the USD/AUD by using vector autoregressive GARCH BEKK. There is a uni-directional spillover effects from the exchange rate return and volatility to the stock market while there is no significant relationship from the stock market to the exchange rate. Implying that agents exposed to the AOI need to carefully follow the impact of the USD/AUD on their assets.

In a paper by Federova and Saleem (2010) a GARCH-BEKK is utilized to determine volatility spillovers between the stock market and the exchange rate for four countries in Eastern Europe. In three of four countries there is a unidirectional relationship from the exchange rate to the stock market. The results imply that the currency risk is a key feature and very important in these countries. A possible explanation, besides the flow oriented model, is that these countries depend heavily on the export market and increased currency risk can lead to unfavourable effects on exporters which affects the stock market. The absence of volatility spillovers from the stock market to the exchange rate point to the fact that the stock markets are not fully developed and don't hold the same importance in these countries as the stock markets in advanced economies.

3.2 Spillovers from the stock market to the exchange rate

As mentioned earlier the "stock oriented" model argues that the exchange rate responds to changes in stock markets and the relationship is positive. When stock market prices increases the exchange rate appreciates. The validation of this model also holding in the second model has had some support from previous studies.

Agrawal, Srivastav and Srivastava (2010) examined the relationship in the Indian market between the Nifty (Indian stock market) and Rupee-US dollar exchange rate. Agrawal *et al.* used a correlation test and employed a Granger causality procedure to examine the relationship and find a unidirectional relationship from the stock market to the exchange rate. An increase in the returns of Nifty caused a decline in the exchange rate (appreciation of the Rupee) but changes in the exchange rate did not have any effect on the returns on the stock market.

Kanas (2000) used a bivariate EGARCH model to look at the interdependence between stock markets and exchange rates for six advanced economies. He finds that at the 5% level, volatility spillovers from the stock market to the exchange rate changes are significant for all but one country. The spillover effects are all positive implying that increased volatility on the stock market increases volatility in the exchange rate market. The volatility spillovers are symmetric in all cases. The results support Zapareto (1995) results that for fully integrated financial markets, volatility spills from the stock market to the exchange rate.

The lack of spillover from the exchange rate can partly be explained by the fact that positive exchange rate volatility effects on returns is offset by negative effects for others (Jorion, 1990). The effects can as well be dampened even more by the use of exchange rate hedges (futures, forwards, etc.) (Bodnar and Gentry, 1993).

3.3 Bidirectional spillovers

Qayyum and Kemal (2006) looked at the relationship between the stock market and exchange rate for Pakistan. They examined the volatility spillover using a bivariate EGARCH and find that returns on stock market are sensitive to the returns and volatility of the exchange rate. The exchange rate is also affected by the volatility of the stock market and there is a strong correlation between the volatility of the exchange rate market and the volatility in the stock market.

Morales (2008) looked at six Latin American countries and one European country using EGARCH to estimate how the stock market and the exchange rate effect each other. The research looks at the bilateral exchange rate between all the countries in the paper. Morales divides the main sample of 1998-2006 into three samples. There are significant spillover effects from the stock market volatility to the exchange rate in all subsamples for three countries while there is some inconsistency for the other three. The spillover effects are significant in some periods while insignificant in others. The spillover from the exchange rate to the stock market are not as strong and in general the spillover from the stock market to the exchange rate are more prevalent then the spillover from the exchange rates to the stock market. As mentioned before the positive exchange rate volatility on stock returns is offset by some firms' negative exchange rate volatility concluding in overall weak or insignificant overall effect. There are still some instances where the effects are bidirectional and can be taken as evidence of a high degree of integration between the money and stock market. According to his result the degree of integration seems to be currency specific rather than a feature of financial markets in these countries.

4 Methodology

There are problems that arise when dealing with financial series like stock market returns and exchange rate returns. Usually these series do not have a constant mean, and most exhibit phases of relative tranquillity followed by periods of high volatility. Additionally there are some key features that apply for returns of the stock market (and changes in the exchange rate). It is important to understand that these stylized facts are present when dealing with returns and adjust the working model accordingly.

Another problem comes up when estimating volatility spillovers between two series, but the assumption of a constant return covariance matrix between two assets is unrealistic. Estimating two univariate GARCH models and examining the correlation between the two series is not sufficient. Volatilities of asset returns vary over time and so does the correlation of the asset. The GARCH-BEKK model takes this into account and is therefore introduced that takes this into consideration.

4.1 ARCH

There is a known phenomenon which occurs in financial data which is called volatility clustering. In fact volatility of financial series display a positive autocorrelation in certain periods, where the high volatility is clustered together in some periods and low volatility is clustered together in other periods.

Squared returns (one estimate of volatility) display significant positive autocorrelation or persistence. The clustering happens when the variance of the series is not the same over a certain period, so volatility clustering is one kind of heteroskedasticity. How persistent a series is depends on how many lags of a series are significant, the more lags the more persistent the series is. There is no correlation in returns themselves but it exists in the volatility of returns (Cont, 2001).

In conventional econometrics, the variance of the disturbance term is assumed to be constant. However many economic series do not have a constant variance and many series may experience periods of high volatility (variance) and other periods of low volatility. These characteristic are illustrative for stock markets and exchange rates. To capture these effects conditional heteroskedastic models have been widely recognised as a good estimator.

The most popular conditional heteroskedastic model is the ARCH model (autoregressive conditional heteroskedastic) which was developed by Engle (1982). The model simultaneously estimates the mean and the variance equation of a series. As the name of the model indicates it assumes heteroskedasticity of the residual and takes it into account. The autoregressive part comes from the fact that it uses realized values of old residuals, which are obtained from the mean equation.

$$\boldsymbol{r_t = \varepsilon_t}$$

$$\varepsilon_t \sim N(0, \sigma_t^2)$$

$$\sigma_t^2 = c$$

This is a simple model where the returns are explained by the residual ε_t which represents shocks that affect returns. The residual is normally distributed with a zero mean and a fixed variance and can easily be estimated by OLS. However if the returns are autocorrelated the OLS fails and the model has to be modified to accommodate this.

When ARCH effects are present the variance will no longer be time independent and the ARCH model that deals with the heteroskedastic variance is:

$$\boldsymbol{r_t = \varepsilon_t}$$

$$\varepsilon_t |\, I_{t-1} \sim N(0, \sigma_t^2)$$

$$\sigma_t^2 = \left(\alpha_0 + \sum_{i=1}^{q} \alpha_i \, \varepsilon_{t-i}^2 \right)$$

The residual is conditionally heteroskedastic and depends on all information available a time t-1, I_{t-1}. The residual can now be divided into two parts.

$$\boldsymbol{\varepsilon_t = v_t \sigma_t}$$

v_t is a white noise process, assumed to be normally distributed with mean 0 and variance 1, $v_t \sim N(0,1)$, and is independent of σ_t. σ_t is a non-negative stochastic process. The variance of ε_t is no longer a constant and depends on the lagged values of the residual, where α_0>0 and α_i≥1 (necessary to restrict the variance to be positive). The main advantage of using ARCH is that the conditional forecasts are vastly superior to unconditional forecasts because they incorporate all information available. For an ARCH(1) model the unconditional forecast for the mean and variance will be:

$$E(\varepsilon_t) = 0$$

$$\boldsymbol{E(\varepsilon_t^2) = \frac{\alpha_0}{1-\alpha_1}}$$

The conditional forecast for the same coefficients will be:

$$E\{\varepsilon_t | I_{t-1}\} = 0$$

$$\boldsymbol{E\{\varepsilon_t^2 | I_{t-1}\} = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2}$$

The conditional mean is still zero because of the white noise process but the conditional variance is different and is dependent on the realized value of ε_{t-1}^2 while the unconditional variance only looks at the estimated values of α_0 and α_1. If the realized value of ε_{t-1}^2 is large so will ε_t^2. It is a desirable feature for financial series since most of them display evidence of volatility clustering and the ARCH process takes it into account.

4.2 GARCH

Bollerslev (1986) extended Engle's original work by allowing the conditional variance to be an ARMA process. The model is called a generalized ARCH(p,q), or GARCH.

The GARCH can be presented as:

$$\boldsymbol{h_t = \omega + \alpha_1 e_{t-1}^2 + \beta_1 h_{t-1}} \qquad \textbf{(*)}$$

Where $\omega = (\alpha_0 - \beta_1 \alpha_0)$. Equation (*) is a GARCH(1,1) which is by far the most common and popular representation of GARCH. The GARCH(p,q) can be written formally like:

$$\boldsymbol{h_t = \alpha_0 + \sum_{i=1}^{q} \alpha_i \, \varepsilon_{t-i}^2 + \sum_{i=1}^{p} \beta_i \, h_{t-i}}$$

The ARCH logic still holds but the conditional variance in GARCH allows for both autoregressive and moving average components in the conditional variance process where lagged values of the conditional variance effect the conditional variance today. An advantage of the GARCH over ARCH is that a high-order ARCH model may have a more parsimonious GARCH representation which is easier to identify and estimate. All coefficients in the ARCH or GARCH must be positive to ensure a positive variance and to make sure that the variance is finite and all characteristic roots must be inside the unit circle. A model with fewer parameters has fewer coefficient restrictions.

4.3 The GARCH-BEKK

Baba, Engle, Kraft and Kroner (1990) introduced a multivariate GARCH model, GARCH-BEKK, to examine volatility spillovers between assets. The GARCH-BEKK will be used to estimate the spillover relationship between the stock market and exchange rate in this thesis. GARCH-BEKK doesn't only investigate what effects the lagged values of the residual and the conditional variance have on its own conditional variance but also the effect that the other series residuals and conditional variance have (the spillover effect). The GARCH-BEKK incorporates the GARCH model and adds some features to allow for cross-sectional effects.

The model for the conditional variance - covariance matrix can be stated as (in matrix form):

$$\boldsymbol{H_t = C'C + A'\, u_{t-1}u'_{t-1}A + G'H_{t-1}G}$$

H_t is a nxn variance-covariance matrix. A and G are unrestricted nxn matrices and C is an upper triangular nxn matrix. The diagonal parameters in G and A focus on traditional aspects of the GARCH model, the effect of own past shocks and conditional volatilities. The off diagonal elements of the matrices however measure the cross market effects of shocks and the volatility spillover among the two markets.

Positivity of H_t is satisfied without restriction but to prevent observationally equivalent structures Engle and Kroner suggest a restriction which ensures positivity of a_{11}, a_{22}, $g_{11}$and g_{22} and the diagonal elements of C. Since our study looks at the relationship between the exchange rate and the stock market (a bivariate case) the matrices are $2x2$. The $2x2$ model of the GARCH BEKK is:

$$H_t = \begin{bmatrix} c_{11} & 0 \\ c_{21} & c_{22} \end{bmatrix}' \begin{bmatrix} c_{11} & 0 \\ c_{21} & c_{22} \end{bmatrix}$$

$$+ \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}' \begin{bmatrix} \varepsilon_{1,t-1}^2 & \varepsilon_{1,t-1}\varepsilon_{2,t-1} \\ \varepsilon_{1,t-1}\varepsilon_{2,t-1} & \varepsilon_{2,t-1}^2 \end{bmatrix} \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}$$

$$+ \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix}' \begin{bmatrix} h_{11,t-1} & h_{12,t-1} \\ h_{21,t-1} & h_{22,t-1} \end{bmatrix} \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix}$$

The BEKK-model is estimated using the maximum likelihood (ML) optimizing numerically the Gaussian log-likelihood function like the univariate case. In the equation below f denotes the multivariate normal density, the contribution of a single observation l_t to the log-likelihood of a sample is given as:

$$l_t = ln\{f(\varepsilon_t | f_{t-1})\}$$
$$= -\frac{N}{2}\ln(2\pi) - \frac{1}{2}\ln(|\textstyle\sum_t|) - \frac{1}{2}\varepsilon_t' \textstyle\sum_t^{-1} \varepsilon_t$$

Maximizing the log-likelihood, requires nonlinear maximization methods. Involving only first order derivatives the algorithm introduced by Berndt *et al* (1974) is easily implemented and particularly useful for the estimation of multivariate GARCH processes.

5 Data

Daily data is observed from a fifteen year period 01/03/1999 to 28/2/2014 from stock indices in Mexico (BMV), Canada (TMX), Brazil (BM&F) and the United States (S&P 500)[1]. The daily exchange rates for the Mexican peso (MXN), Canadian dollar (CAD), and the Brazilian real (BRL) against the US dollar (USD) are also observed. All data is taken from DataStream.

The intuition behind selecting the United States as a subject of this research is that it has the biggest economy and stock markets in the world. As well, they have one of the most developed market with derivatives and are one of few countries with an active market on volatilities. Mexico, Canada and Brazil are chosen because of their close proximity and strong relationship with the United States. All three markets are very important export markets for manufacturers in the United States and it is of much importance for US firms to closely follow the movements in those countries.[2]

The reasoning in using the USD as a benchmark currency for the other three countries is that they all have strong financial relationship with the United States. United States is Mexico's and Canada's largest trading partner and Brazil's second largest trading partner. The USD has also served as a benchmark in other similar studies and is therefore implemented (Dark & Raghavan (2008), Qayyum and Kemal (2006)).

There are limitations to the approach of measuring the volatility of the home currency to one specific foreign currency. Changes in the United States and in the USD that have no relation to the markets that are subject of the research will affect the empirical results. Including more currencies would give a more comprehensive result, especially since the results from other studies have shown that results can vary depending on what exchange rate is used. All countries have other important trading and financial partners but those relationship will not be examined further in this study. The research on the United States will be more extensive as it will be compared to the three currencies, giving a more robust result.

[1] Bolsa Mexicana de Valores, Toronto Stock Exchange, Standard & Poor´s 500 and Bolsa de Valores, Mercadorias & Futuros de Sao Paulo.

[2] Mexico (3rd largest partner), Canada (largest partner), Brazil (9th largest partner) (USTR, 2014).

Three results (nine for the US) are obtained for every country, the whole sample and two subsamples, before and after the financial downturn in September 2008. The reasoning is that the unusual financial situation that came up in 2008 might distort the results from empirical stand point. Also the results can be used to find out whether there have been any changes in spillovers over time or if the results are consistent over time.

5.1 Stock market and exchange rates from 1999-2014

Below are figures of the daily close price on stock markets and exchange rates. There are also figures of the daily squared returns on the stock markets and the squared exchange

Figure 2: Daily close price on stock markets and exchange rates

rate changes for Mexico and Canada to give an approximation of the daily volatility (the figures for the United States and Brazil are in Appendix 1).

The years from 1999 to 2003 were marked by turbulence and relatively high volatility. The driving force behind the high volatility, and rise and fall of the stock market indices was similar for Canada and the United States where the “dot-com” bubble began and ended with increased uncertainty and volatility on the markets. Unstable government situation and lack of trust from investors were bigger reasons for the turbulence in Mexico and Brazil which mostly didn’t take part in the “dot-com” bubble. Additionally the large depreciation of the BRL against the USD was a consequence of the BRL floating freely after some years of tightly controlled exchange rate by the central bank. Political turmoil in those years also contributed to the downfall of the BRL and that spiral didn’t end until a new political party took over which was perceived as more business friendly.

In general the period from early 2003 and up until the financial crisis was characterized by low volatility on the financial markets. The stock markets in all four countries gained a lot of steam and grew substantially in value. The stock indices in Mexico and Brazil grew about 600% and 400% in value respectively and in the United States and Canada they grew about 75% and 240%.

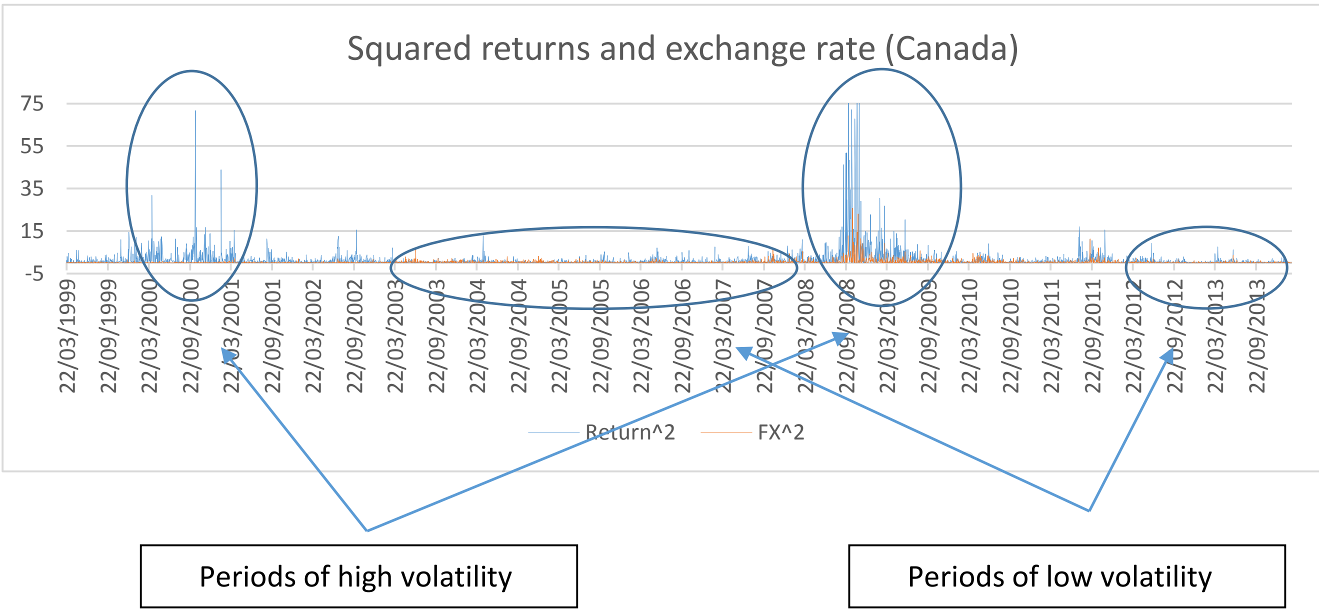


Figure 3: Squared returns in Canada

The effect of the financial collapse in late 2008 had a very strong effect on the volatility in all four stock markets and exchange rates. At the time of the crisis the volatility went to unprecedented levels were uncertainty was very high in financial sectors around the world. The volatility of the exchange rates increased substantially as well, all three currencies depreciated substantially against the USD with investors looking for the security of the biggest economy in the world.

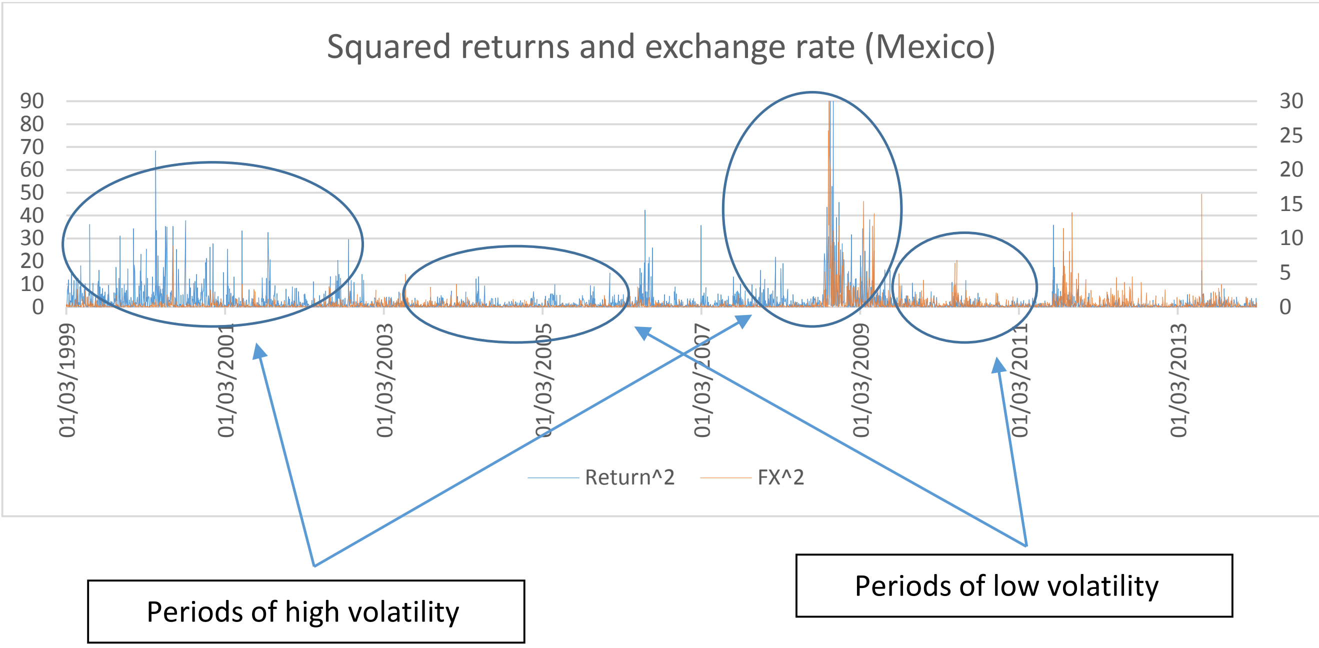


Figure 4: Squared returns in Mexico

5.2 Descriptive statistics and tests

Utilizing the graphs and stylized facts of financial data there is a reason to believe that the series contain a unit root. To test for a unit root an Augmented Dickey Fuller test is implemented.

There are insufficient evidence to reject a unit root for the majority of the series. For the sample from 2009-2014 the close price in Canada, Mexico and Brazil and the exchange rates CAD/USD and PES/USD a unit root can be rejected. The statistics can be seen in the appendix. Even though the unit root is rejected for some of the series all the data is converted and the logarithmic difference of these series are used which gives us the formula for the returns:

$$r_t = 100\, x \ln\left(\frac{p_t}{p_{t-1}}\right)$$

The return series are continuously compounded daily returns as percentage points. Again ADF is used to test for a unit root and now the null hypothesis of unit root is rejected for all series, so the daily returns are stationary.

The series are tested for normality using a Jarque-Bera test and the null hypothesis of normal distribution is rejected soundly for the stock market and the exchange rate in all countries. All series are leptokurtic, meaning that the series have higher distribution around the mean relative to the normal distribution.

The skewness of Brazil's and Mexico's stock market is very close to zero, negative for Canada and the United States. Negatively skewed distribution implies more probability of getting extreme negative returns then positive.

The exchange rate is skewed to the right for Mexico while it is skewed to the left in Brazil and marginally in Canada. This implies that is more common to get positive shocks on the Mexican market (depreciation of the PES relative to USD) and negative shocks on the Brazilian and (marginally Canada) market (appreciation of the BRF and CAD relative to the USD)

The standard deviation is a simple estimate of volatility. The standard deviation in the stock markets is greatest in Brazil and Mexico, Canada and the US have lower standard deviation implying that there is more uncertainty in the returns on the Brazilian and Mexico markets. The exchange rate standard deviation is greatest in Brazil but the other two exchange rates all have lower standard deviation. The table of the descriptive statistics can be found in Appendix 1.

6 Empirical results

The empirical research looks at the volatility spillover between the stock market returns and the foreign exchange rate changes. The volatility spillover is estimated with a bivariate GARCH-BEKK model. It is a two-step procedure where the initial values are obtained from the univariate GARCH series and then maximum likelihood is used to obtain the values in GARCH-BEKK. There is evidence suggesting that an asymmetric term would improve the research but for simplicity no asymmetric term is included. The results from the GARCH-BEKK model are in the appendix.

It is important to note that the model does not look at intraday volatility spillover but looks at the effect of lagged values (one day in this case) on the conditional variance of the series. With the coefficients in hand it is possible to calculate forecasts for the next day/days with similar methods as in ARCH and GARCH.

The coefficients g_{ii} and a_{ii} represent the GARCH and ARCH effect of each series. The conditional variance, g_{ii}, is an estimation of the persistence in the series. A high value of the conditional variance compared to the effect of the squared residual indicates that volatility clustering is present in the series. Both the GARCH and ARCH effect are highly significant in all series and all samples. The conditional variance in all countries, both stock market and exchange rate, is substantially higher than the effect of the squared residual implying that volatility clustering is present in all series.

6.1 Spillovers from the exchange rate to the stock market

The coefficient of interest in this section are g_{21} and a_{21}. Where the g_{21} is the conditional persistence from the exchange rate to the stock market and a_{21} is the effect that shocks in the exchange rate have on the the stock market.

In Canada the volatility spillovers from the exchange rate to the stock market are insignificant or marginal for the whole sample and both subsamples. This is consistent with results of other studies on Canada. Kanas (2000) and Yang & Doong (2004) both find no evidence of volatility spillover from the exchange rate to the stock market in Canada.

The general result for the US is that there is small or no volatility spillover from the exchange rates to the S&P 500. The only significant spillover effects for the S&P 500 is from the USD/CAD exchange rate (after 2008), where the cross market shocks are significant as well as the cross market persistence (only at the 10% level). Arguably their close proximity is important and the fact that Canada is by far United States' largest business partner. These effect are only marginal and the reason for the small volatility spillovers despite their important relationship can be that negative exchange rate volatility effects on some firms may be offset by other firms' positive effects (Bodnar and Gentry, 1993). The firms in the US are well protected by set of hedges against changes in the currency rate which reduces the effects from the exchange rate to the stock market. (Jorion, 1990)

For the whole sample the spillovers from the exchange rate are significant in Mexico, the shock spillover is rather large, about one tenth of the own shock effect, and there is also conditional spillover between the two series. In the two subsamples cross-market persistence is not significant while the cross-market shock spillover is large, about half of the own shock effect. This means that unexpected news on the exchange rate will have large effect on the volatility of the stock market. 80% of Mexico's exports goes to the US and undoubtedly play a part in the large spillover effects from the exchange rate to the stock market (represents 25,6% of Mexico's GDP) (worldbank.org).

Any uncertainty or turbulence in the exchange rate will therefore have large effect on exporting firms in the Mexican stock market as well as the importing firms, 47% of Mexico's imports come from the US. There are also distinctive differences between the two countries that might make the stock market more sensitive to increased risk in the exchange rate than Canada. The United States is a western country and an advanced economy while Mexico is still an emerging market which has a lot of confidence issues that make it more vulnerable to shocks.

In Brazil shocks in the exchange rate have substantial effects on the stock market volatility in the whole sample. It is approximately one fifth of the effects of the effects of the stock market residual. The conditional persistence between the exchange rate and the stock market is insignificant. The two subsamples are not consistent, while spillovers are insignificant in the former subsample the spillovers from the cross-market shocks are highly significant in the later subsample having approximately the same effect on the conditional volatility as the stock market itself. The cross market volatility persistence is also significant according to the 10% confidence level in the later subsample.

The reasons for the spillovers are likely to be similar with Mexico. Brazil is dependent on its exports and a large chunk of their exports go to the United States (about 10%) (worldbank.org).

Any volatility that occurs in the exchange rate will effect forward looking firms and investor that might see increased volatility in the exchange rate as a sign of uncertainty in other sectors exposing them both to exchange rate risk and increased risk at the stock market.

6.2 Spillovers from the stock market to the exchange rate

The coefficient of interest in this section are g_{12} and a_{12}. Where the g_{12} is the conditional persistence from the exchange rate to the stock market and a_{12} is the effect that shocks in the stock market have on the exchange rate.

In Brazil the cross-sectional coefficients are significant in the whole sample. Effects of an increase in the stock market volatility spills over to the exchange rate, but at a very low rate. The conditional persistence from the stock market has substantially larger effect and has about 4x higher coefficient. It implies that there is some persistence from the stock market to the exchange rate and the effect lingers on from some time. In the former subsample the volatility spillovers from the stock market are insignificant while they are highly significant in the later subsample. Where both the conditional and shock coefficient are significant and generally rather large relative to the own effects.

The stock market in Brazil has wide variety of companies and contains most of the biggest firms in Brazil. When the volatility increases on the stock market because of internal reasons, good news, bad news, loss of profits etc., it is natural that the volatility spills over to the exchange rate as the effect of the shock or news is uncertain and it induces increased uncertainty and risk in other sectors of the economy. Brazil has also been a subject to a serious lack of trusts from investors which has led to "confidence crisis" in the past. When stock volatility increases investors become nervous as they are often faced with asymmetry of information in the stock market. That causes them to pull out of their investment in the country as soon as possible and thereby increasing the volatility of the exchange rate (Masson, 1999).

The stock market's volatility spillover in Mexico are insignificant or marginal for the whole period and earlier subsample. The shock effect is insignificant and the conditional persistence is only marginal, having very little effect on the conditional variance of the exchange rate. But the spillovers become highly significant in the later subsample and seem to be very important in the composition of the exchange rates volatility.

In the United States the stock market volatility spills over to the exchange rates BRL/USD and PES/USD in the whole sample. The effects are significant at the 1% level but still very small relative to the own effect of the exchange rates. The effects are insignificant in the CAD/USD. In the former subsample the results are about the same, insignificant in Canada but significant and small for the other two exchange rates (marginally significant in Mexico). In the later subsample the result are again the same for the Mexican and Brazilian exchange rate, significant but relatively small. The major change comes in the CAD/USD exchange rate. Both coefficients are now significant and the stock market volatility spills over to the exchange rate. As for the Mexico and Brazil the effects are not large but do certainly have some effects.

A similar trend is observed for the spillovers in Canada. In the whole sample and the former subsample the spillovers are insignificant and do not seem to have any effect. After the crisis there are substantial and significant spillovers from the stock market to the exchange rate. They are relatively not as great as in Mexico and Canada but do exist never the less. The economic similarities and their share interests with the United States may also be part of the reason that the spillovers aren't as significant as the other countries as they are subject to many of the same external and internal (sometimes) effects. Masson (1999) named these effect Monsoonal effects where countries with similar economic structure respond similarly to external shocks which may be the case for Canada and the United States.

6.3 Summary

To conclude there are some commonalities in the results. The stock market volatility spills over to the exchange rate volatility for all countries in the sample from 2009-2014. For other samples the spillovers from the stock market to the exchange rate are in general small or insignificant.

The volatility spillovers from the exchange rate to the stock market are strong in Mexico and Brazil but have very small or insignificant effect on the stock market in the United Stated and Canada.

The result for the US and Canada in general seem to favour the use of the stock oriented approach at least for the second moments as the stock market causes the exchange rate to respond. For Brazil and Mexico the results are less clear and a mix of the flow oriented and stock oriented approach would be appropriate to explain the bivariate relationship of the second moment.

7 Conclusion

The importance of the stock market and exchange rate are of much importance and have great effect on the competitiveness and investment in any economy. The relationship between these two very important macroeconomic variables is far from being conclusive. Academics disagree on the relationship between the two variables and empirical studies on the second moments have been far from conclusive and seem to depend largely on the markets at hand, with results varying from country to country. A general denominator in these papers is that some spillover effects are present in some way or shape in most countries.

The GARCH – BEKK model was introduced in the thesis to estimate the volatility spillovers between the exchange rate and the stock market. As earlier studies have pointed to the spillover effects vary depending on the stock market and the exchange rate.

In Brazil and Mexico the volatility spillover from the exchange rate to the stock market has a large effect. The importance of the exchange rate is very high in these countries with both countries depending on exports and being internationally competitive. In Brazil the spillover coefficients is significant for the whole sample and the later subsample, while being insignificant from 1999-2008. The spillovers are significant for all samples in Mexico. In Canada and the United States the spillovers from the exchange rate to the stock market are not significant (except marginally from the CAD/USD to the S&P 500 from 2009-2014).

Spillovers of volatility from the exchange rate to the stock market causes the risk of internationally diversified portfolio to increase, reducing the gains for international investors.

After the crisis (2009-2014) there are consistent results showing significant spillovers from the stock market to the exchange rate for all four countries, indicating highly integrated financial markets according to Zapareto (1995). Additionally the spillovers from the stock market to the exchange rate are significant for Brazil in the whole sample and from the stock market in the United States to the BRL/USD (1999-2014 & 1999-2008) and the PES/USD (1999-2008) but the effects are very small in these occasions.

Where the stock market volatility spills over to the exchange rate it is important for exporters and importers to realize that the exchange risk they face is in part driven by volatility of the domestic stock market.

It is clear from the results that it is important for multinational firms and investors to be well aware of the volatility spillover between the two series when making investment decisions in these countries. Specifically they must try to estimate the spillovers in each country as the relationship differs between countries. A better understanding of the relationship between the two series may help them manage their exchange rate exposure and stock market risk.

References

Agrawal, G., Srivastav, A. K., & Srivastava, A. (2010). A Study of Exchange Rates Movement and Stock Market Volatility. *International Journal of Business & Management*, *5*(12), 62-73.

Berndt, E. K., Hall, B. H., & Hall, R. E. (1974). Estimation and inference in nonlinear structural models. In *Annals of Economic and Social Measurement, Volume 3, number 4* (pp. 103-116). NBER.

Black, F., & Scholes, M. (1973). The pricing of options and corporate liabilities. *The journal of political economy*, 637-654.

Bodnar, G. M., & Gentry, W. M. (1993). Exchange rate exposure and industry characteristics: evidence from Canada, Japan, and the USA. *Journal of international Money and Finance*, *12*(1), 29-45.

Bollerslev, T. (1986). Generalized autoregressive conditional heteroskedasticity. *Journal of econometrics*, *31*(3), 307-327.

Branson, W. H. (1983). Macroeconomic determinants of real exchange risk. In Managing Foreign Exchange, *Cambridge: Cambridge University Press*

Brenner, M., & Galai, D. (1993). Hedging volatility in foreign currencies. *The Journal of Derivatives*, *1*(1), 53-59.

Cont, R. (2001). Empirical properties of asset returns: stylized facts and statistical issues. *Quantative Finance, 1*(2), 223-236.

Dornbusch, R., & Fischer, S. (1980). Exchange rates and the current account. *American Economic Review*, *70*(5), 960-71.

Engle, R. F. (1982). Autoregressive conditional heteroscedasticity with estimates of the variance of United Kingdom inflation. *Econometrica: Journal of the Econometric Society, 50*(4), 987-1007.

Engle, R. F., & Kroner, K. F. (1995). Multivariate simultaneous generalized ARCH. *Econometric theory*, *11*(01), 122-150.

Fedorova, E., & Saleem, K. (2010). Volatility Spillovers between Stock and Currency Markets: Evidence from Emerging Eastern Europe. *Finance a Uver: Czech Journal of Economics & Finance*, *60*(6). 519-533.

Francis, B. B., Hasan, I., & Hunter, D. M. (2006). Dynamic Relations between International Equity and Currency Markets: The Role of Currency Order Flow*.*The Journal of Business*, *79*(1), 219-258.

Frankel, J. (1983). Monetary and portfolio balance models of exchange rate determination, In Economic Interdependence and Flexible Exchange Rates, Edited by J. Bhandari and B. Putnam, Cambridge (MIT Press), 84–114.

Glosten, L. R., Jagannathan, R., & Runkle, D. E. (1993). On the relation between the expected value and the volatility of the nominal excess return on stocks. *The journal of finance*, *48*(5), 1779-1801.

Jorion, P. (1990). The exchange-rate exposure of US multinationals. *Journal of Business*, 331-345.

Kanas, A. (2000). Volatility spillovers between stock returns and exchange rate changes: international evidence. *Journal of Business Finance & Accounting*, *27*(3-4), 447-467.

Masson, P. (1999). Contagion: macroeconomic models with multiple equilibria. *Journal of International Money and Finance*, *18*(4), 587-602.

Morales, L. D. L. N. (2008). Volatility Spillovers between Equity and Currency Markets: Evidence from Major Latin American Countries. *Cuadernos de economía*, *45*(132), 185-215.

Office of the United States Representative (no year). Retrieved 19. August, 2014 from http://www.ustr.gov

Raghavan, M. V., & Dark, J. (2008). Return and volatility spillovers between the foreign exchange market and the Australian all ordinaries index. *The IUP Journal of Applied Finance*, *14*(1), 41-48.

Tsay, R. S. (2010). Analysis of Financial Time Series (3. edition). New Jersey: John Wiley & Sons.
Berndt, E. K., Hall, B. H., & Hall, R. E. (1974). Estimation and inference in nonlinear structural models. In *Annals of Economic and Social Measurement, 3*(4), 103-116.

Yang, S. Y., & Doong, S. C. (2004). Price and volatility spillovers between stock prices and exchange rates: empirical evidence from the G-7 countries. *International Journal of Business and Economics*, *3*(2), 139-153.

Qayyum, A., & Kemal, A. R. (2006). Volatility spillover between the stock market and the foreign exchange market in Pakistan.

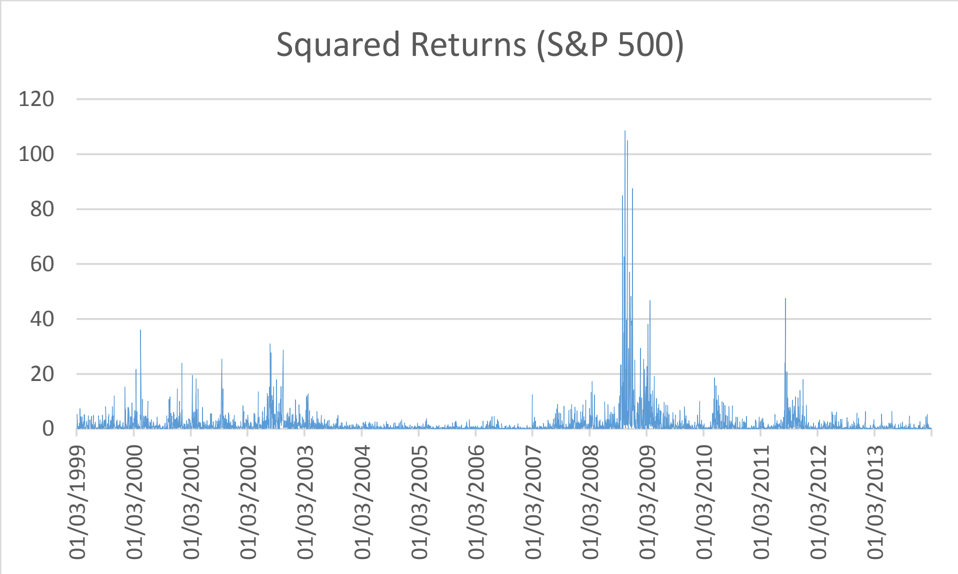
The World Bank (no year). Retrieved 19. August, 2014 from http://data.worldbank.org/country/mexico

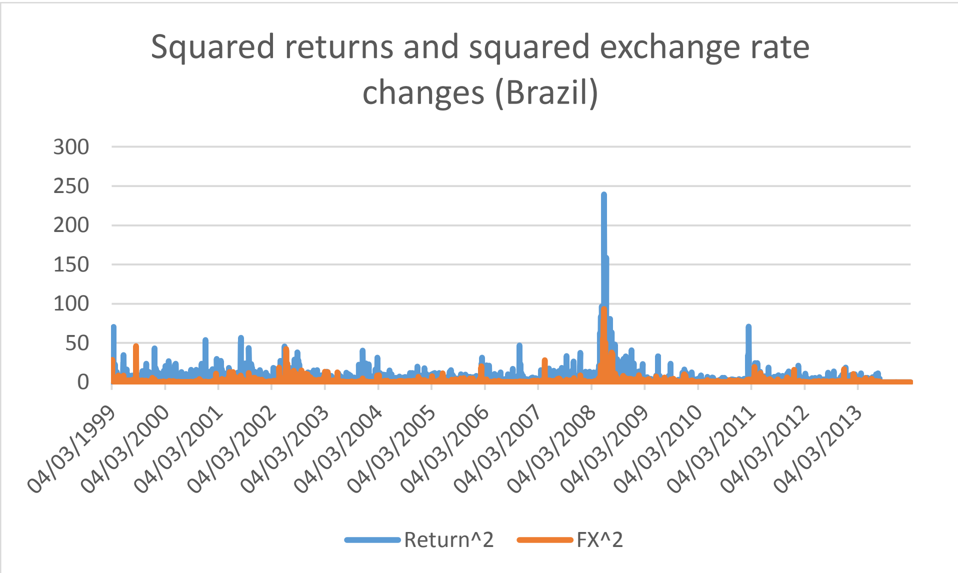
The World Bank (no year). Retrieved 19. August, 2014 from http://data.worldbank.org/country/brazil

Zapatero, F. (1995). Equilibrium Asset Prices and Exchange Rates, Journal of Economic Dynamics and Control, Vol. 19, 99. 787.

Appendix 1

1.A Squared returns and squared exchange rate changes





1.B Augmented Dickey Fuller

Close price

Brazil		
	t-statistic	*P-value*
1999-2014	-1.44	0.56
1999-2008	1.52	0.99
2009-2014	-2.89	0.05

Canada		
	t-statistic	*P-value*
1999-2014	-1.62	0.47
1999-2008	-0.49	0.89
2009-2014	-3.62	0.00

Mexico

	t-statistic	*P-value*
1999-2014	-0.66	0.85
1999-2008	0.86	0.99
2009-2014	3.48	0.00

United States

	t-statistic	*P-value*
1999-2014	-0.90	0.79
1999-2008	-1.67	0.45
2009-2014	-1.24	0.66

Exchange rate

BRL/USD

	t-statistic	*P-value*
1999-2014	-1.56	0.50
1999-2008	-0.87	0.79
2009-2014	-1.63	0.47

CAD/USD

	t-statistic	*P-value*
1999-2014	-1.42	0.58
1999-2008	-0.21	0.97
2009-2014	-4.22	0.00

PES/USD

	t-statistic	*P-value*
1999-2014	-1.52	0.52
1999-2008	-1.44	0.56
2009-2014	-4.46	0.00

Return

Brazil

	t-statistic	*P-value*
1999-2014	-59.58	0.00
1999-2008	-44.40	0.00
2009-2014	-35.77	0.00

Canada

	t-statistic	*P-value*
1999-2014	-45.65	0.00
1999-2008	-44.31	0.00
2009-2014	-34.55	0.00

Mexico

	t-statistic	*P-value*
1999-2014	-42.82	0.00
1999-2008	-41.94	0.00
2009-2014	-32.78	0.00

United States

	t-statistic	*P-value*
1999-2014	-67.23	0.00
1999-2008	-47.90	0.00
2009-2014	-38.13	0.00

Exchange rate return

BRL/USD		
	t-statistic	*P-value*
1999-2014	-60.60	0.00
1999-2008	-34.32	0.00
2009-2014	-33.20	0.00

CAD/USD		
	t-statistic	*P-value*
1999-2014	-60.48	0.00
1999-2008	-47.55	0.00
2009-2014	-35.91	0.00

Mexico		
	t-statistic	*P-value*
1999-2014	-59.82	0.00
1999-2008	-44.50	0.00
2009-2014	-32.54	0.00

1.C Descriptive statistic

Descriptive statistics				
1999-2014	**Brazil**		**United States**	
	Stock	*FX*	*Stock*	
Mean	0,05	0,00	0.01	
Median	0,08	-0,02	0.06	
Maximum	15,47	7,55	10.42	
Minimum	-12,09	-9,67	-9.47	
Std. dev.	1,88	1,06	1.31	
Skewness	0,02	-0,19	-0.22	
Kurtosis	6,94	12,91	10.47	
JB(prob.)	0,00	0,00	0,00	
	Mexico		**Canada**	
	Stock	*FX*	*Stock*	*FX*
Mean	0,06	0,01	0,02	-0,01
Median	0,09	-0,02	0,07	-0,01
Maximum	11,11	8,11	9,37	3,80
Minimum	-8,27	-5,96	-9,79	-5,07

Std. dev.	1,44	0,65	1,19	0,59
Skewness	0,01	0,67	-0,67	-0,04
Kurtosis	7,2	17,49	12,15	9,15
JB(prob.)	0,00	0,00	0,00	0,00

Appendix 2 – GARCH-BEKK results

Coefficient, (standard deviation). ***, ** and *: 1%, 5% and 10% significance level respectively.

Canada	***1999-2014***	***1999-2008***	***2009-2014***
MU(1)	0.049230*** (0.013712)	0.029098 (0.019972)	0.033876 °(0.023725)
MU(2)	-0.008574 (0.007356)	-0.015729* (0.009066)	0.002304 (0.013754
c_{11}	0.086550*** (0.008528)	0.085378*** (0.008842)	0.126126*** (0.021841)
g_{11}	0.966536*** (0.002264)	0.975495*** (0.002894)	0.941167*** (0.010651)
g_{21}	0.006946 (0.005655)	0.004400 (0.008672)	-0.023737 (0.015448)
a_{11}	0.242309*** (0.009178)	0.206571*** (0.012661)	0.275148*** (0.022513)
a_{21}	-0.040892* (0.022575)	-0.027896 (0.032730)	-0.047902 (0.044620)
c_{22}	0.041640*** (0.004800)	0.038101*** (0.007092)	0.063239*** (0.008567)
c_{21}	-0.004385 (0.008350)	-0.000393 (0.014182)	0.029370* (0.012894)
g_{22}	0.976621*** (0.002197)	0.982393*** (0.003010)	0.965129*** (0.005150)
g_{12}	-0.001414 (0.000969)	0.001501 (0.001674)	-0.018635*** (0.002933)
a_{22}	0.198284*** (0.009423)	0.172465*** (0.012607)	0.147710*** (0.018511)
a_{12}	-0.001654 (0.002172)	-0.000100 (0.002378)	-0.022670** (0.005384)
Avg. log likelihood	-2.076058	-2.059786	-2.106059
Akaike info criterion	4.159206	4.131395	4.233360
Schwarz criterion	6.307120	4.165067	4.287632

Mexico	***1999-2014***	***1999-2008***	***2009-2014***

MU(1)	0.080011*** (0.018951)	0.129020*** (0.027906)	0.039083 (0.027677)
MU(2)	-0.010502 (0.008167)	-0.008111 (0.009503)	-0.015990 (0.017928)
c_{11}	0.122510*** (0.011084)	0.129204*** (0.018307)	0.135895*** (0.025607)
g_{11}	0.971424*** (0.002071)	0.976134*** (0.002913)	0.937491*** (0.010354)
g_{21}	0.018253** (0.008156)	0.027572 (0.018293)	-0.033292 (0.031479)
a_{11}	0.220500*** (0.008546)	0.197932*** (0.012054)	0.322755*** (0.020113)
a_{21}	-0.068287*** (0.022339)	-0.109036** (0.047833)	0.269898*** (0.046437)
c_{22}	0.062079*** (0.007980)	0.079640*** (0.009407)	0.093267*** (0.031906)
c_{21}	-0.035866*** (0.011085)	-0.024906 (0.019113)	-0.015702 (0.031881)
g_{22}	0.949788*** (0.003376)	0.952437*** (0.006140)	0.913137*** (0.018718)
g_{12}	-0.005762*** (0.001708)	0.000798 (0.002151)	-0.080864*** (0.018847)
a_{22}	0.281640*** (0.008854)	0.250680*** (0.015328)	-0.211983*** (0.025559)
a_{12}	0.001335 (0.002871)	0.000144 (0.003133)	-0.097055*** (0.014239)
Avg. log likelihood	-2.385526	-2.402129	-2.351477
Akaike info criterion	4.778550	4.811388	4.724353
Schwarz criterion	4.801609	4.833494	4.778948

Brazil	***1999-2014***	***1999-2008***	***2009-2014***
MU(1)	0.075995*** (0.026650)	0.129978*** (0.038898)	0.006866 (0.038121)
MU(2)	-0.033808*** (0.011227)	-0.038569*** (0.014716)	-0.023350 (0.019549)
c_{11}	0.258048*** (0.021530)	0.265835*** (0.041753)	0.367120*** (0.039594)
g_{11}	0.962475*** (0.003358)	0.975764*** (0.005735)	0.907946*** (0.014004)
g_{21}	0.015217 (0.011659)	0.003452 (0.014608)	-0.053937* (0.031597)
a_{11}	0.221266*** (0.010407)	0.160210*** (0.015864)	0.229049*** (0.021615)

a_{21}	-0.095311*** (0.024059)	-0.042625 (0.031774)	-0.210915*** (0.048817)
c_{22}	0.066663* (0.040175)	0.080689 (0.051323)	0.129107*** (0.026974)
c_{21}	-0.097696*** (0.019045)	-0.095313*** (0.030533)	-0.031486 (0.026679)
g_{22}	0.894489*** (0.006407)	0.886905*** (0.008594)	0.906416*** (0.016096)
g_{12}	-0.032571*** (0.006096)	-0.015122* (0.009186)	-0.046994*** (0.014028)
a_{22}	0.393260*** (0.013249)	0.436959*** (0.017970)	0.317355*** (0.024879)
a_{12}	0.007939* (0.004775)	-0.005139 (0.006727)	0.049419*** (0.011813)
Avg. log likelihood	-3.138771	-3.182166	-2.837802
Akaike info criterion	6.284767	6.376409	5.697235
Schwarz criterion	6.307120	6.410673	5.752303
US and BRL/USD	***1999-2014***	***1999-2008***	***2009-2014***
MU(1)	0.053369*** (0.014731)	0.029596 (0.019020)	0.094395*** (0.024367)
MU(2)	-0.029129*** (0.010611)	-0.039299*** (0.014169)	-0.016680 (0.019065)
c_{11}	0.129329*** (0.008538)	0.075533*** (0.009539)	0.203784*** (0.021923)
g_{11}	0.958872*** (0.002923)	0.980977*** (0.002165)	0.907953*** (0.012580)
g_{21}	0.006906 (0.006159)	0.006466 (0.007940)	-0.029310* (0.017771)
a_{11}	0.263275*** (0.009562)	0.180736*** (0.010830)	0.358596*** (0.023414)
a_{21}	-0.025621* 0.014070)	-0.034619* (0.017678)	0.018166 (0.036583)
c_{22}	0.118816*** (0.010901)	0.093250** (0.041025)	0.126051*** (0.016353)
c_{21}	-0.055448*** (0.015357)	-0.092822*** (0.032072)	-0.001795 (0.027896)
g_{22}	0.914463*** (0.004964)	0.891939*** (0.007292)	0.945850*** (0.009849)
g_{12}	-0.018322*** (0.004746)	-0.038905*** (0.013813)	-0.012003** (0.005655)
a_{22}	0.377466*** (0.011282)	0.430928*** (0.015494)	0.253183*** (0.023366)
a_{12}	0.001199 (0.005515)	0.010298 (0.008795)	-0.015128 (0.010072)

Avg. log likelihood	-2.653714	-2.612794	-2.464671
Akaike info criterion	5.314373	5.237164	4.950208
Schwarz criterion	5.335998	5.270253	5.003707

US and CAD/US	***1999-2014***	***1999-2008***	***2009-2014***
MU(1)	0.040919*** (0.015001)	0.029098 (0.019972)	0.065991*** (0.023725)
MU(2)	-0.006595 (0.007273)	-0.015729 (0.009066)	0.004194 (0.013754)
c_{11}	0.109947*** (0.007330)	0.085378*** 0.008842)	0.172435*** (0.021841)
g_{11}	0.962624*** (0.002605)	0.975495*** (0.002894)	0.914806*** (0.010651)
g_{21}	0.002735 (0.006568)	0.004400 (0.008672)	-0.050649*** (0.015448)
a_{11}	0.255192*** (0.009245)	0.206571*** (0.012661)	0.356491*** (0.022513)
a_{21}	-0.014607 (0.025597)	-0.027896 (0.032730)	0.078765* (0.044620)
c_{22}	0.038932*** (0.004172)	0.038101*** (0.007092)	0.046726*** (0.008567)
c_{21}	-0.008758 (0.007372)	-0.000393 (0.014182)	0.008286 (0.012894)
g_{22}	0.977717*** (0.002125)	0.982393*** (0.003010)	0.971806*** (0.005150)
g_{12}	0.000721 (0.000534)	0.001501 (0.001674)	-0.008297*** (0.002933)
a_{22}	0.200153*** (0.008993)	0.172465*** (0.012607)	0.169321*** (0.018511)
a_{12}	8.83E-05 (0.001899)	-0.000100 (0.002378)	-0.013115** (0.005384)
Avg. log likelihood	-2.183701	-2.059786	-2.106059
Akaike info criterion	4.374484	4.131395	4.233360
Schwarz criterion	4.396469	4.165067	4.287632

US and PES/US	***1999-2014***	***1999-2008***	***2009-2014***

MU(1)	0.000490*** (0.000150)	0.000354* (0.000196)	0.000877*** (0.000253)
MU(2)	-6.15E-05 (7.92E-05)	-6.27E-05 (9.33E-05)	-0.000306* (0.000177)
c_{11}	0.001200*** (8.64E-05)	0.000757*** (0.000146)	0.002060*** (0.000215)
g_{11}	0.954942*** (0.003162)	0.975861*** (0.002684)	0.926857*** (0.009032)
g_{21}	-0.001363 (0.008958)	0.000850 (0.027210)	0.007492 (0.016331)
a_{11}	0.280551*** (0.010248)	0.206689*** (0.011953)	0.312722*** (0.022331)
a_{21}	-0.009293 (0.022306)	-0.035210 (0.047563)	-0.059182 (0.045132)
c_{22}	0.000717*** (7.42E-05)	0.001330*** (0.000151)	0.000630*** (0.000193)
c_{21}	-0.000266** (0.000118)	-0.000324 (0.000377)	-0.000776*** (0.000192)
g_{22}	0.944945*** (0.003894)	0.885655*** (0.015395)	0.958347*** (0.006127)
g_{12}	-0.012744*** (0.002123)	-0.015394* (0.008285)	-0.001196 (0.003990)
a_{22}	0.273853*** (0.009066)	0.341423*** (0.022294)	0.261797*** (0.016234)
a_{12}	-0.002730 (0.002961)	-0.008479 (0.005832)	0.021656*** (0.006855)
Avg. log likelihood	6.988388	7.174733	6.911760
Akaike info criterion	-13.96963	-14.33753	-13.80207
Schwarz criterion	-13.94746	-14.30361	-13.74736