Evidence of Financial Contagion caused by Subprime and Global Financial Crisis in NAFTA Stock Markets

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Abstract
This work applies Archimedean family copulas for modeling dynamic dependence out of sample among the stock markets from the North American Free Trade Agreement. To test the existence of contagion among these markets the time series covers the period from January 2nd, 2002 to December 31st, 2016, this period is segmented in three periods of time: before, during and after the subprime and global finance crisis. An econometric analysis that includes a t-statistics test based on a bootstrap analysis has been done in order to complement the estimation of the dynamic dependence, and to complement it a structural change analysis has been done subsequently. Results from the earlier and post subprime and global financial crisis periods are different and statistically significant from those obtained for the USA subprime crisis and the subsequent global financial crisis. Another finding shows that the contagion shock of subprime and global financial crisis is stronger during the earlier crisis period than in the post crisis period, considering the bootstrap p-value and the structural change analysis, under Clayton, Frank and Gumbel copula approaches. Findings provide useful information for investment allocation and international diversification strategies, as well as for risk management practice and derivative pricing.

Keywords: Contagion; Dependence; Copula; Bootstrap; NAFTA stock markets

JEL Classification codes: F37; F65; G01; G15
1. Introduction

Through the times this millennium has testified many economics and financial crisis, among them it can be mentioned the Nasdaq Composite index declining in 2000, the misresponding of Argentina’s public debt in 2001, the financial crisis of United States of America from 2007 to 2009, and the European sovereign debts crisis in 2011. These crisis have had unfavorable important effects in the developed and emerging stock markets, banks, and governments, but with a diverse magnitude. As a consequence the USA crisis which started with the explosion of the housing bubble and the bankruptcy of the Lehman Brothers’ bank has been considered the worse financial disaster since the Great Depression of 1930. The seriousness of the crisis created uncertainty and increased immediately the level of volatility in the stock markets which spread to other international financial systems without a main economics cause, this caused a global contagion effect, and particularly in Latin America.

Nowadays it can be seen through the financial literature that this phenomena of contagion is still calling the attention of professors, individual and institutional investors, and regulators, because there is not an agreement of a correct definition and different definitions are used in the literature, such definitions make its nature something different.

According to Forbes and Rigobon (2001) contagion is defined as the increasing of correlations among stock markets in periods of extreme crisis or extreme volatility. Conversely other authors define contagion as the transmission of the shocks among stock markets which derives in the variation of key macroeconomic indicators or leaded to investors’ behavior in the financial markets.

However, the spreading of shocks is hard to explain as a consequence of the arduous task to find excellent indicators that could help to the impact evaluation of macroeconomic fundamentals. Therefore, an easy way to study this phenomena is through the contagion
effect by analyzing the evolution of correlations among financial markets during stability
periods -pre-crisis, financial turmoil or crisis and post-crisis-. According to Celik (2012) if
two financial markets lightly come across correlated during a stable period and the presence
of a shock in a market increases significantly the correlations this effect is contagion evidence
among financial markets. On the other hand, when two financial markets are highly
correlated and after a shock they have the same tendency, this effect has not the contagion
effect; rather it corresponds to the interrelation which comes from the close connections
among the financial markets through crisis periods and high volatility.

The study of nature of contagion in episodes of high volatility in international
financial markets has important implications in the worldwide economy and finance,
particularly in areas related to international diversification for the efficient assignment of
capital, the formulation of monetary policy, financial regulation, tax policy, financial asset
valuation, efficiency and integration of financial markets, risk administration, and design of
hedging strategies. So the main objective of this investigation is to show the existence of
financial contagion among stock markets of the North American Free Trade Agreement
(NAFTA) during the period of January 2\textsuperscript{nd}, 2002 to December 31\textsuperscript{st}, 2016. The main question
to answer is the following: Were the stock markets of Canada, Mexico, and USA affected by
the devastating effect of Global financial crisis?

This investigation makes a contribution to the financial literature on the financial
contagion. Firstly, it investigates the contagion effect in the stock markets of the NAFTA –
Canada, Mexico, and USA. Additionally, this research applies a family of Archimedean
copulas model, in order to analyze the dependency relations among stock markets of Canada,
Mexico, and USA, all together in the context of Global financial crisis.
There can be seen in the financial literature that there are many econometric techniques that have been applied to analyze the contagion effect among financial markets; the ones that can be included are the proposed by Longin and Solnik (1995) and Cashin et al. (1995) Autorregresive Vectors (VAR model) or Vector Error Correction Model (VECMs). Such models are lineal and they are capable of estimating the lineal dependency of financial returns. Even so, their main weaknesses comes out when we assume that the returns follow a normal distribution, and this leads to reduce the potential of such models to capture the heteroscedasticity and to obtain changing correlations through the time\(^1\), although there are empirical researches that have investigated the effect of financial contagion among financial markets through GARCH multivariate models and under different distributional assumptions\(^2\) (Chiang et al., 2007; Corsetti et al., 2005). But such models are not capable of capture widely the no-lineal dependency of the contagion phenomena, and also the changes in the distribution of tail returns. For instance, the copulas function allows to capture all the information of the group behavior of the multivariate returns through the product of its marginal distributions. In addition, copulas are capable of describing the non-lineal dependency and of modeling the patterns of behavior in the tails, and because of the co-movements they can cause the extreme events of financial markets.

The \(t\) statistics was used in the analysis during periods of stability, financial crisis, and post-crisis to evaluate the effects of contagion and to demonstrate the correlation consistency out of the sample among the stock markets of Canada, Mexico, and USA. So the

\(^1\) In this case, Forbes and Rigbon (2002) correct the skewing of correlations as an alternative to measure the financial contagion. However, the empirical evidence reveals that in few times the contagion occurs in the financial crisis periods.

\(^2\) Generally, the distributions that are used in the structures of GARCH multivariate include the normal distribution, t-Student distribution, and generalized error distribution.
third contribution is that a bootstrap procedure was applied to estimate the statistics sample of $-p$ and $t$ value in order to give robust evidence of the contagion hypothesis or interdependency among stock markets of NAFTA. And the last contribution is to analyze the impact of financial crisis stages above correlations to give additional information about the potential facts that help to explain in a better way the dynamic patterns of correlations.

2. Literature review

There have been many authors who have studied the contagion effect in different financial crisis and financial markets contexts from different countries. Manthur et al. (2002) shows evidence of contagion effect during 1994 in the Mexican peso crisis in the study of emerging countries; such contagion was transmitted efficiently from the Mexican stock market to the Chilean stock market. Serwa and Bohl (2005) determine instability in dependency relations after crisis through adjusted correlations by heteroscedasticity for different countries of Europe. Moreover, Central and Eastern Europe stock markets are not such vulnerable to the contagion effect from the 1997 Asian financial crisis than the Western Europe stock markets. Rodriguez (2007) models the dependency relation through dynamic copulas for five our four stock markets from Asia and Latin America. The findings reveal contagion evidence because the correlations change during 1997 Asian crisis and 1994 Mexican crisis. Also Cho and Parhizgari (2008), Khan and Park (2009) support the presence of contagion in stock markets of Korea, Hong Kong, Taiwan, and Singapore, and its effect extends to Malaysia, Thailand, Indonesia, and Philippines. Other recent research from Wang and Nguyen (2013) has demonstrated the contagion effects on the stock indexes of China, Hong Kong and Taiwan through dynamic correlations in stability periods and during the Asian financial crisis.
Horta et al. (2009) use the copulas theory to demonstrate the existence of contagion from the USA housing crisis to European stock markets from 2005 to 2008. Even so the results confirm the presence of contagion effects for Canada, France, Italy, United Kingdom, except Germany. Naoui et al (2010) find strong evidence of contagion during the Global financial crisis among the USA stock market and developed and emerging stock markets by estimating a multivariate GARCH model of correlations dynamics conditionals (MGARCH-CCD). Additionally, Syllignakis and Kouretas (2011) analyze the structure of correlation of seven Central and Eastern European stock markets returns from 1997 to 2009. The results reveal that emerging stock markets are exposed to external shocks with regime changing in conditional correlations. Inci et al (2011) apply the local correlation in order to study the contagion in developed stock indexes. Their findings confirm the presence of contagion from S&p500 to DAX from Germany, FTSE 100 from London, Nikkei 225 from Japan, and Hang Seng from Hong Kong from January 3rd, 1985 to November 8th, 2008.

On his behalf Bouaziz et al (2012) adopt a GARCH model with Markov’s regime change and demonstrate the presence of the contagion effect of the stock index S&P500 on the CAC 40 of France, DAX of Germany, MIB of Italy, and FTSE 100 of United Kingdom during the Global financial crisis. Gallegati (2012) shows in a research by using short wave approximations for the G7 bloc countries, Brazil, and Hong Kong the evidence that all the analyzed stock markets have been affected by the USA subprime crisis, and particularly Brazil and Japan. The contagion through GARCH, Vech and BEKK models has been studied by Hovarth and Poldauffy (2012) and they find evidence that the global financial crisis represented a common shock for the stock indexes of Germany, Australia, Brazil, Canada, china, Hong Kong, Japan, Russia, South Africa, United Kingdom, and USA because of the light increasing of correlations. Likewise Peng and NG (2012) study the dependency relation
among five international stock indexes and their corresponding indexes of volatility with and approximation of dynamic copula. The findings show the existence of financial contagion and asymmetry in the dependency coefficient of the tale. Even if sometimes the contagion cannot be detected clearly in the stock indexes movements nor because of the dependency among volatility indexes.

Other investigation on the topic is the one of Ahmad et al (2013) which shows the contagion effects of PIIGS, USA, Japan, and United Kingdom stock markets from the BRICS countries. Their results tell that Brazil, China, India, Russia, and South Africa were severely affected by the contagion of the crisis of the Euro Zone while countries like Indonesia, South Korea only suffered interdependency. Additionally Guesmi et al. (2013) tell that the dynamics conditional correlation in the stable period have different patterns from the ones in the crisis period, this means the existence of contagion effect in stock markets of OCDE, except for Germany, Italy, and United Kingdom. A strong evidence from the contagion effect from USA to developed and emerging stock markets during the global financial crisis is given through a latent factor model by Dungey and Gajurel (2014).

A phenomena of contagion and interdependence among stock markets of USA, Latin America –Argentina, Brazil, Mexico-, Asia –Japan, Singapore, Europe –Germany, UK- by using a copulas model with changing parameters in time form September 6th to April 19th, 2013 has been done by Abbara and Zevallos (2014). The bivariate results of the analysis show evidence of contagion among stock markets in the Asian-Russian crisis, and subprime

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3 PIIGS are a group of countries from the European Union that are Portugal, Italy, Ireland, Greece, and Spain, with problems of deficit and balance of payments.
4 BRICS is a true economic and trade partnership association conformed by the Group of five emerging economies -Brazil, Russia, India, China, and South Africa.
global financial crisis. In more recent investigations Hemche at al. (2016) analyze the contagion hypothesis for 10 developed and emerging stock markets with respect to the USA stock market and under the subprime crisis context by using a MGARCH-CCD model. Empirical findings confirm that it is impossible to reject the hypothesis of 1% contagion for France, Italy, UK, and Mexico, and 10% for Argentina while there exists remains of interdependence in stock markets of China, Japan, Egypt, Tunisia, and Morocco. Likewise Mollah et al. (2016) have found evidence of contagion in developed and emerging stock markets during the global financial crisis and European crisis, also they demonstrate that the contagion spreads from USA to international stock markets during both happenings\(^5\).

3. Statistical data and methodology

3.1. Statistical data description

In order to do the analysis of contagion effect of the world financial crisis the data that was used was taken from the daily stock markets closing prices of January 2nd, 2002 to December 30th, 2016 of the NAFTA stock markets. The group of data includes the stock index of the Toronto Stock Exchange Index, S&P 500 Stock Index, and the Mexican Securities Exchange’s Index of Prices and Quotations.

The Lagrange’s interpolation method is used in the standardization of series of prices, which estimates the data that is not available because of holidays or vacations in a specific market. Because of the estimation the overall sample goes from 2002 to 2016, and it has been divided into three sub-samples that belong to 5-years periods, they are: i) 2002 to 2006, ii) 2007 to 2011, y iii) 2012 to 2016, respectively Stable, Crisis and Post-Crisis.

\(^5\) It is important to mention that MSCI global indexes were used in USA dollar in 55 stock markets.
Moreover each sub-period of each period under analysis has exactly the same amount of data, which is homogeneous among data and makes that the estimation would be equivalent and unhurried. Bloomberg was the source of information. Figure 1 shows the segmentation that has been done for the contagion analysis, and it can be seen the proposal of estimation through rolling windows.

![Figure 1. Temporary horizon from 2002 to 2016 through Rolling Windows segmented in Stable, Crisis, and Post-crisis from stock markets of NAFTA](image)

3.2. Copula functions

The copula function is a multivariate distribution function defined in the interval $[0,1]^n$, such function is generated through Uniform marginal distribution functions.

Through Sklar’s theorem (Sklar, 1959), one can know that a copula for each multivariate distribution can be easily derivate.

*Sklar’s theorem*

Let $F$ be an $n$-dimensional distribution function with continuous marginal distribution functions $F_1, \ldots, F_n$, then an $n$-copula exist $C: [0,1]^n \to [0,1]$ so:

$$F_1, \ldots, F_n = C(F_1(x_1), \ldots, F_n(x_n))$$

(1)

Therefore the copula associates the marginals in order to form multivariate distributions. This theorem gives a parameter of the multivariate distribution, and a scheme
of construction of copulas. In fact having an $F$ distribution with multivariate marginal $F_1, \ldots, F_n$, the function:

$$C(u_1, \ldots, u_n) = F(F_1^{-1}(u_1), \ldots, F_n^{-1}(u_n))$$  \hspace{1cm} (2)

Automatically it is an $n$-copula. That is the one for the multivariate $F$ distribution.

According to the Sklar theorem the $n$-dimensional density $f$ can be represented such as:

$$f(x_1, \ldots, x_n) = f(x_1)^* \ldots * f(x_n)^* c(F_1(x_1), \ldots, F_n(x_n))$$  \hspace{1cm} (3)

… where $c$ is the density function of copula $C$. Such result admits that the election of different marginal distribution functions is permissible, also a given structure of dependence given by the copula to then be used in the construction of a multivariate distribution. This makes a contrast with the usual way of building functions of multivariate distribution, which is restricted because the marginal distribution functions are usually of the same type.

There is a huge amount of copulas, but just few families of them play an important role. Archimedean copulas family is one of those ones, it distinguishes because takes into account the asymmetry and giving more value to the estimation in tails. In this research bivariate copulas are used, this means that are the ones generated through interaction between two marginal distribution functions.

**Archimedean Copulas**

Bivariate distribution function of the Archimedean copulas family is represented by,

$$C_\alpha(u_1, u_2) = \phi_\alpha^{-1}[\phi_\alpha(u_1) + \phi_\alpha(u_2)] \quad 0 \leq u_1, u_2 \leq 1$$  \hspace{1cm} (4)
Where \( \phi_\alpha \) is convex and decreasing so \( \phi_\alpha \geq 0 \). The function \( \phi_\alpha \) refers to the generator of the copula \( C_\alpha \) and the inverse of the generator \( \phi_\alpha^{-1} \) it is Laplace’s transformed from a denoted latent variable \( \gamma \), which indices dependence \( \alpha \). In this way the selection of a generator has as a result different copulas of the Archimedean family. In this respect the present investigation just specifies three copulas from the Archimedean family which are the most usual having in mind its easy estimation and characteristics, they are Clayton copula, Gumbel copula, and Frank copula.

**Clayton copula**

The bivariate copula from the Clayton family is,

\[
C_\alpha(u_1, u_2) = \left[ u_1^{1-\alpha} + u_2^{1-\alpha} - 1 \right]^{\frac{1}{\alpha}}, \quad \alpha > 1
\]  

(5)

Where the generator is \( \phi_\alpha(t) = t^{1-\alpha} - 1 \), and Laplace’s transformation \( \phi_\alpha^{-1}(s) = (1 + s)^{\frac{1}{\alpha-1}} \).

**Gumbel Copula**

The bivariate copula from the Gumbel family is,

\[
C_\alpha(u_1, u_2) = \exp \left\{ - \left[ (- \ln u_1)^{\frac{1}{\alpha}} + (- \ln u_2)^{\frac{1}{\alpha}} \right] \right\}, \quad 0 < \alpha < 1
\]  

(6)

Where the generator is \( \phi_\alpha(t) = (- \ln t)^{\frac{1}{\alpha}} \), and Laplace’s transformation \( \phi_\alpha^{-1}(s) = \exp \left\{ - s^{\alpha} \right\} \).

**Frank copula**

The bivariate copula from the Frank family is,

\[
C_\alpha(u_1, u_2) = \ln \left[ 1 + \frac{\left( \alpha u_1 - 1 \right) \left( \alpha u_2 - 1 \right)}{(\alpha - 1) \ln \alpha} \right], \quad \alpha > 0
\]  

(7)
Where the generator is \( \phi_a(t) = \ln\left(\frac{\alpha^t}{\alpha-1}\right) \), and Laplace’s transformation \( \phi_a^{-1}(s) = \ln\left[\frac{1}{\ln\alpha}\right] \).

**Kendall’s Tau dependence measure and copulas**

Each multiple family of copulas is given a parameter, this one is a dependence measure between marginals and it is called dependence parameter \( \theta \).

In connection with the copulas that where analyzed in this investigation there could be seen a relation between the dependence parameter and the Kendall’s Tau measure correspondence, as it is mentioned below.

Having \( X_1 \) and \( X_2 \) as two randomly variables with continuous marginal distribution functions \( F_1 \) and \( F_2 \) and joint distribution function \( F \). Traditional concepts of dependence, Pearson correlation, and \( \tau \) Kendall can be expressed in terms of copula.

Pearson correlation is given by

\[
\rho(X_1, X_2) = \frac{\int \int \left[ C(u_1, u_2) - u_1u_2 \right] dF_1^-(u_1)dF_2^-(u_2)}{\text{SD}(X_1)\text{SD}(X_2)}
\]  

\( (8) \)

Tau Kendall correlation is defined by

\[
\tau(X_1, X_2) = 4\int_0^1 \int_0^1 C(u_1, u_2) dC(u_1, u_2) - 1
\]  

\( (9) \)

\( \tau \) Kendall is observed in the function of copula \( X_1 \) and \( X_2 \), while the coefficient of Pearson’s lineal correlation also depends from the marginals.

To sum up, if \( (X_1, X_2) \) have a bivariate Archimedean copula and continuous marginals \( \tau \) Kendall is,
<table>
<thead>
<tr>
<th><strong>Copula</strong></th>
<th><strong>τ Kendall</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Clayton</td>
<td>((\alpha-1)/(\alpha+1))</td>
</tr>
<tr>
<td>Gumbel</td>
<td>((\alpha-1))</td>
</tr>
<tr>
<td>Frank</td>
<td>(1 + \frac{4}{\ln \alpha} \left(1 + \frac{1}{\ln \alpha} \int_{-1}^{1} \left(1-\mu \right) d\mu \right))</td>
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</table>

**Estimation of copula parameters**

There are many methodologies to estimate parameters associated to a copula. The one that was applied for this investigation was the estimation through the maximum likelihood. Such methodology of estimation can be applied to any copulas family because it gets the estimation of parameters of the copula through the maximum of the log-likelihood function.

Given \(X\) as a vector of random variables equally and independently distributed with multivariate distributed function \(F\) and continuous marginal distributes functions \(F_1, \ldots, F_n\) and given the copula \(C\), so:

\[
F(x_1, \ldots, x_2) = C(F_1(x_1), \ldots, F_n(x_n))
\]  
(10)

with density function

\[
f(x_1, \ldots, x_2) = c(F_1(x_1), \ldots, F_n(x_n)) \prod_{j=1}^{n} f_j(x_j)
\]  
(11)

The log-likelihood function is defined,

\[
l(\theta) = \sum_{j=1}^{n} \ln c(F_1(x_{j,1}), \ldots, F_n(x_{j,n})) + \sum_{j=1}^{n} \sum_{i=1}^{d} \ln f_i(x_{j,i})
\]  
(12)
where $\theta$ is the parameter of the copula. In a certain way, given the group of marginals and a copula, the log-likelihood can be maximized getting the estimator of maximum likelihood,

$$\theta_{\text{MLE}} = \max_{\theta \in \Theta} l(\theta) \quad (13)$$

3.3. Statistics evidence of financial contagion

In this section there is a description of statistics evidence that allows to prove the hypothesis that stock markets of the NAFTA suffered from contagion during the world financial crisis. However, the presence of heteroscedasticity in the volatility of the market can distort the coefficient of correlations and give biased results to prove the effect of contagion (Forbes and Rigobon, 2002). The main objective of the analysis is to compare estimated correlations out of the sample for the periods of stability, crisis, and post-crisis in order to have better evidence of contagion or simple independency.

The main objective of the contagion test is to compare the estimated correlations out of the sample of crisis against correlations of stability and post-crisis periods. It is necessary to contrast the following invalid and alternative hypothesis:

$$H_0 : \rho_{ij}^{\text{crisis}} = \rho_{ij}^{\text{stable}}, \quad H_1 : \rho_{ij}^{\text{crisis}} \neq \rho_{ij}^{\text{stable}},$$

$$H_0 : \rho_{ij}^{\text{crisis}} = \rho_{ij}^{\text{post-crisis}}, \quad H_1 : \rho_{ij}^{\text{crisis}} \neq \rho_{ij}^{\text{post-crisis}}, \quad (14)$$

where $\rho_{ij}^{\text{stable}}, \rho_{ij}^{\text{crisis}}$ and $\rho_{ij}^{\text{post-crisis}}$ represent respectively the Kendall’s Tau obtained out of the sample by proposed copulas during stability, crisis, and post-crisis periods. The null hypothesis that says that stock markets of the NAFTA did not suffered from contagion during the world financial crisis is rejected when estimated correlations out of the sample among stock markets increase meaningfully in the period of crisis in respect of the stable and post-
cisis periods. In this sense the contagion effect is measured through the alternative hypothesis and with the statistical significance of correlations of the respective periods.

Under the null hypothesis Collins and Biekpe (2003) demonstrated that the statistics of the t-Students with \( n_{\text{stable}} + n_{\text{crisis}} - 4 \) or \( n_{\text{stable}} + n_{\text{unstable}} - 4 \) grades of liberty, and it is expressed by:

\[
t = \frac{(\rho_{ij}^{\text{crisis}} - \rho_{ij}^{\text{stable}})}{\sqrt{n_{\text{stable}} + n_{\text{crisis}} - 4 \cdot \left(1 - (\rho_{ij}^{\text{crisis}} - \rho_{ij}^{\text{stable}})^2\right)}
\]  

(15)

where \( n_{\text{stable}} \), \( n_{\text{crisis}} \) and \( n_{\text{unstable}} \) are referred to the number of correlations in the stability periods, crisis and instability.\(^6\)

In order to get strong results of the contagion effect among stock markets of Canada, United States of America, and Mexico, and the value of the statistics probability of \( t \)-Student stationary bootstrap methodology is suggested based on Politis and Romano (1994). This procedure consists on the generation of bootstrap samples \( (d_{b,1}^{*}, \ldots, d_{b,n}^{*}) \) with \( b = 1, \ldots, B \) to find the distribution of statistics under the null hypothesis, the statistics \( t_{b,n}^{*} \) is measured to each bootstrap sample with \( d \)-variables that are defined by \( d_{b,n}^{*} = \rho_{ij}^{\text{crisis}} - \rho_{ij}^{\text{stable}} \) or \( d_{b,n}^{*} = \rho_{ij}^{\text{crisis}} - \rho_{ij}^{\text{post-crisis}} \) to reach reliable results and that they do not affect current samples, \( B \) must be huge.

In this sense the estimated value of bootstrap probability is defined by

\[
p\text{-value} = B^{-1} \sum_{b=1}^{B} 1_{\{t_{b,n}^{*} > t\}}
\]  

(16)

\(^6\) Because of the length of this document \( t \)-Student is described for the periods of stable-crisis, but statistics for relations of periods stable-unstable and crisis-unstable are going to be measured too.
For the significance level $\alpha$, the null hypothesis is rejected when the p-value bootstrap is higher than $\alpha$. To determine the statistical significance there are generated 10,000 bootstrap samples from the original samples of correlations for the different periods of analysis.

4. Empirical evidence

4.1. Analysis of basic statistics

Chosen stock indexes returns were used to do estimations. In order to get a better comparison the returns were standardized in a single denomination, USA dollars. Stock indexes returns and North America’s stock indexes are seen in Figure 2.

Figure 2. Returns and indexes of NAFTA 2002-2016 stock markets

[Stable, Crisis, Post-Crisis]

Panel A. USA

Panel B. Canada
Panel C. Mexico

It is through Figure 2 that it can be seen that indexes and returns have a similar behavior during all the period that was analyzed, also highlighting the similarity in the crisis period. In addition it can be seen that the stock market returns’ behavior have volatility clusters no matter the sub-period and as a consequence analysis under normality lack of an appropriate foundation.

As a complement of this investigation there can be seen in Table 1 that there are estimations of descriptive statistics, and it can be seen that taking into account the data of returns stock market indexes and the three sub-periods have a non-lineal behavior and showing a high kurtosis and skewness, also complementing each other through Jarque-Bera’s normality test (Jarque and Bera, 1987), which is rejected in the full period and in sub-periods of stability, crisis, and post-crisis.
Table 1. Descriptive statistics of NAFTA 2002-2016 stock markets

[Stable, Crisis, Post-Crisis]

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<tbody>
<tr>
<td></td>
<td>USA (S&amp;P 500)</td>
<td>CAN (S&amp;P TSX)</td>
<td>MEX (IPC)</td>
<td>USA (S&amp;P 500)</td>
</tr>
<tr>
<td>Mean</td>
<td>0.00018</td>
<td>0.00024</td>
<td>0.00031</td>
<td>0.00017</td>
</tr>
<tr>
<td>Median</td>
<td>0.00059</td>
<td>0.00103</td>
<td>0.00097</td>
<td>0.00054</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.10424</td>
<td>0.11932</td>
<td>0.16946</td>
<td>0.05570</td>
</tr>
<tr>
<td>Minimum</td>
<td>-0.09470</td>
<td>-0.13259</td>
<td>-0.11210</td>
<td>-0.04307</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.01256</td>
<td>0.01408</td>
<td>0.01627</td>
<td>0.01038</td>
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<tr>
<td>Skewness</td>
<td>-0.22340</td>
<td>-0.52161</td>
<td>-0.08572</td>
<td>0.29942</td>
</tr>
<tr>
<td>Probability</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
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</tbody>
</table>

4.2. Dynamics of dynamic correlations through Archimedean copulas

In this section dynamics of correlations is analyzed out of the sample between each pair of stock markets of Canada, USA, and Mexico during stable, crisis, and post-crisis periods from 02/08/2002-29/12/2006, 02/08/2007-30/12/2011 and 02/08/2012-30/12/2016 respectively. Marginal distribution functions are used to adjust though a density kernel Gaussian function and then used in the estimation of each of the Archimedean copulas under analysis. The overall sample was 1054 estimations out of the general sample for each analyzed period. Periods were chosen according to the events that worsen subprime crisis and world financial crisis.

There are some key dates of June, 2007 when the first structure products with subprime mortgage or high-yield bond start to fall in the Bear Stearns bank this generates a lack of credit and suspicion among banks like Merrill Lynch, JPMorgan Chase, Citigroup and Goldman Sachs on September 17, 2007. Such problems propitiated the early period of
crisis with Bear Stearns takeover, and was worse with the Lehman Brothers bankruptcy and the purchase of Merrill Lynch by the Bank of America in September 17\textsuperscript{th}, 2008. The world financial crisis has been considered by experts like the most profound recession since the World War II because its negative effects quickly spread around the world until they impacted European community in 2010 mainly in Greece, Italy, Ireland, Portugal, and Spain. Figures 3, 4, and 5 show changing patterns through time of estimated correlations out of the sample.

**Figure 3. Dynamics of correlations between USA and Canada**

![Clayton Copula](image1)

![Frank Copula](image2)

![Gumbel Copula](image3)
Figure 4. Dynamics of correlations between USA and Mexico

Figure 5. Dynamics of correlations between Canada and Mexico
Through the analysis of the three correlation graphics there can be seen that correlations behavior are similar to a non-stationary process to each pair of stock markets returns under Clayton, Frank and Gumbel copulas but with a different scale in the three periods of study. It can be seen that in the three graphics during the stable period correlations start going up until reaching a maximum value of 0.5024, but its tendency is immediately interrupted and its fall is maintained during an interval of time. Even though correlations correct such fall tendency after registering a minimum value of 0.1912, however the levels never reached again the maximum average, even they are under this value, but an exception is for the correlations between USA and Mexico.

The variability during the world financial crisis in the correlation level is notorious compared to the stability period as it can be seen in the three graphics. During the crisis period the difference between the minimum and maximum reduced to reach average values of 0.3557 and 0.6480 under different respective copulas. In spite of the characteristic of this period is a high integration degree of NAFTA stock markets especially between USA and Mexico. The pattern of correlation dynamics has experimented long periods of correlations decreasing tendency that also reached stability levels of this period. As an example USA-Canada and Mexico-Canada correlations of their relationship decreased drastically from 0.5412 to 0.2606 and 0.2581 in September, 2007 to September, 2008 under the Clayton copula respectively.

The next decreasing period in correlations was during the European sovereign debt crisis although with a few impact in respect to the sub-prime mortgage crisis. Correlations between USA-Canada decreased from December, 2010 to April, 2011 from 0.5289 to 0.4097, 0.6223 to 0.4878 and 0.6368 to 0.4925 under Clayton, Frank and Gumbel copulas. For the relationship USA-Mexico correlations decreased from 0.5484 to 0.4590, 0.6478 to 0.5051,
0.6398 to 0.4796, while the tendency of the relationship Canada-Mexico was from 0.6137 to 0.4590, 0.6823 to 0.5522, and 0.6556 to 0.5419 in the same order of the copulas family.

During the post-crisis period the three graphics show that correlations start immediately with a decreasing tendency during the first nine months, followed by a change in the tendency that starts oscillating levels over the stable period, but under the reached levels of the financial crisis, except for the correlations between stock markets of Canada and Mexico. Finally, other important finding is that correlations react quickly to changing conditions of analyzed markets, this contributes to a higher exposure to the systemic risk associated to the impact of the world financial crisis and the European sovereign debt crisis. Although long spaces can be seen with low correlations between NAFTA stock markets particularly during stable and crisis periods. This fact increases the interest of national and international institutional investors to invest and get benefits of diversification of the design of financial assets portfolios of such stock markets even in extreme likelihood periods.

4.3. Statistical evidence of contagion

The existence of financial contagion is proved in this section through the \( t \) statistics under the Clayton, Frank and Gumbel copulas. This statistical evidence is rejected or accepts the null hypothesis that correlations do not increase during the financial crisis period in respect to the correlation of stability and post-crisis periods. This investigation replicates correlations for stable, crisis, and post-crisis periods by using 10,000 bootstrap stationary replicas to determine bootstrap \( p \)-value.

In Table 2 there can be seen reported the average and variance of estimated correlations out of the sample through the copulas family, the average \( t \) statistics of the 10,000 bootstrap replicas, also the \( p \)-value of the contagion effect statistics among the three stock markets of the NAFTA during the three periods of analysis.
## Table 2. Statistical evidence of contagion effect

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th></th>
<th>Variance</th>
<th></th>
<th>Estable-Crisis</th>
<th></th>
<th>Crisis-Post crisis</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stable</td>
<td>Crisis</td>
<td>Post crisis</td>
<td>Stable</td>
<td>Crisis</td>
<td>Post crisis</td>
<td>t-test statistic</td>
<td>p-value</td>
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<tr>
<td>Panel A: Results for the Clayton copula</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USA-Canada</td>
<td>0.3088*</td>
<td>0.4823*</td>
<td>0.4187*</td>
<td>0.0050</td>
<td>0.0047</td>
<td>0.0026</td>
<td>57.1263*</td>
<td>0.0045</td>
</tr>
<tr>
<td>USA-Mexico</td>
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<td>0.4934*</td>
<td>0.3553*</td>
<td>0.0037</td>
<td>0.0008</td>
<td>0.0025</td>
<td>81.8732*</td>
<td>0.0009</td>
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<tr>
<td>Canada-Mexico</td>
<td>0.2784*</td>
<td>0.4029*</td>
<td>0.3576*</td>
<td>0.0024</td>
<td>0.0059</td>
<td>0.0053</td>
<td>76.8757*</td>
<td>0.0021</td>
</tr>
<tr>
<td>Panel B: Results for the Frank copula</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USA-Canada</td>
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<td>0.5599*</td>
<td>0.4891*</td>
<td>0.0097</td>
<td>0.0065</td>
<td>0.0053</td>
<td>47.9634*</td>
<td>0.0051</td>
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<tr>
<td>USA-Mexico</td>
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<td>0.5777*</td>
<td>0.4266*</td>
<td>0.0038</td>
<td>0.0009</td>
<td>0.0032</td>
<td>68.7022*</td>
<td>0.0030</td>
</tr>
<tr>
<td>Canada-Mexico</td>
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<td>0.5658*</td>
<td>0.4074*</td>
<td>0.0052</td>
<td>0.0064</td>
<td>0.0091</td>
<td>65.5549*</td>
<td>0.0052</td>
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<tr>
<td>Panel C: Results for the Gumbel copula</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USA-Canada</td>
<td>0.3587*</td>
<td>0.5497*</td>
<td>0.4614*</td>
<td>0.0117</td>
<td>0.0064</td>
<td>0.0051</td>
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<td>0.0094</td>
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<tr>
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<td>0.0035</td>
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<td>0.0038</td>
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<tr>
<td>Canada-Mexico</td>
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<td>0.5525*</td>
<td>0.4073*</td>
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<td>0.0069</td>
<td>0.0089</td>
<td>66.6986*</td>
<td>0.0039</td>
</tr>
</tbody>
</table>

Note: The term * shows the significance level of 5%.

Under any copulas approximation the results show that average correlations are statistically significatives. Also average correlations tend to increase during the financial crisis period. Although the intensity of correlations is highly pronounced in respect to the stable period this shows evidence the contagion effect of most of the stock markets that were studied here. Relationships Canada-Mexico and USA-Canada seem to be affected by contagion of world financial crisis according to the increasing in terms of percent to register increasing of 59% and 77% of Clayton copula, 53% and 68% with Gumbel copula, followed by the 52%, 41%, and 38% for the relationship USA-Mexico in that order respectively. Such finding comes from the variance level that was experimented during the stable period, which is similar to the crisis period in some cases. This fact is also associated with the wide differential reached between the minimum and maximum level in the stable period that implies that estimated correlations out of the sample have high volatility.

On the other hand, t statistics results prove consistency in the estimated correlations out of the sample between each pair of NAFTA stock markets during stable-crisis and crisis-
post-crisis periods. If correlations are statistically significatives and the null hypothesis is rejected because of its p-value low or high statistics –which must be low than the 5% meaningful level- it gives clear evidence of the existence of financial contagion among stock markets of Canada, USA, and Mexico. Nevertheless, the existence of an interdependence correlation is reached when estimated correlations out of the sample are statistically significatives and the null hypothesis is nor rejected for the reached p-value. Results of low p-value and high t-statistics under any copula approximation confirm the strong evidence of contagion effect of world financial crisis among all NAFTA stock markets according to the increasing in estimations of stable and post crisis periods to the crisis period.

According to the statistics value and its significance the evidence of financial contagion seems to be stronger between developed and emerging markets, this is in the relationships between USA-Mexico and Canada-Mexico followed by the relationship between USA-Canada. Such fact confirms a higher financial interaction as a consequence from the important participation of Mexico in the North American Free Trade Agreement. Because of this the dependency of NAFTA stock markets tends to increase during finance turmoil periods and as a consequence correlation coefficients are bigger in respect to the average value. Such results are consistent to the findings in the investigations of Arouri et al. (2013) and Mollah et al. (2016), they support statistically the evidence of financial contagion of the USA stock market to the stock markets of Canada and Mexico.

4.4 Correlations behavior during the financial crisis period

The estimated correlation analysis out of the sample among NAFTA stock markets shows relatively higher and volatile patterns during the global financial crisis. Such findings could have great implications for portfolio designers or hedge funds that constantly interact in stock markets of Canada, United States of America and Mexico. Something that is commonly
found in literature is that high levels in correlations can reduce the benefits of diversification facility, because those portfolios that were done by capital titles from these countries are exposed to a higher systematic risk. Likewise, high observed volatility in estimated correlations can be suspicious among institutional international investors to use them like tools in the efficient assignment of capital. For such reasons the study of dynamic behavior of changes and variability of correlations is important during the global financial crisis because it gives more information about the impact of external collisions in correlations.

Dynamic behavior of estimated correlations is governed by the mean conditional equation, which includes a dummy variable to catch the global financial crisis regime like this:

$$\rho_{ij,t} = \delta + \sum_{k=1}^{p} \phi \rho_{ij,t-k} + \phi DM_t + \epsilon_{ij,t},$$

(17)

where $\rho_{ij,t}$ is the correlation among each return of Canada, United States of America and Mexico stock markets. $DM_t$ is the dummy variable that measures the direct impact of the event of the global financial crisis over the dynamic of the estimated correlations when the $\phi$ estimated parameter is positive and meaningful.

According to Ljung-Box test to squared correlations\(^7\) the results show strong heretoscedasticity presence which is meaningful in the estimated correlation series to all relations based on the copula estimation. Such fact shows the need of an estimation of a GARCH model with a dummy variable to appropriately model the changes of volatility in

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\(^7\) The results of the Ljung-Box statistics test are not reported in the analysis because of the lack of space but they are available for concerns.
the behavior of correlations of Canada, United States of America and Mexico stock markets respectively.

The conditional variance equation follows a GARCH process (1,1) such as:

\[
h_{ij,t} = w + \alpha \varepsilon_{ij,t-1}^2 + \beta h_{ij,t-1} + \gamma DM_i
\]  

(18)

Where the statistics meaning of \(\gamma\) parameter of the dummy variable receives the crisis event impact which implication is that more volatile fluctuation in estimated correlations during the global financial crisis.

As an overview the meaning of the dummy variable parameters shows structural changes in mean or variance of estimated correlations as a consequence of external collisions during the global financial crisis period. Tables 3 and 4 show estimated parameters of GARCH model (1,1) using the maximum likelihood method for the pre-crisis vs crisis and crisis vs post-crisis periods.

For pre-crisis vs crisis most of coefficients of constant terms and AR (1) are statistically meaningful to the three relations in 1% and 5% levels, and under three copula functions. The ideal number of backwardness in the mean equation of correlations was determined through information criteria of Akaike (AIC) and Schwarz (SIC). Also the estimations of dummy variable in the conditional mean equation show strong evidence that the global financial crisis hand an important impact in the correlations of Canada-Mexico and USA-Canada, because \(\varphi\) parameter is positive and statistically meaningful at 1% level.
### Table 3. Structural changes test in correlations of pre-crisis and crisis periods

<table>
<thead>
<tr>
<th></th>
<th>Mean equation</th>
<th>Variance equation</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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<tr>
<td></td>
<td>$\delta$</td>
<td>$\phi$</td>
<td>$\omega$</td>
<td>$\alpha$</td>
<td>$\beta$</td>
<td>$\gamma$</td>
<td>$Q^{(20)}$</td>
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<tr>
<td><strong>Panel A:</strong></td>
<td>Estimate</td>
<td>Parameters for</td>
<td>under the Clayton copula</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>1.0070*</td>
<td>0.0013*</td>
<td>0.0002*</td>
<td>0.2156*</td>
<td>0.7478*</td>
<td>-0.0000006**</td>
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<td>(0.0009)</td>
<td>(0.0003)</td>
<td>(0.0000)</td>
<td>(0.0294)</td>
<td>(0.0146)</td>
<td>(0.0000)</td>
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<tr>
<td>USA-Mexico</td>
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<td>0.0001</td>
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<td>0.1503*</td>
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</tr>
<tr>
<td></td>
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<td>(0.0012)</td>
<td>(0.0005)</td>
<td>(0.0000)</td>
<td>(0.0078)</td>
<td>(0.0089)</td>
<td>(0.0000)</td>
</tr>
<tr>
<td>Canada-Mexico</td>
<td>-0.0011*</td>
<td>1.0023*</td>
<td>0.0018*</td>
<td>0.0003*</td>
<td>0.2558*</td>
<td>0.6831*</td>
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<td>(0.0003)</td>
<td>(0.0008)</td>
<td>(0.0002)</td>
<td>(0.0000)</td>
<td>(0.0238)</td>
<td>(0.0133)</td>
<td>(0.0000)</td>
</tr>
<tr>
<td><strong>Panel B:</strong></td>
<td>Estimate</td>
<td>Parameters for</td>
<td>under the Frank copula</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USA-Canada</td>
<td>-0.0004</td>
<td>1.0005*</td>
<td>0.0015*</td>
<td>0.0003*</td>
<td>0.1693*</td>
<td>0.8010*</td>
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<tr>
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<td>(0.0006)</td>
<td>(0.0013)</td>
<td>(0.0004)</td>
<td>(0.0000)</td>
<td>(0.0262)</td>
<td>(0.0179)</td>
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<tr>
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<td>0.0001</td>
<td>0.0011*</td>
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<td>0.5821*</td>
<td>-0.000003*</td>
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<tr>
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<td>(0.0015)</td>
<td>(0.0003)</td>
<td>(0.0000)</td>
<td>(0.0268)</td>
<td>(0.0464)</td>
<td>(0.0000)</td>
</tr>
<tr>
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<td>0.9956*</td>
<td>0.0015*</td>
<td>0.0006*</td>
<td>0.2498*</td>
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<td>(0.0011)</td>
<td>(0.0003)</td>
<td>(0.0000)</td>
<td>(0.0241)</td>
<td>(0.0241)</td>
<td>(0.0000)</td>
</tr>
<tr>
<td><strong>Panel C:</strong></td>
<td>Estimate</td>
<td>Parameters for</td>
<td>under the Gumbel copula</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USA-Canada</td>
<td>0.0017**</td>
<td>0.9959*</td>
<td>0.0021*</td>
<td>0.0013*</td>
<td>0.0033</td>
<td>0.4902*</td>
<td>-0.000017*</td>
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<tr>
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<td>(0.0019)</td>
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<td>(0.0000)</td>
<td>(0.0039)</td>
<td>(0.0338)</td>
<td>(0.0000)</td>
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<tr>
<td>USA-Mexico</td>
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<td>(0.0184)</td>
<td>(0.0381)</td>
<td>(0.0000)</td>
</tr>
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<td>0.0012*</td>
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<td>(0.0000)</td>
<td>(0.0267)</td>
<td>(0.0239)</td>
<td>(0.0000)</td>
</tr>
</tbody>
</table>

Such finding supports the presence of a regime change in the incorporation of stock markets which made that institutional investors adopted a mob behavior in such countries, because of the panic to finish their positions from the market this was because of the global financial crisis that worsen because of credit restrictions from the banking sector. And since such stock markets were settled in by the NAFTA the chances of international diversification are non-existent because of the mob behavior phenomena. On the other hand, the lack of evidence in USA-Mexico correlations were not meaningful affected during the global financial crisis, this does not mean that such stock markets were less susceptible to the devastating effects of the crisis. Such finding can be explained by the fact that correlations between USA-Mexico did not have the same drastic falling in the beginning of the subprime financial crisis like it happened in the correlations between Canada-Mexico and USA-
Canada. In the case of USA-Mexico correlations they increased meaningfully during subprime financial crisis and global financial crisis, and they kept a relative stable tendency under different functions of copulas because they never backed to the pre-crisis period levels. Such fact is supported by the high level of integration of USA and Mexico during the crisis period.

According to the estimation of the variance equation the statistics of $\alpha$ and $\beta$ parameters show the existence of ARCH effects and high persistence in volatility to most of estimated correlations through different copula functions. Also coefficients of the dummy variable $\gamma$ are meaningful at 1% and 5% levels even though their impact is negative because of correlations experimented important swinging after the contradiction in the global credit which implies that the volatility of estimated correlations tend to decrease or simply they do not have abrupt changes during crisis period. Such finding shows the fact that the structure of correlations is stable among the stock markets of Canada, United States of America and Mexico. So certain periods of global financial crisis can be taken as an advantage by institutional investors unfavorable to the risk to obtain benefits from the diversification in the design of strategies of ideal investments.

To the crisis vs post-crisis period the results of equation of mean are similar to the ones of the pre-crisis period, because most of coefficients of constant terms and AR (1) are statistics meaningful at 1% and 5%. In the case of the dummy variable coefficients results show that the impact in correlations are still positive and meaningful during the global financial crisis, and also for the relation between USA and Mexico under Frank copula.
<table>
<thead>
<tr>
<th></th>
<th>Mean equation</th>
<th>Variance equation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>δ</td>
<td>ϕ</td>
</tr>
<tr>
<td><strong>Panel A</strong>: Estimate Parameters for correlations under the Clayton copula</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USA-Canada</td>
<td>0.0025*</td>
<td>0.9941*</td>
</tr>
<tr>
<td></td>
<td>(0.0007)</td>
<td>(0.0016)</td>
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<tr>
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<td>(0.0022)</td>
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<tr>
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<td>(0.0006)</td>
<td>(0.0015)</td>
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<tr>
<td><strong>Panel B</strong>: Estimate Parameters for correlations under the Frank copula</td>
<td></td>
<td></td>
</tr>
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<td>USA-Canada</td>
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<td><strong>Panel C</strong>: Estimate Parameters for correlations under the Gumbel copula</td>
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<td>(0.0013)</td>
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<tr>
<td>USA-Mexico</td>
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<tr>
<td>Canada-Mexico</td>
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<tr>
<td></td>
<td>(0.0004)</td>
<td>(0.0009)</td>
</tr>
</tbody>
</table>

Such finding implies that estimated correlations of the simple are meaningfully higher among Canada, USA and Mexico during the contagion of global financial crisis period in comparison to the correlations of the post-crisis period.

In the case of the estimation of variance equation the evidence of clustering phenomena and the high persistence in volatility are still meaningful. The statistics meaning of the γ coefficient shows that volatilities of estimated correlations do not change through time, in fact they decrease. Such finding confirms that administrators of the international portfolio can reach diversification benefits during the contagion crisis period, because of the exposure to the risk of portfolios that are compound of financial instruments from such stock markets can decrease.
5. Conclusions

Proving the financial contagion which was leaded by the subprime and post-crisis among the NAFTA stock markets of the North American Free Trade Agreement. The dates that were taken to analyze the data were form January 2nd, 2002 to December 31st, 2016, having three periods: stable or pre-crisis from 2002 to 2006, crisis from 2007 to 2011, and post-crisis from 2012 to 2016.

This investigation did an analysis about financial contagion by applying copulas theory through Archimedean family copulas in order to analyze the relationships of dynamics dependency or the dynamics correlations among stock markets of the NAFTA. The t statistics was used to prove correlations out of the sample from the sample of stock markets during stable crisis, financial crisis, and post-crisis periods to evaluate the effects of contagion. The analysis was also complemented firstly by applying bootstrap procedure to estimate p-value of the t statistics, and to give robust evidence of the contagion hypothesis among stock markets of Canada, Mexico, and USA, and to end it through a structural change analysis between pre-crisis vs crisis and crisis vs post-crisis periods, also to robust the evidence of contagion through a structural change.

Statistics sustained results confirm the existence of financial contagion among NAFTA stock markets. The empirical evidence shows that the existence of financial contagion was stronger among developed and emerging markets, this is in relationships of USA-Mexico and Canada-Mexico, followed by the relationship among developed markets, this is the relationship of USA-Canada, and Canada- Mexico, then the relationship among developed markets, and this is the relationship of USA-Canada. To sum up Canada, Mexico and USA stock markets were affected by the world financial crisis.
References


