**Sectoral dependence and contagion in the BRICS grouping: an application of the R-vine copulas**

# **Chapter 1 Introduction**

## **Background and problem statement**

The minimum variance portfolio introduced by Markowitz (1952) had a major effect on how portfolio allocation is considered. The main pivot in ideology was that a portfolio should not only maximize future individual asset returns, but also minimize the correlations between said assets. Several prominent methods are based on the principle of correlation of assets. For example, a simplified approach is proposed by Elton, Gruber, & Padberg (1976) which attempts to describe the correlation structure using either a single index model or by assuming that all pairwise correlations are the same. More advanced techniques that dampen unusually large estimates for correlations have also been considered by Ledoit & Wolf (2004).

Other studies propose that portfolio allocation should depend on whether the economy is in a tranquil or turmoil market regime. For example, multiple market regimes have been represented by asset returns that follow bimodal distributions (Buckley, Saunders, & Seco, 2008). The authors of the latter paper generalize the minimum-variance portfolio of Markowitz (1952) so that the returns of assets can follow a Gaussian mixture distribution.

In addition, still in the context of rebalancing portfolios, studies attempted to uncover whether correlations of asset returns increase during turmoil market regimes. For example, Ang & Bekaert (2002) develop a regime-switching process that considers the increase in correlation of assets during turmoil periods. The same authors found that following such a strategy dominates other static strategies in the out-of-sample testing period (Andrew Ang, 2004). This lead to a variety of authors studying the increase in correlation during turmoil market conditions (see for example Campbell, Koedijk, & Kofman (2002), Graflund & Nilsson (2002) and Pelletier (2006)). Thus, these studies determine their asset allocation strategy by distinguishing between contagion, a surge in correlation during turmoil market regimes, and interdependence, whereby the correlation during tranquil and turmoil market regimes are not significantly different.

While literature abounds in distinguishing between contagion and interdependence, there is however, no consensus in terms of the methodology to be used to distinguish between the two concepts. Early papers only focussed on changes in the correlation structures between assets if there is a shock in one of the markets (King & Wadhwani, 1990). A prominent paper of Forbes & Rigonon (2002) in turn proved that the correlation estimate is biased since it depends on the variance of both markets. Forbes & Rigonon (2002) and others (see Boyer, Gibson, & Loretan (1999) and Loretan & English (2000)) continue to study unbiased estimators of the correlation structure but Corsetti, Pericoli, & Sbracia (2005) proves that these estimators have too stringent assumptions. Other authors like Horen, Jager, & Klaassen (2006) focussed on multiple regression techniques whilst others like Billio, Duca, & Pelizzon (2005) and Ye, Luo, & Liu (2017) considered regime switching models and quantile regression, respectively. Generalized Auto Regressive Conditional Heteroscedasticity (GARCH) type models have also been considered by Bonga-Bonga (2018) and Akhtaruzzaman & Shamsuddin (2018). By leaning more on extreme value theory, Longin & Solnik (2001) test for contagion by testing for significant correlation in the case of extreme returns. Furthermore, other authors have considered incorporating the copula methodology to measure contagion (Costinot, Roncalli, & Teiletche, 2000). When this methodology is used, it allows the practitioner to determine changes in linear and non-linear correlation structures. This is important since linear relationships assume that a change in one asset corresponds to a constant change in the other. On the other hand, non-linear relationships allow the relationship between the variables to change as their values change. By incorporating the R-Vine copula methodology, it allows one to find the optimal correlation structure as well (Cubillos-Rocha, Gomez-Gonzalez, & Melo-Velandia, 2019).

This study aims to add to this line of literature by proposing a new methodology to distinguish between contagion and interdependence. Contagion is in general defined as the extent of transmission of shocks during a financial crisis from one market to another. Hence, two assets will experience contagion if one can find significant correlation in the negative tails of their joint distributions, i.e. during turmoil regimes. This study adds to this line of reasoning by also testing the significance of the correlation in the positive tails of the joint distributions, i.e. during tranquil, prosperous regimes. If significant correlations can be found in the negative and positive tails, we argue that the markets are experiencing interdependence rather than contagion. This will be done by estimating the joint distributions using the R-Vine Copula methodology introduced by Joe (1997) and testing the Tail Dependence Coefficients introduced by Longin & Solnik (2001) for significant correlations in the tails of the joint distributions.

The developed methodology to distinguish between contagion and interdependence is presented by considering the Financial, Industrial and Resource sectors of the BRICS countries, i.e. Brazil, Russia, India, China and South Africa, since it consists of 5 major emerging economies that provide 23.2% of the world GDP as of April 2018 (IMF, 2018). Also, since developed markets tend to have lower costs of capital whilst emerging markets provide a higher return on capital (Henry, 2007), this set of countries should be of heightened interest to investors considering international portfolio diversification. The sectors are chosen to represent the main sources of growth for these countries and to focus on the effect of the continuous effort to align their stances on regional, financial and economic challenges (Info BRICS, 2019).

## **Research question**

Contributions to the study of contagion and interdependence by making use of copulas are presented by authors such as Hu (2006), Rodriguez (2007), Chollete, Heinen, & Valdesogo (2009) and Horta, Mendes, & Vieira (2010). These authors focus mainly on mixture copula models, regime switching copula models and testing whether there is an increase in the Kendall’s tau coefficient, a non-linear estimate of correlation, between turmoil and tranquil regimes. Other authors like Costinot, Roncalli, & Teiletche (2000), (Chan-Lau, Mathieson, & Yao (2004) and Cubillos-Rocha, Gomez-Gonzalez, & Melo-Velandia (2019) focus on integrating the copula methodology with extreme value theory.

It is against this backdrop that this study aims to add to the methodological literature by distinguishing between contagion and interdependence using R-vine copulas and Tail Dependence Coefficients (TDC). The methodology is displayed by considering the contagion and interdependence between the Financial, Resource and Industrial sectors of the BRICS economy. Contributions to the study on contagion and interdependence within the BRICS context include works by Zhang, Li and Yu (2013), Bekiros (2014), Jin and An (2016), Mensi, Hammoudeh, Nguyen et al (2016), Paul and Gideon (2017), Ji, Bouri and Roubaud (2018) and Bonga-Bonga (2018). To consider contagion on a sector level within the BRIC countries and international markets, Ahmad, Mishra and Daly (2018) study contagion between six key sectors of the BRIC countries, US and Europe. The authors show the relevance of studying contagion on a sectoral level by proving that the contagion effect is different for different sectors.

The focus of this study is then to consider a different methodology to identify contagion and interdependence as well as consider contagion on a sectoral level on the BRICS grouping. Hence, our research questions are as follows:

* Can one distinguish between contagion and interdependence by testing for significant upper and/or lower tail dependence?
* Does contagion *or* interdependence exist between sectors of the same country?
* Is there contagion *or* interdependence between the same sectors of different countries?
* Is there contagion *or* interdependence between different sectors of different countries?

## **Research methodology**

To study the contagion effects between the sectors of the BRICS countries, the study will make use of the regular vine methodology as suggested by Cubillos-Rocha, Gomez-Gonzalez and Melo-Velandia (2019), who studied exchange rate contagion between different regions of the world. The tail dependence coefficients will be considered to measure the extent of tail dependence between the different indices. Unlike other studies, this study proposes that if it is found that only the lower tail dependence coefficient is significant, then contagion is observed between the two indices. On the other hand, if the lower and upper tail dependence coefficient is significant, then interdependence rather than contagion is observed between the two indices.

Daily data over the period of January 2006 to May 2019 is used in this study. This period is chosen as to include major events from a BRICS and an international perspective. The returns are computed using indices registered on the São Paolo Stock Exchange (BOVESPA) for Brazil, Moscow Exchange (MOEX) for Russia, the National Stock Exchange of India (NSE) for India, the Shanghai Stock Exchange (SSE) for China and the Johannesburg Stock Exchange (JSE) for South Africa. A robustness check will also be performed where the sample period will be reduced to exclude the 2007-2009 US financial crisis.

## **Importance of the study**

The analysis of the relationships between different financial assets are of integral importance in portfolio optimisation. This is due to the typical goal of diversification, which is to use the relationships of different assets to minimise the risk of an investment portfolio. These relationships change when contagion is observed, thus dampening the desired effects of diversification.

Discerning between contagion and interdependence is also of significance since it may lead the investor to different investment strategies compared to the case of contagion only.

The study of contagion and interdependence is also a clear indicator of changes in relationships of financial assets post-crisis. Hence it is important for policy makers since it may allow them to mould policies in a pre-emptive fashion.

Despite the former arguments, very few studies have considered the contagion effects between the BRICS countries, let alone on a sectoral level. This study will contribute to this line of literature as well. Moreover, with the use of the regular vine copula methodology, this study will ensure that a multitude of different correlation structures are considered and non-linear relationships are accounted for.

## **Structure of the study**

The remainder of the study is structured as follows: Chapter two presents the literature review on the evolution of contagion models. Chapter three presents the econometric technique used in the study, namely, the regular vine copula methodology with the estimation and simulation of tail dependence coefficients. Chapter four presents the data and conducts the econometric estimation. Lastly, Chapter five presents the conclusion of the study and policy implications derived from the results.

# Chapter 2 Literature Review

There has been a wide array of authors that have developed models to distinguish between interdependence and contagion. Initial studies on the subject focussed on testing whether correlations increased after economic shocks, with the seminal paper of King & Wadhwani (1990) introducing this line of literature. Using hourly stock market data from the New York, Hong Kong and London stock exchanges before and after the October 1987 US stock market crash, the authors studied what the effect of an idiosyncratic shock in one market will be on another market, and how this shock will affect the correlation structure of the two markets. The authors found increases in correlation after the stock market crash and concluded that there in fact exists contagion between the markets rather than interdependence. This line of work was extended by Lee & Kim (1993) who considered the weekly returns of 12 stock markets over the October 1987 crash. The authors also considered whether significant changes in correlation is observed after the crash. The literature was extended by incorporating a factor analysis component, which in turn is used to measure the relative importance before and after the crash of domestic and international factors in the investment decision making process.

Later studies, however, have revealed that focussing solely on changes in correlation might lead to ambiguous results. A prominent paper by Forbes & Rigobon (2002) proves that a correlation estimate is biased and is in fact conditional on the variance of the market that provides the initial shock. This leads to the finding that heteroscedasticity in market indices will naturally lead to higher correlations during a financial crisis. Hence, solely studying the raw correlation estimate after a financial shock will more often than not lead to the spurious conclusion of contagion when, in fact, there is only interdependence at play between two indices. The authors proceed with this line of thought and provide a closed form expression for an unconditional correlation estimate under the assumptions of no exogeneous global shocks and no feedback from the market that did not initially experience the shock. This methodology is tested by considering contagion between the financial markets of 28 countries during the US stock market crash of 1987, the Mexican Peso crisis of 1994 and the East Asian crisis of 1997. A Vectorised Auto Regression (VAR) model is applied to tranquil and turbulent periods to consider the changes in the variance-covariance structure. Short term interest rates of the US, country in crisis and corresponding country are also included for control variables. After applying the correction factor to the calculated correlations, it is shown that no contagion effect was truly present, but rather interdependence of the market indices. Others like Boyer, Gibson, & Loretan (1999) and Loretan & English (2000) have also considered correcting for the bias in the correlation measure but Corsetti, Pericoli, & Sbracia (2005) show that the supposed results of these improvements are not realistic since too stringent and unrealistic assumptions are made regarding the variance of the country-specific shocks.

To circumvent these issues, multiple regression techniques have also been considered. This line of literature of discerning between interdependence and contagion using regression was introduced by Horen, Jager, & Klaassen (2006). The authors considered studying the existence of contagion effects during the Asian crisis of 1997 from the origin of the crisis, the exchange market of Thailand, to the exchange markets of the Philippines, Indonesia, Malaysia and Korea. The authors follow the work of Girton & Roper (1977) by constructing an Exchange Market Pressure (EMP) variable as the response variable which is a function of the change in exchange rate, the change in interest rate and money supply for each country. This is necessary since the bulk of the exchange rates that are considered are pegged against the US dollar. Finally, the authors model the EMP of a country by considering a set of macro-economic factors and the EMP of Thailand. To find the degree to which contagion takes place, the authors also add a variable that is equal to zero in tranquil periods and equal to the EMP of Thailand in crisis periods. The coefficient of this variable indicates the degree of contagion from Thailand to other countries. If this state variable is significant, contagion is present. If not, only interdependence is observed. Evidence of contagion is found from Thailand to Indonesia and Malaysia, whereas interdependence is observed between Thailand and Korea and the Philippines. In line with this methodology, Billio, Duca, & Pelizzon (2005) incorporate endogenous regime switching by using Markov switching Error Correction Models. By doing this, the authors provide a way to ensure that the crisis periods are endogenously defined instead of arbitrarily by the researcher. Moreover, by considering the estimated coefficient of the error correction term, the authors can directly test whether investors ignore economic fundamentals during times of economic crisis. The authors continue by discerning between contagion and interdependence for the European stock market, Hong Kong stock market and the American Stock market during the Asian crisis of 1997. The authors found evidence for contagion between these markets and by considering the error correction term, they could deduce that economic fundamentals tend to be ignored during crisis periods. By utilizing time-varying quantile regression, Ye, Luo, & Liu (2017) studied contagion and interdependence between Asian, US, and European equity markets during the 2007-2009 US banking crisis and during the 2010 Greek sovereign bonds downgrading. The authors make use of the quantile-specific odds ratio (qor) that indicates the odds of two return indices simultaneously being below specified quantiles. This method has the added advantage of a clear interpretation since it is location and scale independent, thus providing a more transparent assessment of the local association structures. The authors found strong evidence of contagion from the US to all tested markets during the banking crisis. The Greek sovereign bonds downgrading, in comparison, did not have such a strong contagion effect on the other markets, indicating that Greece may play a much more subdued role in the global economy. By utilizing quantile regression, Lyocsa & Horvath (2018) also considered contagion from the US equity market to the equity markets of 6 developed countries. The authors also incorporate a wide array of control variables that consider the level and volatility in developed equity markets, gold and oil markets, foreign exchange markets, market liquidity, the credit market and business cycle-related expectations. By controlling for these variables, the authors can test for contagion following the definition provided by Bekhaert, Harvey, & Ng (2005). The methodologies of Billio, Duca, & Pelizzon (2005) and Ye, Luo, & Liu (2017) were combined by Ye, Zhu, Wu, & Miao (2016) who consider a Markov regime-switching quantile regression model to detect financial contagion. The authors continue to use this technique to consider changes in financial contagion, estimated through the quantile regression component, throughout different Markov states, i.e. different periods of financial shock.

Correlation analysis is also circumvented by authors like Bekhaert, Harvey, & Ng (2005). A two-factor asset pricing model of the excess return of a country is used to detect interdependence and contagion between the regions of Europe, Latin America and Southeast Asia. The two factors are the regional equity portfolio return and the U.S. equity market return. The estimated coefficients of the model are also allowed to be time-varying, allowing researchers to study varying degrees of market interdependence. The idiosyncratic shocks of the regional equity portfolio and the U.S. equity market return are also included in the two-factor model. This is expanded by modelling the idiosyncratic shocks with a Generalised Auto Regressive Conditional Heteroscedasticity (GARCH) model with asymmetry. Overall and period specific contagion is then identified by studying the relationship of the residuals of different markets. The authors found that the Mexican Peso crisis (1994) did not provide a significant surge in contagion between markets. The Asian crisis (1997), however, shows clear evidence of being a contagious event, especially within the Oceanic countries. The use of GARCH-type models can be seen by a variety of authors. A VAR-DCC-GARCH model is employed by Bonga-Bonga (2018) to specifically assess contagion between South Africa and the other BRICS nations during global and BRICS-specific financial crises. The main findings from the author is that there exists capital market interdependence between Brazil and South Africa and that the contagion effect of crises originating from Russia, India and China on South Africa is greater than the contagion effect of crises originating in South Africa on said countries. A DCC-GARCH model was used by Akhtaruzzaman & Shamsuddin (2018) to measure interdependence and contagion between the US and other developed, emerging and frontier economies. The main contribution is that the authors provide a disaggregated view by focussing on contagion between financial and non-financial firms. By using a Fractionally Integrated Asymmetric Power ARCH (FIAPARCH) model, Kenourgios & Dimitriou (2015) considered contagion on a sectoral level between six developed and emerging economies. The authors found that Consumer Goods, Healthcare and Technology were less affected by the Global Financial Crisis (GFC).

The use of the copula methodology in the context of financial contagion has received much attention in recent literature. The inaugural study by Costinot, Roncalli, & Teiletche (2000) use Normal and Extreme Value copulas to study interdependence and contagion during the Asian Crisis between the stock and exchange markets of Thailand, Korea, Malaysia, Philippines and Indonesia. It is found that the main advantage of using the copula methodology is the fact that it allows for the analysis of scenarios that go beyond normal dependence structures. Building on this, Chan-Lau, Mathieson, & Yao (2004) used Extreme Value Theory measures whilst utilizing copulas. Specifically, they developed contagion measures for the bottom and top 5 percent returns, hence defining bear and bull market contagion respectfully. By studying the weekly stock market returns of a wide array of mature and emerging economies, the main findings of the authors are that there is a significant difference in the contagion patterns across regions. Also, contagion is higher for negative returns, i.e. during bear markets. A mixed copula approach is considered by Hu (2006) to take account for various patterns of dependence structures. The authors consider a Gaussian copula with no tail dependence, Gumbel copula with positive right tail dependence and its survival counterpart with positive left tail dependence. By considering the weights of the mixture model, the author can ascertain whether contagion exists and whether it is more prominent during positive or negative shocks. The authors study contagion between the S&P 500, FTSE, Nikkei and Hang Seng markets. The main finding is that only left tail dependence is observed, indicating that markets are expected to depreciate together instead of appreciate together. A mixed copula approach with Markov switching parameters is used by Rodriguez (2007) to discern between interdependence and contagion between four Latin American markets during the Mexican crisis of 1994 and five East Asian markets during the Asian crisis of 1997. The advantage of using this methodology is that determining periods of economic turmoil become endogenous to the model. In studying multivariate dependence structures, Chollete, Heinen, & Valdesogo (2009) expands on this by doing a comparison between mixture copula models and canonical vine copulas. The authors find that canonical vine copulas will generally outperform mixture copulas since the latter implicitly limits the feasible region of dependence between variables. The authors continue by utilizing a regime switching canonical vine copula methodology to study the dependence structures between the G5 countries and Latin American regions. The two main findings are that canonical vine copulas generally dominate alternative dependence structures and the choice of copula can have a significant effect in modelling international portfolio returns. The copula methodology is also used by Horta, Mendes, & Vieira (2010) to test for interdependence and contagion from the US stock market to the stock markets of the Netherlands, Belgium, France and Portugal during the US subprime crisis of 2007 - 2009. Hypothesis tests based on the Kendall’s tau statistic are designed to test for the existence and the homogeneity of contagion from the US stock market to the other stock markets. The authors also develop a hypothesis test to test whether contagion to financial firms are the same as contagion to industrial firms. The authors found that there were no statistically significant differences in contagion when global or sectoral indices were considered. The existence of interdependence and contagion between developed foreign exchange and stock markets to African stock markets was studied by Paul & Gideon (2017). The authors focussed on calculating the downside cumulative mean distribution Conditional Value-At-Risk (CoVaR) whilst using copula functions. They found that the effect of global shocks to African stock markets might only manifest post-crisis. Utilizing the flexibility of regular vine copulas, Cubillos-Rocha, Gomez-Gonzalez, & Melo-Velandia (2019) studied contagion between developed and large developing economies whilst also considering whether contagion follows a geographical pattern. They found that contagion only occurs in times of currency appreciation with respect to the US dollar. The authors also find that whilst contagion is more observable within countries of similar regions, emerging market currencies are more affected by developed market currencies. This paper utilizes the techniques introduced by Cubillos-Rocha, Gomez-Gonzalez, & Melo-Velandia (2019) since the regular vine copula methodology allows for a multitude of different correlation structures that do not have to be predefined. Where the latter paper only focussed on identifying contagion, this article extends on this line of literature in a methodological manner by attempting to distinguish between interdependence and contagion. This is extremely relevant to an investor since one can follow different investment strategies in the case of interdependence or contagion. This paper also focusses on interdependence and contagion on a disaggregated level, i.e. by considering the sectors of the BRICS countries. This is relevant since diversification strategies by modern investors can underestimate the correlation between different sectoral indices, whereby additional risk is unknowingly introduced into their portfolios.

(Longin & Solnik, 2001) (Markowitz, 1952) (Elton, Gruber, & Padberg, 1976) (Ledoit & Wolf, 2004) (Ang & Bekaert, 2002) (Campbell, Koedijk, & Kofman, 2002) (Graflund & Nilsson, 2002) (Pelletier, 2006) (Forbes & Rigobon, 2002) (Boyer, Gibson, & Loretan, 1999) (Loretan & English, 2000) (Corsetti, Pericoli, & Sbracia, 2005) (Horen, Jager, & Klaassen, 2006) (Billio, Duca, & Pelizzon, 2005) (Ye, Luo, & Liu, Time-varying quantile association regression model with applications to financial contagion and VaR, 2017) (Bonga-Bonga, 2018) (Akhtaruzzaman & Shamsuddin, 2018) (Hu, 2006), (Rodriguez, 2007), (Chollete, Heinen, & Valdesogo, 2009) and (Horta, Mendes, & Vieira, 2010) (Costinot, Roncalli, & Teiletche, 2000), (Chan-Lau, Mathieson, & Yao, 2004) and (Cubillos-Rocha, Gomez-Gonzalez, & Melo-Velandia, 2019) (King & Wadhwani, 1990) (Lee & Kim, 1993)(Forbes & Rigobon, 2002) (Boyer, Gibson, & Loretan, 1999) (Loretan & English, 2000) (Corsetti, Pericoli, & Sbracia, 2005) (Horen, Jager, & Klaassen, 2006) (Girton & Roper, 1977) (Billio, Duca, & Pelizzon, 2005) (Lyocsa & Horvath, 2018) (Bekhaert, Harvey, & Ng, 2005) (Ye, Zhu, Wu, & Miao, 2016) (Bonga-Bonga, 2018) (Akhtaruzzaman & Shamsuddin, 2018) (Kenourgios & Dimitriou, 2015) (Costinot, Roncalli, & Teiletche, 2000) (Chan-Lau, Mathieson, & Yao, 2004) (Hu, 2006) (Rodriguez, 2007) (Chollete, Heinen, & Valdesogo, 2009) (Horta, Mendes, & Vieira, 2010) (Paul & Gideon, 2017) (Cubillos-Rocha, Gomez-Gonzalez, & Melo-Velandia, 2019)

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