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*Article.*

# Dynamic Asymmetric Effect of Currency Risk Pricing of Exchange Rate on Equity Markets: A Regime-Switching based C-Vine Copulas Method.

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**Abstract:** This paper investigates whether currency risk is priced differently in the different sectors (industrial, financial, and basic materials) of equity markets in a sample of developed United States of America (USA) and developing economies (Brazil, India, Poland, and South Africa). The paper makes use of the following techniques: (i) Univariate Autoregressive Fractionally Integrated Moving Average and Exponential General Autoregressive Conditional Heteroskedastic (ARFIMA-EGARCH), (ii) the Markov-Switching method (MS), and (iii) the Canonical Vine Copulas (C-Vine) techniques. Using a sample of daily data made of the foreign exchange rate against the domestic currency and equity market sectors; our findings show that there is an asymmetry effect between equities markets and the foreign exchange rate: there is a heterogeneous, strong, and positive dependence between the two. Higher equities prices are associated with depreciation of local currencies, according to US dollar (USD) exchange rates. In addition, we find that the selected emerging economies are pricing a positive and considerable currency risk. The pricing of currency risk has a varied effect in both regimes representing the states of the economy. In fact, when currency risk pricing has a beneficial impact on certain sectors of the economy, investors predict better returns.

**Keywords:** Pricing currency risk, regime-switching, sectors equity markets, state of economy, C-Vine copulas, developed, emerging.

## 1. Introduction

Foreign exchange risk is defined by Jacque (1996) as the increased unpredictability in a multinational company's worldwide consolidated earnings caused by unanticipated currency movements. In their study, Kabundi and Muteba Mwamba (2012) define exchange rate risk as the difference between the percentage change of the logarithm of the spot rate and the percentage change of the logarithm of the forward rate of the domestic currency versus the foreign currency. The currency risk price is significant in this regard since the exchange rate, which is the price of one currency in terms of another, plays a role in determining a country's economic health and that of its citizens. Setting up a foreign currency account and then using it to control foreign currency risk is the first step in managing foreign currency risk. In international business, foreign exchange risk management is critical, as it is the procedure that allows companies to protect themselves from currency risk. As a result, currency risks affect organizations operating both domestically and globally in distinct ways.

Exchange rate risk is the possibility that changes in currency exchange rates will harm a company's operations and profitability. Currency fluctuation exposes these firms to three categories of risk: economic, transaction, and translation. In both financial and macroeconomic development, exchange rate volatility is a major factor. The main purpose of this study is to figure out why currency risk pricing in equity markets is so volatile, as well as to see if currency risk pricing in equity markets has distinct effects on the conditions of their economies, given that both markets are mainly interconnected. Investors and enterprises involved in the import and export of products or services to various countries and different sectors of the economy, such as industry, financial, basic materials, technology, mining, banking, consumer staples, and so on, are susceptible to foreign exchange risk. Currency risk affects both individuals and businesses who participate in overseas markets. Institutional investors, such as mutual funds and hedge funds, as well as large multinational organizations, use the forex market and derivatives to manage currency risk.

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According to Cassel's (1918) theory of international exchange, the rate of exchange between two countries is essentially governed by the quotient between the internal purchasing power parity (PPP) and the goods of the money of each country. He previously demonstrated that if trade between the two countries is impeded more severely in one direction than in the other, the exchange rate will deviate from purchasing power parity. According to Meese & Rogofp (1988), the real interest differential and real exchange rates have the theoretically expected sign, but trade balance repressors do not. Nonetheless, the correlation is not statistically significant, and real interest differentials, save in a few exceptional circumstances, do not provide a meaningful advantage over a random walk model in forecasting real exchange rates. For more details on the theoretical and empirical framework and concept of exchange rate risk see Porter (1971).

A currency risk premium rises for each isolated country that contributes for a large percentage of market demand, resulting in the international CAPM of (Adler & Dumas, 1983; Solnik, 1974a; and Stulz, 1981). The currency risk premium, in particular, is typically tiny and inconsequential. In today's global economy, real currency risk is undeniably essential and growing for more businesses. While Bartram et al. (2010) argue that the currency risk exposure remains relevant when more of the risk is hedged, this suggests that most stocks are likely to face significant currency risk. This does not, however, imply that currency risk is priced. Then, according to a previous study, uncovered interest parity (UIP) returns are predictable and can be quite large under certain conditions. Currency risk premia must be equivalent to the return on a zero-investment portfolio position that is perfectly linked to real currency value changes. If each country has risk-free assets, the currency-premium-mimicking portfolio is just a UIP position. The unconditional and long-term UIP returns, according to Perold & Schulman (1988), are minimal. As a result, the unconditional international CAPM has a quantitatively small currency risk premium. Because PPP deviations behave roughly like real exchange rates, Adler & Dumas (1983) show that foreign currency risk is simply the percentage difference between forward and spot rates.

The pricing of currency risk in the stock market is still a contentious topic to some extent. The influence of currency risk on asset pricing has been established by several academics. De Santis & Gérard (1998), for example, establish that the risk premium's time-varying character explains why unconditional models are unable to detect extremely time-varying currency risk. In Finland, Antell & Vaihekoski (2007) find support for currency risk pricing. This suggests that the linear currency risk model may not be appropriate for non-free fluctuating currencies.

Currency risk is identified using statistical numbers that represent the possibility of a home or foreign currency's real domestic purchasing power differing from its original anticipated value on a specific future date. Changes in exchange rates alter the value of assets, resulting in currency risk exposure, as proposed by finance theory (Jorion, 1990; Adler & Dumas, 1984). Some issues, such as the breakdown of the fixed exchange system in 1973 and currency inconsistencies, have become an interesting topic to investigate. Currency crises have also shaken emerging market economies (EMEs) in recent decades, with the Asian financial crisis in 1997-98 serving as an example. Firms that operate in an international setting regard currency swings as a source of risk as a result of the global rise of financial markets and goods. In this case, the corporation will be concerned with first determining whether currency changes expose cash flows, and if this is the case, then currency risk hedging will be an issue.

According to financial theory, exchange rate risk is an unsystematic risk that can be hedged away in a well-developed market. Systematic risks, according to traditional portfolio theory, cannot be diversified away and must be priced into the capital market (Eissa et al., 2010; Mahapatra & Bhaduri, 2019). Tai (2008) investigated the possibility of asymmetric currency exposure using weekly US industry data from 1978 to 2001. That could explain why past research that focused solely on linear exposure had trouble finding it. They then look into whether asymmetric currency exposure has a price.

Currency risk is one of the most significant concerns for international investors, as exchange rate volatility can reduce the benefits of international diversification (Carrieri & Majerbi, 2006). According to standard portfolio theory, if

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the influence of currency risk does not vanish in well-diversified portfolios, there is exposure, causing investors to pay a premium to avoid this systematic risk. Hedging policies affect a firm's cost of capital, according to this idea, and it is appropriate for the firm to engage in currency hedging. As a result, if there is evidence of significant currency exposure, it is one of the price considerations considered by Ross (1976), who evaluated the arbitrage pricing hypothesis. This is a serious situation for both corporate financial managers and investors.

Mahapatra & Bhaduri (2019) investigate the dynamics of exchange rate risk pricing on the Indian stock market. In the specific period 2005 to 2016, covering the period of the financial crisis and after the financial crisis, using a random coefficient model. Antell & Vaihekoski (2012) reported a similar supportive conclusion for the pricing of currency risk in Finland. Emerging markets have presented a significant opportunity for portfolio diversification to be merged with developed markets over the previous decade (Bekaert & Harvey, 1997). The simultaneous occurrence of equity market segmentation and unconditional currency risk pricing in Africa's major stock markets was evaluated (Kodongo & Ojah, 2011). For empirical and theoretical reasons, the pricing of currency has lately attracted the attention of economists, since they play significant roles in influencing the development of a country's economy. As a result, investors frequently use the relationship between equity markets and foreign exchange rates to forecast future trends for each other.

According to Alder and Dumas (1984), finance theory posits that changes in exchange rates affect the value of assets, resulting in currency risk exposure. This theory illustrates how, depending on the multinational characteristics of the organization, any change in exchange rates might alter a corporation's overseas processes and overall benefits, which can affect stock prices. A general decline in the stock market, on the other hand, will encourage investors to seek better profits elsewhere. Following the breakdown of the Bretton Woods system, numerous international asset-pricing models were proposed to deal with unbalanced exchange rates, with currency risk playing a prominent role as a systematic element determining global asset returns. Using the multivariate GARCH-M framework, Saleem and Vaihekoski (2010) examine currency risk in the Russian stock market as well as the pricing of global and local market risks from the perspective of an international investor. Using the stochastic discount factor (SDF) framework and the generalized method of moments (GMM) technique, Kodongo & Ojah (2014) required to determine whether the volatility of African currencies drives equity risk premia.

Despite the large quantity and range of previous studies on currency risk pricing in equity markets, only a few studies focused on specific countries such as (Loudon 1993; Saleem & Vaihekoski, 2010; Antell & Vaihekoski, 2007; Al-Shboul & Anwar, 2014; Azher & Iqbal, 2016; Mahapatra & Bhaduri, 2019); whereas very few studies focused on emerging countries and African countries, such as (Kodongo & Ojah, 2012; Carrieri & Majerbi, 2006; Phylaktis & Ravazzolo 2004; Chkili 2012; Kodongo & Ojah, 2011; Kodongo & Ojah, 2014; Boako & Alagidede, 2017). Moore and Wang (2014) employed the DCC-GARCH technique to look at developed and emerging Asian markets.

This study's contribution is threefold: First, in regard of unexplored global context except Moore & Wang (2014), the study fills in the gap by considering US and emerging economies, in contrast of Moore & Wang (2014), this paper examines currency risk pricing in sectorial equity (industrial, financial, and the basic materials) markets of developed (US) and emerging (Brazil, India, Poland, and South Africa) economies in the state of the economy (calm and turmoil period). To the limit of our knowledge, this is the first study that uses empirically the ARFIMA-EGARCH Markov-Switching based C-Vine copulas approach. The use of this method allows, the flexibility, the numerical simulation to identify the risk linked to the states of the economy (high risk and the low risk) and the tractability. These characteristics differ from those of previous approaches described in the literature. Our method is more essential because it produces reliable results, overcomes the limits and assumptions of other methods, and captures the volatility in higher dimensions from exchange rates and returns in various regimes.

Second, using a structured tree and predicted durations, this paper examines the multivariate dependent structure in the upper dimension, letting us see the regime's persistence in remaining longer in one stage of economy before moving to another. The choice of sectors is based on the fact that these are among the most volatile sectors in terms of

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currency risk price volatility affected. These sectors of the economy also pique the interest of national and international investors. The choice of the US and Brazil, India, Poland and South Africa is also motivated by the fact that US is the benchmark of word economy and the selected emerging economies is among the most representative emerging economies of the continent such as America, Asia, Europe and Africa respectively.

Third, alternative methodology, which can uncover asymmetric impacts in the volatility distribution of each sector of the equity markets, backs up the findings. Using the state of the economy, we study if the shocks from floating currency risk differ in different sectors of equity markets in developed and emerging economies, as well as whether the impacts of pricing currency risk on equities are heterogeneous in sectorial markets.

The rest of this paper is organised as follows: - section two reviews existing literature, section three presents the methodology used in the study followed by a discussion of result in section four. Section five concludes the study and proposes some policy recommendation.

## 2. Literature review

Theoretically, currency risk can and should be priced. This happens when countries' consumption-opportunity sets differ, as in asset-pricing models studied by (Stulz, 1981; Adler & Dumas, 1983; and Solnik, 1974, 1993). Al-Shboul & Anwar (2014) examine whether the currency risk is priced in the Canadian equity markets prior to, during, and after the financial crises of 2007 and 2008. Using the quasi maximum likelihood estimation based multivariate GARCH and the GMM. The findings suggest that the local currency and global market risks are priced in the Canadian stock market. Furthermore, the Canadian equity market is segmented, with local market, global market, and currency risk pricing fluctuating over time. Doukas et al. (1999) use an intertemporal asset pricing testing approach to see if exchange-rate risk is priced in Japanese equity markets, allowing risk premia to alter over time in response to changes in macroeconomic conditions. The foreign exchange-rate risk premium is a crucial component of Japanese stock returns, according to their multiperiod asset pricing tests. The results show that currency risk imposes a significant risk premium for multinationals and high-exporting Japanese enterprises. The currency risk component is found to be less relevant in understanding the behaviour of average returns for low-exporting and local companies. Karolyi & Wu (2021) look into the economic mechanisms that are used to price exchange rate changes into foreign stock returns. They looked at how well two currency risk variables: a dollar-risk factor and a carry-trade-risk factor; for a range of test assets, explained monthly returns for over 47,000 shares from 46 countries over four decades. They discovered that businesses that produce tradeable goods are more likely to be exposed to currency risk, particularly during times of high exchange rate volatility. This is true independent of the criteria used to assess corporate internationalization, the benchmark factor models utilized, or the sub-periods examined. To model downward currency price risk spillover effects to Africa's equity markets, Boako & Alagidede (2017) employed value-at-risk (VaR) and conditional value-at-risk (CoVaR) based on stochastic copulas. The findings reveal that stock prices and the USD and Euro (EUR) exchange rates have a non-homogeneous weak negative relationship, meaning that higher (lower) equities prices are followed by domestic currency depreciation (appreciation). Foreign currency price risk may command a premium in several African equity markets, particularly during market upheaval, weakening any hedge capabilities of domestic stock markets for investors, according to the research. In Africa's equity markets, Kodongo & Ojah (2014) study the conditional pricing of currency risk. The findings show strong evidence of foreign exchange risk pricing with conditional time-varying currency risk in equity returns using the stochastic discount factor (SDF) framework and the generalized method of moments (GMM) technique, indicating that international investors are interested in the small size of African equity markets and factor the effect of foreseen low trading into their pricing calculus.

Azher and Iqbal (2016) analyse whether foreign exchange rate risk is priced and how well the Pakistani stock market is related to global stock markets using empirical evidence. They use industry and size portfolios generated from 180 firms trading on the Karachi Stock Exchange to investigate unconditional pricing using the iterated generalized method of moments from 1993 to 2013. Using the multi-beta asset pricing model, the results reveal that exchange risk

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is priced into the Pakistani equity markets across the whole study period. Mahapatra and Bhaduri (2019) investigate the dynamics of currency fluctuation on the Indian stock market in order to assess the risk of currency pricing and exchange rates during turbulent periods, such as before and after financial crises. They utilized a random coefficient model, and the results suggest that stock returns following the crisis react meaningfully to fluctuations in the foreign exchange rate. This shows that the bigger an industry's foreign exchange exposure, as measured by net inflows, the more exposed it is to exchange rate risk. The improper hedging by Indian firms to mitigate currency rate risk could be a valid rationale for such a premium. To analyse how capital market liberalisation has impacted risk pricing, an international model of capital asset pricing with foreign currency risk was built (Phylaktis & Ravazzolo, 2004). The findings show that not only is currency risk priced in both pre- and post-liberalisation periods, but that the efficiency of this model is also higher than that of the model that does not include currency risk, which is misspecified. Saleem & Vaihekoski (2010) look at how global and local market risks are priced, as well as international asset pricing models and currency risk in the Russian stock market.

Using the multivariate GARCH-M framework, the findings reveal that currency risk pricing in the Russian market is time-varying and affected by oil price. Market integration and currency risk pricing in the Nigerian and South African equity markets are investigated by Kodongo & Ojah (2012). They use the GMM with a multi-beta asset-pricing model to uncover the risk currency partially priced unconditionally in South Africa's stock market, which is integrated with global equity markets, using firm-level data. Nigeria's stock market, on the other hand, is not linked to the global stock market, and currency risk is not priced. Eichler and Roevekamp (2018) devised a novel currency risk metric based on American depositary receipts (ADR). They employed an ADR augmented pricing model, and the results showed a worsening fiscal balance, resulting in a rise in currency risk due to rising inflation. Antell & Vaihekoski (2012) investigate the impact of currency risk on Nordic stock markets, revealing a progressive shift from stable to variable exchange rates. They use a multivariate GARCH-M model to test a conditional international asset-pricing model with a covariance stationary specification. The findings reveal that the price and risk premium for currency risk in both stock markets are lower after currency fluctuations, particularly for Finland and its exchange rate shocks, which influence the price of currency risk in Sweden, but the opposite is not true. Carrieri & Majerbi (2006) combined portfolio and firm-level data from nine emerging economies data sets to come up with a novel indicator for the unconditional pricing of currency rate risk in the stock market. In contrast to most unconditional tests for developed markets, the findings support the concept of a significant unconditional exchange risk premium in emerging stock markets.

Nonetheless, evidence of the importance of the exchange risk element, including local market risk, at the aggregate market level exists. Tai (2008) study an asymmetric and pricing currency risk by trying to offer new empirical evidence on the matters, which are critically linked to corporate risk management and investors and also discover the possibility of asymmetric currency exposure that could clarify and tests the pricing of asymmetric currency exposure. The findings show a strong correlation between asymmetric currency exposure and currency risk pricing, implying that conditional heteroscedasticity and asymmetry play important roles in currency risk testing. Chkili (2012) uses an international capital pricing model (ICPM) to evaluate the impact of currency risk in emerging countries. Currency risk and market risk are both priced in emerging stock markets and vary over time, according to the research. Salifya & Lumengo (2020) examine the amount of currency risk pricing in ten South African firms and ten firms in the US economy to see if there is systematic or unsystematic risk in these economies. The results provide a clear signal of exchange rate risk premia when using the two- and three-factor extended capital asset pricing models. In all circumstances, exchange rate risk is systematic in developed economies, despite the availability and diversity of exchange rate hedging tools in these economies, particularly in developed economies, contrary to numerous research. Loudon (1993) stressed the need of determining whether Australian equity returns are sensitive to foreign exchange rates, as well as the decisions made in attempting to price currency risk. A two-factor asset pricing model suggests that equities returns do not include a premium for currency risk, and this study supports that theory.

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Gupta & Finnerty (1992) investigate currency risk in the price of multinational equities from an empirical approach. The significance of both the domestic and global market indexes is investigated. The data is based on monthly stock price returns for five countries, and the technique is based on Asymptotic Principal Components (APC). The findings show that, in most circumstances, exchange risk is unpriced and the domestic market index price is always known. The World Index is priced in a mixed manner, which means it is priced in some situations but not others. By looking at the Finnish stock market through the eyes of a US investor, Antell & Vaihekoski (2007) investigate whether conditional international asset pricing models are utilized to price global, domestic, and currency risks. The estimation is done with a modified version of multivariate GARCH framework of (De Santis & Gerard, 1998). During a sampling period spanning 1970 to 2004, they discovered that global risk varies with time. Local risk is not priced in the United States, but it has become considerable in Finland over time. Although it is not time-varying, this model is utilized to price currency risk in the Finnish market. This suggests that the linear currency risk formulation may be inaccurate.

Many studies have looked into currency risk pricing and found that it is valued in an international setting (Dumas & Solnik, 1995; Ferson & Korajczyk, 1995; De Santis & Gerard, 1997, 1998). Nonetheless, there is a limited quantity of evidence, and whether it is priced in a domestic environment is less certain. For example, Jorion (1991) used Ross (1976)'s Arbitrage Pricing Theory (APT) model to demonstrate that currency risk was not priced in the US stock market from 1971 to 1987. Hamao (1988), who studied the price of currency risk in the Japanese market, came to the same conclusion. As a result, the conclusions may not be accurate because these research are all based on unconditional APT, despite the fact that the literature on time-varying risk premium has been well documented in asset pricing. When the time-varying feature is ignored, the findings may be biased. As a result, the test of a conditional intertemporal capital asset pricing model (CAPM) permits risk prices to alter over time, and the conclusion demonstrates evidence of bilateral and multilateral exchange rate pricing in Japanese stocks (Choi et al., 1998).

In summary, prior studies on the pricing of currency risk in equity markets relied heavily on unconditional models and other methods based on individuals, and emerging countries. Except for Moore and Wang (2014), who look at how currency risk is priced on stock markets in developed and emerging Asian markets. The majority of these studies use data from the US, Japan, Europe, and a few African countries. Some research found evidence of exchange rate risk pricing on stock markets, while others found no evidence of significant exchange rate risk pricing. Because the results were so diverse, some researchers employed unconditional models, while others used innovative estimating techniques including conditional methods (CAPM and ICAPM). They also employed the GARCH-in-Mean approach in the previous literature, whilst others depended on the GMM, SDF, APC, ADR, CAvaR, VaR, coVaR, GARCH, and APT. The majority of these techniques have certain drawbacks. Because of the volatility of these markets, all linear models used to investigate the pricing of exchange rate risk, for example, are ineffective. The VaR model in time series has some drawbacks, such as failing to measure worst-case loss, becoming difficult to calculate with big portfolios, and different VaR approaches yielding different findings, among others. The GARCH model is particularly inappropriate because currency risk pricing in emerging economies is more unpredictable. It is preferable to employ the EGARCH model. The DCC is a diagnostic tool rather than a model. It produces non-asymptotic two-step estimators and has no asymptotic features. In this study, we employ the ARFIMA-EGARCH Markov-Switching based C-Vine copulas technique, which is a very flexible and appropriate model, after taking into account these restrictions.

As a result, our main purpose and addition to the literature is to see if currency risk pricing exists in developed and emerging sectorial equity markets, and if the risk varies depending on the economy's state. In this study, we use an EGARCH model to capture the major distribution properties of foreign exchange rate risk and the returns of the selected sectors (industrial, financial and basic material) and their conditional volatility that have been established in the literature and empirical investigations, namely serial correlation, heteroscedasticity, and asymmetry in marginal distributions (Kanas, 2000; Choy, et al., 2014). Furthermore, we use a paradigm that allows for a risk regime switch, which affects the sector of equity returns when they are exposed to foreign investors. As we analyse the states of the

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economy in this study, regime change is critical. It is obvious from the literature that this strategy is appropriate for time-series data and produces accurate findings, as evidenced by studies of (Engel, 1994; Engel & Hamilton, 1990; Bollen, et al. 2000).

After the seminar of Bedford & Cooke (2002) and the study of Aas, et al., (2009), vine copulas became increasingly prominent in statistical modelling because of their numerical adaptability and flexibility. The Vine copulas exhibit a variety of desirable qualities as compared to other copula constructions, including flexibility and wide range dependency, co-monotonicity and independence, flexible tail reliance, flexible tail asymmetry, accurate results, closed-form density, and simulation simplicity. We chose vine decomposition over other types of copulas because vine copulas, also known as pair-copula constructions, are a prominent technique for modelling copulas in high-dimensional data. They are built on a breakdown of the joint copula density into bivariate building blocks. According to Brechmann & Joe (2015) vine copulas are optimal and suited for applications requiring upper and lower asymmetric tail dependence, even better than Gaussian or multivariate Student's tv. Reason why these properties of the vine cupulas suit in the application of pricing of currency risk on sectorial equity markets.

It is clear from the foregoing review of literature on currency risk pricing on equity markets that this problem still requires additional attention. Some studies find evidence of currency risk pricing on equity markets, whereas others show no evidence of currency risk pricing on equity returns when employing various approaches that may be inappropriate with limiting assumptions. This study contributes to the existing literature by looking into the dynamic asymmetric effect, and the pricing of currency risk that may differ according to different sectors (industry, financial, and basic materials) of developed and emerging economies, as well as the state of the economy. To this end MS-based C-vine copulas is used to distinguish between the different state of the economy determined by the extent of market volatility. C-Vine is a flexible method, based on simulations of multivariate of dependence structure constructed on the tree structures. On the other hand, to find asymmetric impacts of the pricing currency risk in equity returns and, ultimately, to establish if the effects of the pricing currency risk in these sectors are homogeneous or heterogeneous

## 3. Methodology

In this section, we are going to present the univariate marginal; then, the multivariate vine copula model; and finally, we include a Markov-Switching model in the dependence structure.

### *3.1. ARFIMA-EGARCH model*

The Autoregressive Fractionally Integrated Moving Average (ARFIMA) process is expressed as:

$$\gamma(L)(1-L)^d y_t = \varphi(L)\varepsilon_t \quad (1)$$

where L and (1 − L) denote, respectively, the lag operator and the standard difference operator of an ARIMA process, it is replaced with a fractional difference operator $(1-L)^d$, where d indicates the fractional differencing parameter, $\varepsilon_t$ is independently and identically distributed (iid) and the process is covariance stationary for − 0.5 < d < 0.5; with mean reversion when d < 1. This model is a generalisation of the fractional white-noise process as described in Granger (1980), Granger & Joyeux (1980), and Hosking (1981), where, for the purpose of analysing the properties of the process, $\varphi$(L) is set equal to unity.

### *3.2. Univariate conditional volatility model*

It is clear that 1 lag is the optimal lag length, as revealed in the preliminary tests, of an EGARCH (1,1) model tested for the sample data. Furthermore, the vast majority of literature strongly supports an EGARCH (1,1) since it is sufficient to capture the instantaneous transmission of daily stock returns (Arouri, et al., 2011; Chang, et al., 2013). The heteroskedasticity test and the ARCH test are used to examine the robustness of these models' standardised residuals. Nelson (1991) introduced an asymmetric GARCH model called the EGARCH model designed to capture the asymmetry in the volatility distribution of each stock market. Let us consider a time series

$y_t = E_{t-1}(y_t) + \varepsilon_t,\ \varepsilon_t \backslash I_{t-1}$ where $E_{t-1}(y_t)$ is the conditional expectation of $y_t$ at time t − 1. The variance of the error term estimated by a univariate EGARCH (1,1) model is given by:

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$$h_t = \ln(\sigma_t^2) = \omega_t + \sum_j^k \alpha_t f(z_{j,t-1}) + \beta^* h_{t-1} \quad (2)$$

$$f(z_{j,t-1}) = [|z_{t-1}| - E(|z_{t-1}|)] + \gamma_t z_{t-1} \quad (3)$$

The conditional variance $\sigma_t^2$ of the residual factors as given by (2) is an exponential function of past own, GARCH effect measured by $\beta^*$and past standardised innovations, $z_t = \frac{\varepsilon_t}{\sigma_t}.f(z_{t-1})$ as given by (3), is a zero-mean, i.i.d. random sequence and $\gamma$ is an asymmetric effect. When $\gamma$ is negative and significant, there is indication of a leverage effect. In other words, bad news has a bigger effect on the volatility of a market than good news. The GARCH model expresses the magnitude effect, $\alpha$ measure the ARCH effect, when it is positive and significant, it indicates the presence of volatility clustering. Hence an EGARCH model is mostly practical in financial modelling (Wang & Wang, 2011). The sum of ARCH and GARCH effects is normally interpreted as a simple measure of the persistence of stock volatility.

### *3.3. Vine copula*

Primarily, copulas are known as multivariate distribution functions with uniform margins. After filtering these from the temporal patterns in each univariate series, they allow the dependency among multivariate time series innovations to be flexibly captured. Joe (1997) and Nelsen (2006) provide a more comprehensive treatment of copula models than found in their monographs. Patton (2006) pioneered research efforts to incorporate time-varying dependence in copula models, which primarily focused on parametric specifications. While the copula family is assumed to be time-invariant in these approaches, the appropriate dependence parameter is supposed to evolve according to an AR(MA)-type process. Because modelling dependence in higher dimensions is extremely difficult, most uses of dynamic or time-varying copulas have been limited to bivariate time series. This challenge is addressed by vine copula models (Bedford and Cooke, 2002).

Sklar (1959) was the first to introduce copulas, where $x = (x_1, x_2, \dots, x_n)\epsilon\mathbb{R}^n$ an n-dimensional vector with a joint cumulative distribution function F. The following formula, proven in Sklar's theorem, makes copulas suitable for statistical applications. Let the copula function C: $[0,1]^n \rightarrow [0,1]$, the multivariate distribution function is given in terms of univariate marginal Fi, for $i\,\epsilon\,(1.2, \dots, n)$, and each marginal $u_i = F_i(x_i)$ is uniformly and independently distributed on [0,1]. Such that $u_i$ is called the probability integral transformations (PIT) of the marginal distributions.

$$F(x_1, \dots, x_n) = c(F_1(x_1), F_2(x_2) \dots, F_n(x_n)) \quad (4)$$

If x is continuously a random variables, that generate a unique copula C constructed as a joint distribution F for any combination of univariate distributions $F_1, F_2 \dots, F_n$.

The density function is given by:

$$f(x_1, x_2 \dots, x_n) = c_{1,2,\dots,n}(F_1(x_1), F_2(x_2) \dots, F_n(x_n)) \prod_{i=1}^n f_i(x_i) \quad (5)$$

The expression of copula density is: $c_{1,2,\dots,n}(u_1, , \dots, u_n) = \frac{\partial^n(u_1,\dots,u_n)}{\partial u_1,\dots,\partial u_n}$. (6)

The multivariate copulas, is implemented for dimension $n \geqslant 3$, and is restricted to the non-tail dependent Gaussian and symmetric Student's t. in case of more complicated copulas, as well as asymmetric tail dependence functions. An n-dimensional distribution is decomposed from the density into a series of linked trees of bivariate copulas as constructed blocks named regular (R) vines Bedford & Cooke (2002). Moreover, R-vines are numerically tractable, Aas et al. (2009) have showed that R-Vines is decomposed in two: C-vines and D-vines. In this paper we use C-vine, the n-dimensional density in (5) is decomposed to the equation of the C-Vine given by:

$$f_c(x) = \prod_{k=1}^n f(x_k) \prod_{j=1}^{n-1} \prod_{i=1}^{n-j} C_{j,j+i\backslash 1,\dots,j-1}[F(x_j \backslash x_1, \dots, x_{j-1}), F(x_{j+i} \backslash x_1, \dots, x_{j-1})] \quad (7)$$

where j denotes the trees, i the edges that connect these trees, and c $\{\cdot,\cdot\}$ is a bivariate copula density. The tree $T_j$ has a unique node linked through edges to all the other n-j nodes. The C-Vine looks like a star graph at each level, where one variable is the centre of interactions with other variables. Aas et al. (2009) propose two inference algorithms to estimate

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C- and D-vine log-likelihoods. But in this paper we use C-Vine. Hence, by setting the copula log-likelihood function, it is given by:

$$L_c(x,\omega) = \sum_{t=1}^{T}[\sum_{j=1}^{n-1}\sum_{i=1}^{n-j} c_{j,j+i\backslash 1,\dots,j-1}\left[F(x_{j,t}\backslash x_{1,t},\dots,x_{j-1,t}), F(x_{j+i,t}\backslash x_{1,t},\dots,x_{j-1,t});\omega_{j,i}\right])] \quad (8)$$

We denotes, $x_{i,t}$ with $i = 1,\dots,n$ as the number of variables and $t = 1,\dots,T$ as the time and finally $\omega_{j,i}$ the parameter vectors.

For vine copulas, model selection entails determining the vine decomposition as well as selecting copula families for each pair copula component.

### 3.4. *Dependence Structure*

We are concerned with investigating the dependence structure at each node of the bivariate copula for enhancing a comprehensive understanding of the dynamics fundamental to financial markets, and therefore, there is no application of the truncation technique in this study. It is noted that Kendall's Tau ($\tau$) usually calculates the no-linear dependence given as follows:

$$\tau = 4\int\int_{[0,1]^2} C(u,v)dC(u,v) - 1 \quad (9)$$

Copulas have also been shown to be useful in the areas of credit risk measurement, portfolio optimization, and risk management. The dependence structure of traditional copula models is purely dependent on one or two parameters, which is a severe limitation. When modelling the joint distribution of several asset returns, such a small number of parameters is unlikely to adequately reflect the actual dependence pattern. Moreover, because ordinary multivariate copulas lack the flexibility to accurately express the dependence among a large number of variables, the spectrum of appropriate copula families for high-dimensional structures is very limited. Vine copula models transcend these restrictions.

A vine copula is a very useful model used for dependence structure. In this study, the vine structure belongs to a special class, named canonical C-vine, which has a unique node at each tree leading to the dependence. It is a multivariate dependence model. Constructing a vine model using time-varying pair copulas in the first tree and conditioning only on the arguments of time-varying pair copulas in the following ones. The temporal characteristics of the dependent structure can be integrated into the pair copula parameters by enabling them to change over time when each conditional pair copula belongs to a parametric copula family.

### 3.5. *Markov Regime-Switching*

Following Hamilton (1989), Markov switching models, along with a variety of alternate variations, have been widely used to study many types of economic and financial time series. According to Bollen et al. (2000), a regime-switching model with an independent shift in the mean and variance displays a closer fit and more accurate variance forecast than a range of other models. Regime-switching models excel at capturing the time series behaviour of a wide range of financial variables.

This model will be applied to model potential changes within the dependence structure of the sectors (industries, financials, and basic materials) of developed and emerging countries. It was initially introduced by Hamilton (1989). Given $S_t$ to be a state variable of a Markov chain, standing for different hidden regimes of the time-dependent variable. The variable $S_t$ follows a first-order Markov chain, which has a probability transition matrix P, such that each element $P_{i,j}: P(S_t = j\backslash S_{t-1} = i)$ gives the probability of being in state j at time t, knowing that at time $t-1$ the state was i, and the sum of each column of P is equal to one. In the case of two regimes, the state variables take two different values $S_t = \{1,2\}$, states k=1 and k=2, which are also called regimes of high risk and low risk, respectively, and it is given by:

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$$P = \begin{pmatrix} p_{1,1} & p_{2,1} \\ p_{1,2} & p_{2,2} \end{pmatrix} = \begin{pmatrix} p & 1-q \\ 1-p & q \end{pmatrix} \quad (10)$$

Equation (10) uses regime-switching, introduced only for dependence structure. Henceforth, the maximum log-likelihood becomes:

$$L(x;\varphi;\omega) = \sum_{t=1}^{T}\sum_{i=1}^{n} lnf_i\left(x_{i,t};\varphi_i\right) + \sum_{t=1}^{T} \ln\left[p_{1,t}C_{k=1}(F_1(r_{1,t,s_t}),\dots,(F_n(r_{n,t,s_t});\omega_{k=1}\backslash s_t = 1) + p_{2,t}C_{k=2}(F_1(r_{1,t,s_t}),\dots,(F_n(r_{n,t,s_t});\omega_{k=2}\backslash s_t = 2)\right] \quad (11)$$

where $C_k$ denotes the copula density function in the k[th] regime (k =1,2), $\omega_k$ denotes the copula parameters and $P_{k,t} = P(s_t = k\backslash I_{t-1})$, knowing that k={1,2}, is the ex-ante probability

to be in regime k at time t given the availability of information at time $t-1$. The recursive computed expression of Hamilton (1989) is given by:

$$p_{1,t} = \frac{p\left[l_c\left(x_{t-1\backslash s_t=1}\right)p_{1,t-1}\right]+(1-q)\left[l_c\left(x_{t-1\backslash s_t=2}\right)(1-p_{1,t-1})\right]}{l_c\left(x_{t-1\backslash s_t=1}\right)p_{1,t-1}+l_c\left(x_{t-1\backslash s_t=2}\right)(1-p_{1,t-1})} \quad (12)$$

Where $l_c(.)$ is the likelihood function of the copula dependence structure, without considering the logarithm.

## 4. Empirical results and discussion

### *4.1. Data*

In this paper, we empirically study the pricing of currency risk on equity markets for a group of emerging economies against the US dollar (USD) sampled by data availability for the US and emerging countries, particularly Brazil, India, Poland, and South Africa. The data was collected from Thompson Reuter's database for the following sectors: industrial, financial, and basic materials, while the foreign exchange rate data was collected from Yahoo Finance. Both sample sizes range from 25/05/2005 to 31/05/2021, including the global financial crisis, the European debt crisis, and the COVID-19 pandemic. The following formula is used to convert all series to log returns:

$$r_t = \ln\left(\frac{p_t}{p_{t-1}}\right) * 100 \quad (13)$$

The Regime-Switching based C-Vine copula approach will be used in this paper. This model is useful for assessing multidimensional financial market dependency, the dynamic asymmetric contagion impact, the tail dependence structure, and the detection of financial market regime shifting. It's a versatile model with precise results that gets over the limits of bivariate copulas' higher-dimensional difficulties. The model will be executed in three steps: first, the marginal distributions will be presented; then Markov-Switching will be applied; and finally, C-vine copula for dependence associated with low and higher regimes will be applied.

### *4.2. Baseline results*

The descriptive statistics for sectorial equities and foreign exchange are reported in Table 1 below. The volatility is represented by the standard deviation (Std. Dev), which is highest in most sectorial equity markets in the developed US and emerging India, South Africa, Poland, and Brazil, indicating a dispersion in volatility across markets. All sectors of the equity markets are negatively skewed, whereas foreign exchange is positively skewed, implying that the distributions have longer left-hand tails and longer right-hand tails. Investors can expect frequent small gains and a few large losses in markets with negative skew parameters. The positive skewness for foreign exchange returns is presumably due to the fact that the more liquid currencies appear in the denominator of each of the four

Table 1. Descriptive statistics of sectorial equity markets

| | Mean | Maximum | Minimum | Std. Dev. | Skewness | Kurtosis | J_B |
|---|---|---|---|---|---|---|---|
| US_IND | 0.026755 | 11.55863 | -12.6966 | 1.366582 | -0.63797 | 13.44387 | 19497.45 |

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| | | | | | | | |
|---|---|---|---|---|---|---|---|
| US_FIN | 0.012389 | 13.39396 | -16.1858 | 1.762570 | -0.35547 | 18.79598 | 44034.48 |
| US_BM | 0.024656 | 12.03580 | -12.5339 | 1.528348 | -0.57452 | 12.24117 | 15273.48 |
| SA_IND | -0.00317 | 10.07320 | -24.2074 | 1.942142 | -0.78719 | 12.03517 | 14814.38 |
| SA_FIN | 0.002017 | 13.08737 | -18.4021 | 2.019813 | -0.60227 | 10.17559 | 9324.058 |
| SA_BM | -0.00252 | 14.27977 | -25.0735 | 2.170143 | -0.76386 | 13.94047 | 21492.16 |
| POL_IND | -0.01461 | 8.898671 | -12.4758 | 1.698961 | -0.46303 | 7.540011 | 3781.277 |
| POL_FIN | -0.00238 | 13.07611 | -17.2146 | 2.038059 | -0.40243 | 9.937797 | 8591.521 |
| POL_BM | 0.024540 | 15.13124 | -18.8784 | 2.306260 | -0.46092 | 8.207299 | 4925.468 |
| INDIA_IND | 0.025005 | 18.52398 | -16.0518 | 1.775778 | -0.33802 | 11.06042 | 11523.41 |
| INDIA_FIN | 0.039818 | 21.54056 | -18.2563 | 1.987820 | -0.24973 | 11.89892 | 13991.42 |
| INDIA_BM | 0.036115 | 17.32909 | -15.9711 | 1.812589 | -0.45332 | 9.898488 | 8526.412 |
| BRA_IND | -0.03085 | 25.98706 | -78.8724 | 2.720403 | -6.81601 | 187.1002 | 6002117.0 |
| BRA_FIN | 0.018060 | 29.41346 | -28.062 | 2.523391 | -0.15135 | 16.64445 | 32805.49 |
| BRA_BM | 0.024265 | 38.04701 | -38.0486 | 2.844938 | -0.34231 | 24.25961 | 79685.94 |
| USDBRL | 0.021192 | 9.759292 | -11.6623 | 1.188909 | 0.003242 | 12.57718 | 16154.62 |
| USDINR | 0.008380 | 4.205428 | -5.18427 | 0.587404 | 0.228820 | 9.922931 | 8478.025 |
| USDPLN | 0.003488 | 30.25045 | -21.6332 | 1.061985 | 3.609295 | 200.5722 | 6884177.0 |
| USDZAR | 0.018826 | 15.58170 | -10.7878 | 1.095831 | 0.866063 | 18.03802 | 40357.71 |

Notes: Test statistics are tabulated in the table for sectorial equity returns of United States industrials (US_IND), United States financials (US_FIN), Unites States basic materials (US_BM), Brazil industrials (BRA_IND), Brazil financials (BRA_FIN), Brazil basic materials (BRA_BM), India industrials (INDIA_IND), India financials (INDIA_FIN), India basic materials (INDIA_BM) , Poland industrials (POL_IND), Poland financials (POL_FIN), Poland basic materials (POL_BM) , South Africa industrials (SA_IND), South Africa financials (SA_FIN), and South Africa basic materials (SA_BM). Statistics for foreign exchange for Brazil (USDBRL, India (USDINR, Poland (USDPLN) and South Africa (USDZAR) Jarque-Bera test (J-B). ‘’***’’,’’ **’’, “*” denote respectively the significance at 1% level, 5% level and 10 % level.

exchange rates; an increase in the exchange rate implies a depreciation in the less liquid currency (emerging countries) relative to the more liquid currency (USD). The kurtosis level is higher and greater than 3 in all markets, which indicates that their distributions are more leptokurtic (fat tails). This shows that large daily changes occur more frequently in equity and foreign exchange markets. It is evident that the daily return series for all equities are leptokurtic, indicating that significant fluctuations in the daily prices are much more common than estimated by the normal distribution. The null hypothesis of normal distribution at the 1% significance level is rejected as indicated by J-B tests, which is consistent with the statistics for skewness and kurtosis. The average of industrial, financial, and basic materials sectors for developed and emerging economies for each selected country is close to zero both negatively and positively. The USD against emerging currencies is all positive, which implies that the USD appreciated against four emerging currencies on average over our sample period. The descriptive statistics show evidence that is general in the exhibition of characteristics of returns of equity markets in financial time series data.

### *4.3. Marginal model results*

Table 2 displays the coefficient estimated for the selected ARFIMA (1, 0, 1)-EGARCH (1,1) model for the developed US economy as well as emerging economies (Brazil, India, Poland, and South Africa). Panel A presents the entire period of the selected sectors (industrial, financial, and basic materials) and panel B, the foreign exchange rates against the local currency based on USD in India, South Africa, Poland, and Brazil. The chosen model is well-suited to the data. For both equities and foreign exchange, the EGARCH coefficients are positive and significant at the 1% level.

Table 2. ARFIMA (1,0,1) +EGARCH (1,1) estimates for equities

| | AR | MA | | EGARCH | | | | Shape | Q(9) | $Q^2(9)$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | $\mu$ | $\theta_1$ | $\theta_2$ | $\omega$ | $\alpha$ | $\gamma$ | $\beta$ | $\varphi$ | | |
| Panel A: equity markets | | | | | | | | | | |

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| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| US_IND | 0.0712*** | 0.6401*** | -0.6589*** | -0.0019 | -0.1279*** | 0.1353*** | 0.9855*** | 4.7334*** | 2.7744 | 7.918 |
| | (0.0113) | (0.0450) | (0.0443) | (0.0025) | (0.0119) | (0.0152) | (0.0010) | (0.3894) | [0.9219] | [0.1337] |
| US_FIN | 0.0536*** | -0.0817** | 0.0206 | 0.0026 | -0.1190*** | 0.1937*** | 0.9877*** | 4.2152*** | 5.3310 | 25.400 |
| | (0.0111) | (0.0338) | (0.0341) | (0.0029) | (0.0120) | (0.0189) | (0.0010) | (0.3059) | [0.3815] | [0.0860] |
| US_BM | 0.0626*** | 0.7281*** | -0.7510*** | 0.0027 | -0.1065*** | 0.1228*** | 0.9873*** | 5.9093*** | 4.7535 | 3.8354 |
| | (0.0125) | (0.0192) | (0.0188) | (0.0021) | (0.0106) | (0.0228) | (0.0016) | (0.5564) | [0.5107] | [0.6168] |
| BRA_IND | 0.0671*** | 0.2518*** | -0.3097*** | 0.0809** | -0.0346** | 0.1615*** | 0.9429*** | 4.7893*** | 7.3072 | 0.0361 |
| | (0.0179) | (0.0622) | (0.0615) | (0.0352) | (0.0143) | (0.0358) | (0.0240) | (0.3401) | [0.1012] | [1.0000] |
| BRA_FIN | 0.0613** | -0.9271*** | 0.9177*** | 0.0291*** | -0.0601*** | 0.1486*** | 0.9807*** | 6.3066*** | 2.4245 | 8.0970 |
| | (0.0270) | (0.0102) | (0.0129) | (0.0030) | (0.0090) | (0.0328) | (0.0018) | (0.5788) | [0.9583] | [0.1234] |
| BRA_BM | 0.0536* | -0.8964*** | 0.8875*** | 0.0348*** | -0.0520*** | 0.1298*** | 0.9803*** | 5.8487*** | 4.5260 | 15.300 |
| | (0.0322) | (0.0184) | (0.0191) | (0.0020) | (0.0092) | (0.0061) | (0.0004) | (0.5104) | [0.5649] | [0.067] |
| INDIA_IN | 0.0851*** | 0.4940*** | -0.3667*** | 0.0242 | 0.0242*** | 0.2021*** | 0.9684*** | 4.9701*** | 6.6770 | 9.1770 |
| D | (0.0150) | (0.0473) | (0.0504) | 0.0199 | (0.0198) | (0.0181) | (0.0192) | (0.3149) | [0.1622] | [0.0747] |
| INDIA_FIN | 0.0912*** | 0.2416*** | -0.1417*** | 0.0145*** | -0.0737*** | 0.1566*** | 0.9845*** | 5.2548*** | 5.4810 | 38.6533 |
| | (0.0216) | (0.0228) | (0.0234) | (0.0024) | (0.0096) | (0.0183) | (0.0010) | (0.4252) | [0.3507] | [0.0800] |
| INDIA_BM | 0.0920*** | 0.5103*** | -0.4089*** | 0.0198*** | -0.0901*** | 0.1818*** | 0.9750*** | 5.4161*** | 3.4277 | 6.2670 |
| | (0.0234) | (0.0404) | (0.0434) | (0.0030) | (0.0112) | (0.0163) | (0.0010) | (0.4551) | [0.8158] | [0.2687] |
| POL_IND | 0.0273 | 0.4992*** | -0.4169*** | 0.0110*** | -0.0399*** | 0.1126*** | 0.9860*** | 5.7887*** | 2.9390 | 3.620 |
| | (0.0234) | (0.0529) | (0.0556) | (0.0016) | (0.0079) | (0.0031) | (0.0003) | (0.4860) | [0.8997] | [0.6538] |
| POL_FIN | 0.0061 | 0.1021*** | -0.0370* | 0.0101*** | -0.0486*** | 0.1165*** | 0.9911*** | 7.1810*** | 4.6220 | 4.9880 |
| | (0.0302) | (0.0211) | (0.0223) | (0.0016) | (0.0078) | (0.0040) | (0.0000) | (0.7395) | [0.5418] | [0.4311] |
| POL_BM | 0.0419 | 0.1560*** | -0.0978* | 0.0155*** | -0.0338*** | 0.1178*** | 0.9893*** | 6.7287*** | 4.0580 | 2.9795 |
| | (0.0274) | (0.0519) | (0.0508) | (0.0015) | (0.0073) | (0.0028) | (0.0000) | (0.6873) | [0.6773] | [0.7623] |
| SA_IND | 0.0429 | 0.0924 | -0.0376 | 0.0143*** | -0.0543*** | 0.1018*** | 0.9871*** | 6.3082*** | 3.0862 | 16.751 |
| | (0.0263) | (0.1042) | (0.1047) | (0.0016) | (0.0082) | (0.0046) | (0.0000) | (0.6388) | [0.8771] | [0.0730] |
| SA_FIN | 0.0171 | 0.0326 | 0.0244 | 0.0202*** | -0.0742*** | 0.1112*** | 0.9830*** | 6.3530*** | 6.0930 | 16.403 |
| | (0.0249) | (0.0306) | (0.0306) | (0.0019) | (0.0092) | (0.0041) | (0.0003) | (0.6309) | [0.2416] | [0.0761] |
| SA_BM | 0.0035 | -0.2372*** | 0.2719*** | 0.0143*** | -0.0450*** | 0.0960*** | 0.9895*** | 6.4754*** | 1.4681 | 20.4846 |
| | (0.0261) | (0.0741) | (0.0729) | (0.0014) | (0.0081) | (0.0063) | (0.0001) | (0.6568) | [0.9974] | [0.0821] |
| Panel B: Foreign exchange | | | | | | | | | | |
| USDINR | 0.0005 | 0.0557 | -0.1737*** | -0.0178*** | 0.0288*** | 0.2064*** | 0.9879*** | 5.7356*** | 9.3200 | 6.8910 |
| | (0.0059) | (0.0461) | (0.0454) | (0.0055) | (0.0096) | (0.0216) | (0.0034) | (0.4927) | [0.0770] | [0.2084] |
| USDPLN | -0.0114 | -0.3035*** | 0.2680*** | -0.0030*** | 0.0135** | 0.0679*** | 0.9960*** | 6.2107*** | 4.8359 | 0.0157 |
| | (0.0100) | (0.0208) | (0.0207) | (0.0008) | (0.0058) | (0.0085) | (0.0001) | (0.5367) | [0.4914] | [1.0000] |
| USDZAR | 0.0040 | 0.8528*** | -0.8684*** | -0.0018 | 0.0411*** | 0.0921*** | 0.9857*** | 8.5139*** | 4.2270 | 1.3830 |
| | (0.0126) | (0.0431) | (0.0409) | (0.0014) | (0.0077) | (0.0121) | (0.0010) | (0.9125) | [0.6370] | [0.9646] |
| USDBRL | 0.0043 | 0.0345 | -0.1356*** | 0.0007 | 0.0459*** | 0.1792*** | 0.9818*** | 5.1361*** | 6.5480 | 8.1390 |
| | (0.0110) | (0.0265) | (0.0265) | (0.0025) | (0.0099) | (0.0177) | (0.0010) | (0.4081) | [0.1777] | [0.1211] |

Note: Values in parentheses denote the standard errors of the estimators; Q(9) and $Q^2(9)$ are the Ljung–Box statistics in the ninth order in standardized residuals and standardized residuals squared respectively, ARCH(7) Weighted ARCH LM Tests, values in brackets are p-values. Autoregressive Fractionally Integrated Moving Average (ARFIRMA) is a Long-memory processes that are stationary processes whose autocorrelation functions decay slowly ''***'', ''**'', and'' *'' denote the significance at the 1%, 5%, and 10% levels, respectively. Most of estimators are statistically significant at 1% level in both panel and all EGARCH parameters $\alpha$, $\beta$ and $\gamma$ are significant at the 1% level, and at 5% level for $\alpha$ of BRA_IND and USDPLN suggesting that our specification is appropriate.

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Furthermore, the goodness of fit presents ARCH (7), the p-values of the Ljung–Box Q-statistics, Q (9), and are greater than the 5% level of significance. We fail to reject the null hypothesis of no autocorrelation. In this specific case, there is no presence of autocorrelation to the order of 9 for standardized residuals and their squares. Indeed, serial correlation functions show that standardized residuals are independent and identically distributed, and this allows one to avoid copula model misspecification. Hence, they are more appropriate for the estimation of copula functions than the returns of raw data series. In general, these results support the suitability of our model specification.

All sectors of the equity markets for developed and emerging economies presented in panel A and the foreign exchange for emerging based USD in panel B exhibit a positive gamma ($\gamma$) and are statistically significant at the 1% level, showing the presence of the inverse leverage effect. The parameter of the leverage estimate is always positive, which yields the usual interpretation of large negative returns being followed by higher volatility. As $\gamma > 0$ it shows an asymmetric effect, in other words, bad news has no greater effect on the volatility of a market than good news. An indication of inverse leverage effects proposes that currency market responses to informational shocks during the sample period were asymmetrical. It seems that a positive shock to currency pricing has the greatest effect on rising volatility for the industrial, financial, and basic materials sectors of equity markets. $\beta$ is positive and statistically significant at the 1% level in both panels, expressing the degree of volatility persistence in the equity and foreign exchange markets.

The coefficients $\alpha$ denote the size effect, which specifies how much volatility increases regardless of the direction of the shock. It appears that in panel A, most sectors of equity are negative, except for the industrial sector of India, that shows $\alpha$ positive and significant. It indicates, the presence of volatility clustering. Whereas in panel B, all coefficients for USD exchange rates against domestic currencies are positive and statistically significant at the 1% level. The expression of $\alpha + \beta < 1$, specifies a mean reverting process, confirms variance stationarity. When this sum is close to 1, it shows that the volatility has long memory and is mean reverting. The shape parameter ($\varphi$) is greater than 4 confirming the kurtosis parameter in Table 1 that is greater than 3 for all equities markets and foreign exchange, implying that the distribution shows evidence of fat tails.

Table 3 presents the State 1, or regime 1 (high-risk regime) and state 2, or regime 2 (low-risk regime), with the respective estimated parameters and the transition probabilities. Regime 1 shows some significant parameters for USDBRL and USDINR compared to regime 2. The USDPLN and USDZAR are significant in regime 2 compared to regime 1. The foreign exchange rate against the domestic currency is high in both regimes. The findings show higher transition probabilities in both regimes, with a likely change to shift from a low-risk regime to a high-risk regime and vice versa. The estimated transition probabilities indicate that there is a higher probability that the system stays in the same regime, thus implying few switches in other regimes. The USDBRL, USDINR, USDPLN, and USDZAR results indicate an 89%, 99%, 92%, and 98% probability of remaining in the high risk regime and a likely change to a lower probability of 11%, 1%, 8%, and 2% switching to the low risk regime. Alternatively, when the system is in the low risk regime, there are respectively 96%, 98%, 99%, and 90% probabilities of staying in the low risk regime and respectively again likely change of a lower probability of 4%, 2%, 1%, and 10% switching to the high risk regime. The expected average duration of each regime supports the findings. The expected duration of the high risk regime for each foreign exchange (USDBRL, USDINR, USDPLN, and USDZAR) has an average duration of 9.23, 87.72, 11.92, and 63.69 days, while the low risk regime has an average duration of 25.77, 42.37, 67.57, and 10.18 days. Similarly, it implies, for example, that emerging currencies against the USD exchange rate of Brazil will be in a high-risk regime for an average of 9.23 days and a low- risk regime for an average of 25.77 days. This implies that there is a persistence to stay in a low-risk regime for a longer period of time.

### *4.4. Markov-Switching results*

Table 3. Markov-Switching (MS) estimates

| Foreign exchange | USDBRL | | USDINR | | USDPLN | | USDZAR | |
|---|---|---|---|---|---|---|---|---|
| coeff. | Regime 1 | Regime 2 | Regime 1 | Regime 2 | Regime 1 | Regime 2 | Regime 1 | Regime 2 |
| $\theta$ | 0.1573*** | -0.0179 | 0.0014 | 0.0244 | 0.1781** | -0.0263*** | -0.0202 | 0.3096*** |
| | (0.0598) | (0.0146) | (0.0065) | (0.0247) | (0.0939) | (0.0112) | (0.0149) | (0.1056) |
| $\theta_1$ | -0.2036*** | -0.0693*** | -01185*** | -0.0790*** | -0.0034 | -0.0277*** | -0.0006 | -0.0665 |
| | (0.0327) | (0.0140) | (0.0199) | (0.0273) | (0.2620) | (0.0019) | (0.4328) | (0.0460) |
| $\theta_2$ | -0.0429 | -0.0024 | -0.0402** | 0.0246 | -0.0264 | 0.0167 | 0.0013 | -0.1019*** |
| | (0.0267) | (0.0809) | (0.0201) | (0.0275) | (0.0484) | (0.0135) | (0.1043) | (0.0208) |

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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Transition prob. | | | | | | | | |
| | $p_{1i}$ | 0.8916 | 0.0388 | 0.9886 | 0.0236 | 0.9161 | 0.0148 | 0.9843 | 0.0982 |
| | $p_{2i}$ | 0.1084 | 0.9612 | 0.0114 | 0.9764 | 0.0839 | 0.9852 | 0.0157 | 0.9018 |
| ED | | 9.23 | 25.77 | 87.72 | 42.37 | 11.92 | 67.57 | 63.69 | 10.18 |

Note: This table presents the estimates parameters $\theta$ the regime dependent intercept, and $\theta_1, \theta_2$ the autoregressive coefficients, transition probabilities $(p_{1i}, p_{2i})$ with $i = 1,2$ representing the states of regimes and Expected durations (ED) of the MS for the USD exchange rate against domestic currencies.

Figure 1. shows more spikes during the Global Financial Crisis (GFC) in all emerging countries and also shows shocks from the European Debt Crisis (EDC) in Poland, Brazil, and SA. But the impact of COVID-19 is still short-term for Brazil and SA for the considered period of study. There is a smoothed probability of the foreign exchange rate of emerging currencies against the USD, with a high risk of being in a high-risk regime and a low-risk regime, respectively. It is clear to observe that the low risk regime dominates the counterpart of the high risk regime for Brazil and Poland, while, the high risk regime dominates the counterpart low risk regime for India and SA, which confirms the statistical analysis reported in Table 3.

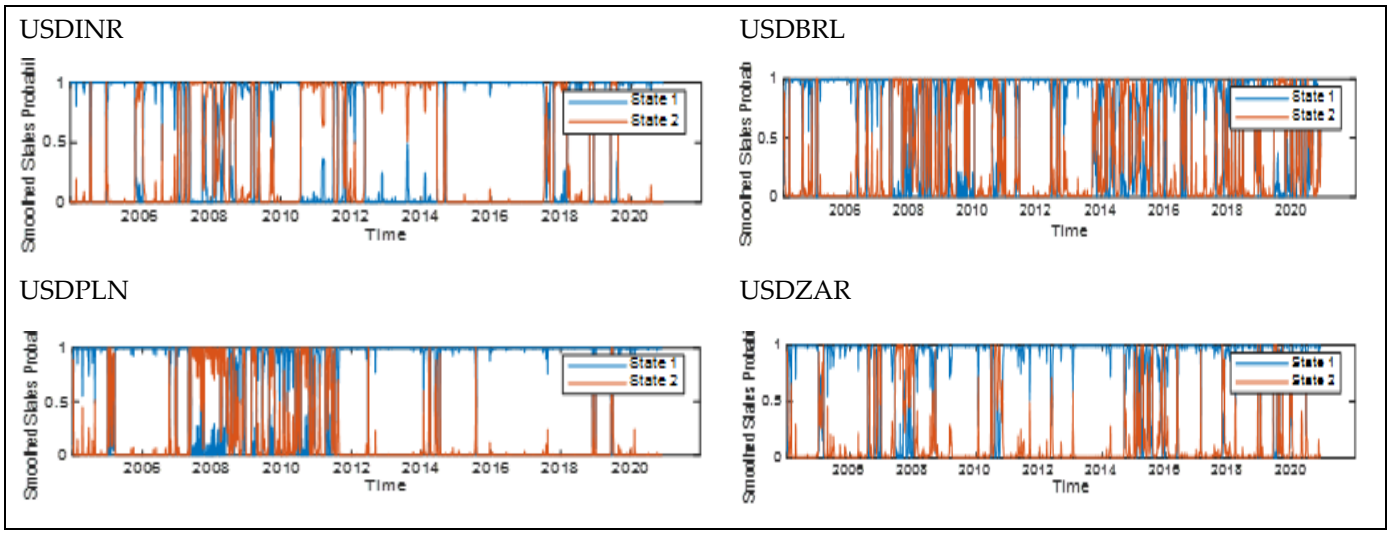


Figure 1. illustrates the smoothed regimes (state 1 and state 2) evolved over time for the US foreign exchange on domestic currencies of Brazil, India, Poland and SA.

The results in Table A1 are reported in Appendix A. The estimated parameters of the MS are mostly statistically significant for the US, Brazil, and Poland for state 1, while SA is significant in state 2 for the industrial sector. The financial sector also exhibits the most significant parameters in regime 1 for the US, Poland, and SA, while the basic materials are significant in regime 2 for the US, SA, and finally India, which shows significant parameters in both regimes. Implies the mean behaviour of industrial, financial, and basic materials sectors that exhibit distinct dynamic patterns during different time periods. We observe that the state-dependent constant term $\theta$ estimates were negative and positive, respectively, in the two states in which the smoothed probabilities had low and high values for the periods generally related to economic downturns and growth, respectively, an analogous perception as in Hamilton & Lin (1996). The transition probabilities of sectors of equity markets based on USD risk regimes for industrial, financial, and the basic materials sectors are high in both regimes.

For example, in the industrial sector, we notice a considerable state dependence in the transition probabilities of the US, Brazil, India, Poland, and SA, with a relatively higher probability of remaining in the high-risk regime, respectively, 95%, 83%, 97%, 98%, and 96% and the likely change of the low regime probabilities given by 5%, 7%, 3%, 2%, and 4% to shift to a low regime. The probabilities of remaining in the low risk regime respectively given by 98%, 99%, 92%, 92%,

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and 99% and the likely change of the low regime probabilities are respectively 2%, 1%, 8%, 8%, and 1% switching to the high risk regime. This shows that the low risk regime remains longer with the expected durations of 53.48, 91.74, and 80 days, respectively, for the US, Brazil, and SA, while the high risk regime remains longer with the expected durations of 34.60 and 45.45, respectively, for India and Poland. This shows the persistence of remaining in one regime before shifting to another.

For further support in the interpretation of the different regimes, panel A in Figure B1 displays the smoothed probabilities plot of being in the high-volatility regime, which indicates that industrial equity risk regimes over the sample period are highly aggregated in both regimes but mostly higher in the low risk regime for the US, Brazil, and SA, and also mostly higher in India and Poland in the high risk regime. When the regime switches are independent, then the average probabilities are nearly flat. Instead, the two regimes show a pattern quite similar to the pattern of the probabilities of regime 1 and regime 2 for the equity index in panel A (see Appendix B). The high-volatility period common across sample markets appeared from 2007 to 2008, from 2009 to 2012, and in 2020, reflecting the GFC, the EDC, and the COVID-19, which had an indirect effect on the developed US markets and in the emerging markets. Furthermore, the policy attracts investor attention because investors get information about the risk of pricing currency through different channels, such as the internet, expectations, and other channels that cause a switch to a high-risk regime. More jump in the sector of industrials risk regime exists in both regimes and are observed in all countries. Several periods of high risk of volatility in which the probabilities of being in higher regime is close to 1, showing spike in the GFC (2007-2008), EDC (2009-2012), Brexit from June 2016 and the COVID-19 from 2020. Finally, COVID-19 affected all the selected countries in this industrial sector, but the impact still in short term.

The results of the financial sector show the state dependence in the transition probabilities of the US, Brazil, India, Poland, and SA with a relatively higher probability of remaining in the high risk regime, respectively, 94%, 98%, 98%, 99%, and 99%, and there is a likely change to switch from low regime probabilities to high regime probabilities, respectively, given by 6%, 2%, 2%, 1%, and 1%. Confirming the persistence of the high-risk regime in the financial sector, it will take longer before shifting to another regime. See their respective expected durations, which are higher for emerging countries compared to the US in terms of the number of days where shocks will remain longer in state 1. The low risk regime also has probabilities of 98%, 93%, 95%, 97%, and 96%, respectively, for the US, Brazil, India, Poland, and SA. In comparing the two states, we observe that the financial sector is more volatile in regime 1 in all emerging economies, whereas the developed US is more volatile in the low regime. On one hand, the behaviour of investors prefers to take risk in a country with higher expectations, secure institutions, and stability of policies. On the other hand, there is an attraction for investors to invest in a low-risk regime in making hedging strategies or market strategies. Figure B1 in Panel B confirms the same finding as in Table A1, where the higher volatilities are observed in high-risk regimes. The shocks from the GFC and EDC are more visible in the US, India, and Brazil, where they are less visible in Poland and SA. The impact of COVID-19 on the financial sector still has a short-term influence, and it will be more visible in the long term. The findings in the sector of basic materials for the US, Brazil, India, Poland, and SA show the states dependent on the transition probabilities to remain longer in the high risk regime and low risk regime with the respective probabilities of 98%, 93%, 95%, 99%, and 92%, and 96%, 99%, 98%, 97%, and 99%. This result is supported by the expected durations and the graph in Panel C of Figure B1, showing how long one state will remain invariant before switching to another regime, confirming the persistence of the basic materials in regime 1 for the US and Poland and in regime 2 for Brazil, India, and SA.

### *4.5. Vine copula results*

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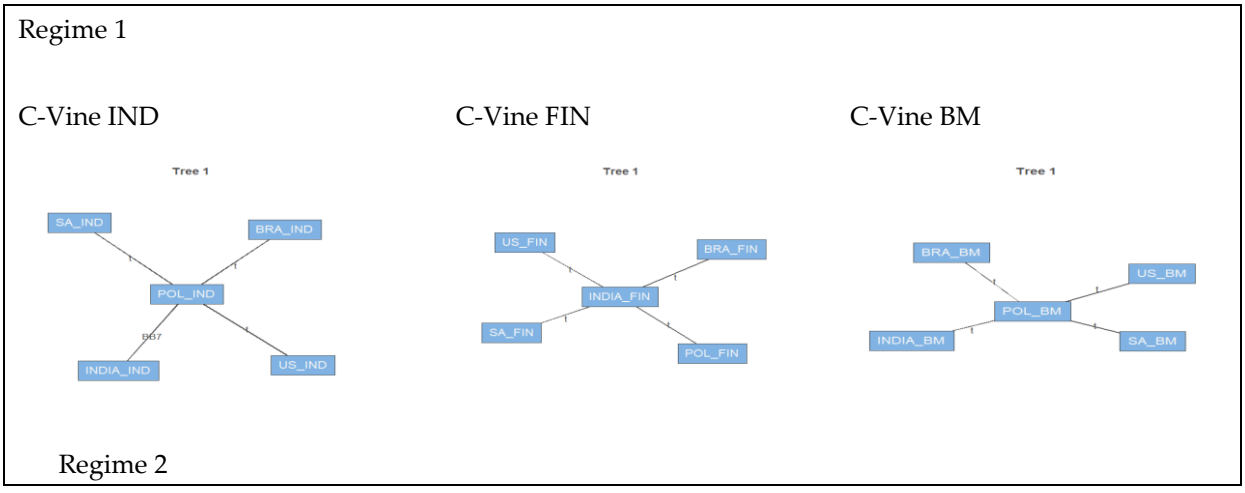
Table 4 exhibits the estimated C-Vine copulas for the industrial, financial, and basic materials sectors of the equity markets of the US, Brazil, India, Poland, and South Africa in both regimes. The empirical results describe the estimates of the student's t copula dominating and statistically significant at the 1% level. An indication of the dependence structure of developed-country equity and that of emerging-country equity in the industrial, financial, and basic materials sectors.

Table 4. estimates parameters of C-Vine copulas in the sectors of equity markets.

| Regime 1 | | | | | | Regime 2 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Edge | Industrials | Edge | Financials | Edge | Basic Materials | Edge | Industrials | Edge | Financials | Edge | Basic Materials |
| 4,1 | 7.1525*** | 2,4 | 4.8475*** | 4,2 | 6.9261*** | 1,4 | 6.6230*** | 2,4 | 4.8374*** | 1,2 | 7.8195*** |
| | (1.250) | | (0.310) | | (0.210) | | (0.200) | | (0.289) | | (0.027) |
| 4,2 | 6.3505*** | 2,3 | 4.5384*** | 4,3 | 5.0956*** | 1,3 | 4.6075*** | 2,4 | 4.6058*** | 1,3 | 5.0116*** |
| | (0.690) | | (0.141) | | (0.134) | | (0224) | | (0.126) | | (0.035) |
| 4,3 | 6.2096*** | 2,1 | 4.3895*** | 4,1 | 5.6403*** | 1,2 | 6.1473*** | 2,1 | 4.3284*** | 1,4 | 5.6533*** |
| | (0.106) | | (0.112) | | (0.103) | | (0.475) | | (0.142) | | (0.134) |
| 5,4 | 8.2413*** | 5,2 | 4.3651*** | 5,4 | 7.3039*** | 5,1 | 7.1409*** | 5,2 | 4.3686*** | 5,1 | 4.0900*** |
| | (0.497) | | (0.503) | | (0.337) | | (0.208) | | (0.123) | | (0.014) |
| | AIC: -889.54 | | AIC: -1830.29 | | AIC: -1380 | | AIC: -1126.03 | | AIC: -1853.64 | | AIC: -1951.87 |
| | BIC: -825.90 | | BIC: -1766.64 | | BIC: -1316.35 | | BIC: -1062.39 | | BIC: -1789.99 | | BIC: -1888.22 |

Notes: This table exhibits the estimates C-Vine copulas for industrials, financials and the basic materials sectors of the equity markets of US, Brazil, India, Poland and South Africa, corresponding to the first tree, the edge linked the bivariate student's t copula with their respective parameters, "***", "**" and "*" indicate respectively the level of significance at 1%, 5% and 10

Figure 2 indicates intuitive graphs of the vine structures combining trees and edges corresponding to a specific five-dimensional C-vine copula in the sectors of equity markets, especially industrial, financial, and basic materials in regimes 1 and 2 for the selected developed US and emerging countries (India, SA, Poland, and Brazil). Each node denotes a margin, representing a pair copula model for two connected nodes, and the label corresponds to the bivariate copula's type. The presentation of vine-copula is similar to the conventions introduced by (Bedford & Cooke, 2001, 2002).



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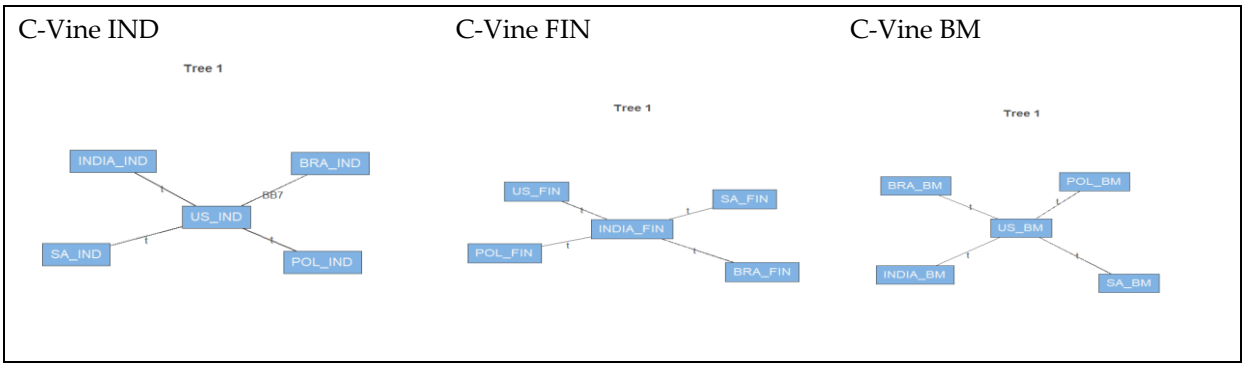


Figure 2 presents the first trees structures of regime 1 and regime 2 of the C-Vine model, and the corresponding bivariate copulas for industrials sectors (IND), financials sectors (FIN) and basic materials sectors (BM) of US, Brazil, India, Poland and South Africa.

In the industrial sectors of equity markets, we consider the high-risk regime and the low-risk regime, defined as the state of economies. The bivariate copula presenting different structures in both regimes. We can see that the industrial sector markets are symmetric from the functions in the Vine copula structure, showing that at high risk of volatility, the dependence between Poland and India is significant, characterized by the fat tail correlation, and at low risk of volatility, the dependence between the US and Brazil is also symmetric and significant for emerging countries. Regime 1 represents a high-risk regime with a positive and strong dependence structure between Poland, the centre of interactions, and the United States, India, and South Africa. Poland and Brazil are dependent on each other. In the low-risk regime, the industrial sector of the US is linked positively with those of Brazil, Poland, SA, and India.

The financial sector shows India at the centre of interactions between the financial sectors of the countries selected in both regimes. In fact, India shows a positive and strong significant dependence structure at 1% level with SA in the high-risk regime and Poland in the low-risk regime, maybe due to the fact that the two countries are in tied relationships in this sector with India. See the same evidence in Table 4 with the estimated parameters that are significant. There is a significant 1% level of dependence with Poland, the US, and Brazil in the high regime, and SA, the US, and Brazil in the low regime, implying that shocks from the US can affect positively the emerging countries' financial sectors during times of turmoil and calm periods.

In the basic materials sector, Poland is at the center of interactions in the high regime, while the US is in the low regime. In both regimes, the two countries have a positive and significant 1% level dependence structure, as seen in Table 4. In this area, we see a beneficial association between the US and Brazil and South Africa in the low-risk regime.

The results in Table A1 and Table A2 are reported in Appendix A, exhibiting the C-Vine copula of the bilateral copula dominated by the student's t copula of USD against the domestic currencies of Brazil, Poland, India, and SA as well as their respective equities with the associated equity of the US. We observe that the estimated parameters for all sectors are significant at 1% level, indicating the strong dependence between foreign exchange and equity markets in both regimes. For the industrial, financial, and basic materials sectors of India, SA, Poland, and Brazil, there is evidence of symmetric lower and upper tail dependence between all pairs, with similar dependence during downward and upward periods. In the industrial and basic materials sectors, there is an asymmetric dependence between Brazil and the USDBRL. This research shows that investors in India, South Africa, Poland, and Brazil can utilize foreign exchange as a hedge on sectorial equity markets. In both regimes, the exchange rate of the US dollar against the domestic currencies of emerging economies reveals a considerable reliance on each country rather than US industries.

Empirically, the evidence shows that in both regimes, all emerging countries have a significant dependence structure at 1% level between industrial sectors and the foreign exchange-based USD. Hence, the estimated parameters are all significant for all countries. Therefore, the industrial sector co-moved in a way that increasing (decreasing) equity prices were linked with the USD against domestic currencies that appreciated or depreciated with respect to the USD.

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The results in Figure B1, Figure B2 and Figure B3 are presented in Appendix B with the indication that an increase (decrease) in equity market prices (industrials sector) attracts (discourages) capital inflows. In that way, there is an appreciation (depreciation) of the domestic currency. This evidence supports the findings reported by Cho et al. (2020). The bivariate pairs from the C-vine, show a symmetric tail dependence given by the Student-t copula dominating the dependence of the industrial sector.

For all emerging countries and in the state of economies, the outcomes of the USD exchange rate versus emerging currencies for the financial sector show evidence of a considerable dependence between equity markets and USD exchange returns. As a result, the USD co-move with financial equities values against emerging-market currencies, suggesting that domestic currency appreciation (depreciation) against the USD moved in same direction as equity prices rose and dropped. The finding is related to that of Boako et al. (2017), who find dependence between the returns of certain African stock markets and the EU and USD exchange rates with the local currency, and infer that such occurrences suggest euro and dollar-denominated assets can give better and varied opportunities to investors during crisis periods of the equity market. Cho et al. (2016) and Reboredo et al. (2016) show that investors regularly develop reduced appetite for portfolio investments in an increasing market, which leads to lower foreign capital flows. They refer to the herd-like investors behaviour to move out of risky assets during bear markets, with the attendant devastating effects on the performance of the domestic currency.

In both regimes, the projected parameters of the USD exchange rate against emerging currencies for the basic materials sector of all emerging stock markets have a 1% significance level. Because all equity markets have a strong and positive relationship with the USD exchange rate, any change in the volatility risk of foreign exchange will have a substantial impact on the basic materials sector in emerging economies under both regimes. As a result, the USD co-moved in the pricing of basic resources in developing markets, implying domestic currency appreciation (depreciation) versus the USD and moving in the same direction as equities prices (drops). Figure B2 shows the similar results for the low-income group and Figure B3 for high regime.

In summary, the sectorial equity markets are priced differently according to the USD exchange rate appreciation (depreciation) against USD, as all the estimated parameters are positive and significant at 1% level, showing a fat tail dependence on the state of the economy. The information and integration between sectoral equity markets and the USD exchange rate against emerging countries imply systemic risk and necessitate investor safety strategies. In the two regimes of the C-Vine copulas in Table A2, we observe that the low risk regime is better than the high risk regime in India, SA, and Brazil, with the smallest AIC of low risk being given by -135.05, -247.65, and -254.48, except Poland, which has the smallest AIC in the high risk regime. In the financial sector, the smallest AIC is found in the low risk for SA and Poland, respectively -231.39 and -302.22, whereas India and Brazil have the smallest AIC in the high risk regime of -226.28 and -542.74. Finally, in the basic materials sector the smallest AIC is in the low risk regime for SA, Poland and Brazil except for India were the smallest is in the high risk regime.

There is evidence of positive dependency between emerging-market stock markets (India, South Africa, Poland, and Brazil) and the USD exchange rate varies depending on the sector of the economy and the state of the economy (high-risk, low-risk). Higher (lower) equity prices in the specified industries are accompanied by a depreciation (appreciation) of domestic currencies in USD terms. This result is in line with the findings of Carrieri & Majerbi (2006), Boako & Alagidede (2017); Kodongo & Ojah (2014). The feature of seeing if the pricing of currency risk differs in different sectors of equity markets (industrial, financial, and basic materials) and the heterogeneous nature of currency pricing in equity markets is a specific focus of this paper. This may be seen in all of the emerging countries' selected areas as well as their economic status.

## 5. Conclusion and policy implication

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In this study, we use a Markov-Switching based C-Vine copulas approach to examine the asymmetric effect of currency risk pricing in sectorial equity markets to see how their effects differ depending on the state of the economy. We used equity data for three sectors[1] of four emerging economies[2] and USD foreign exchange against the local currencies. The sample period spans from May 25, 2005, to May 25, 2021. The ARFIMA_EGARCH and MS models are used to examine the asymmetric effect, the leverage effect, and the pricing of currency risk in equity markets in the low-risk and high-risk regimes. Finally, we looked at evidence of the influence of risk and the market reliance structure using C-Vine copulas. The empirical findings show that there is a general positive relationship between equity markets and foreign exchange markets. This means that increased equity market prices in these industries are accompanied by a depreciation of the local currencies in terms of the US dollar. Boako et al. (2017), who looked at the pricing of currency risk in six African countries, came to the same conclusion. The overall observation of equity and foreign exchange dependence over time indicates a fluctuating high and low risk dependence for all markets with the USD exchange rates. The heterogeneous nature of the time-varying dependence on the pricing of currency risk on equity markets shows positive evidence suggesting the equity markets are risk priced. There is an indication of spillover effects during crisis periods across the markets.

The implication is that, while the flow-oriented theory of exchange rate determination suggests that a decline in local currency levels improves the competitiveness of domestic export-based firms, they increase their trade and foreign currency current account balances, thereby improving equity market performance. The massive volumes of trades and stronger demand that are dependent on domestic currency devaluation, signalling an increase in equities markets, will persuade investors and governments. As a result, the policy implication is that during crisis periods, foreign currency price risk may command a premium in equities markets in order to escape the worst of any hedging gains in the equity market. Otherwise, when the local currency slides against the US dollar, emerging countries and their decision-makers might issue local currency-denominated securities on the local market, which international investors may see as less expensive and hence suggest a buy.

There is an indication of inverse leverage effects, implying that large negative returns are followed by higher volatility. The currency market's responses to informational shocks during the sample period were not asymmetrical. In this situation, bad news has no more impact on a market's volatility than good news. It seems that a positive shock to currency pricing appears to have a significant impact on increased volatility for equity markets sectors, and there is a presence in the level of volatility persistence in the equity and foreign exchange markets. In the MS findings, we discover that the foreign exchange against the domestic currency of emerging countries is higher in both regimes. The transition probabilities in both regimes are high, with a likely change to shift from a low-risk regime to a high-risk regime and vice versa.

During various time periods, the mean behaviour of the industrial, financial, and basic materials sectors displays diverse dynamic patterns. Smoothed probabilities have low and high values for periods often associated with economic downturns and growth in a negative and positive state-dependent manner. For the industrial, financial, and basic materials sectors, the transition probabilities of sectors of equity markets based on USD risk regimes are high in both regimes. In the given regime, each sector has a different level of dependency than the others. The high-volatility period common across sample markets appeared from 2007 to 2008, from 2009 to 2012, and in 2020, reflecting the GFC, the EDC, and the COVID-19, which had an indirect effect on the developed US markets and the emerging markets in the state of the economy. The persistence of a high-risk regime in the financial and basic materials sectors of emerging economies will make it take longer before they move to another regime. Therefore, investors' behaviour is at risk in the country with higher expectations, but with secure institutions and stability of policies. Otherwise, there is an attraction for investors to invest in a low-risk regime in making hedging strategies in this sector.

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[1] Industrials, financials and basic materials for developed US and emerging countries

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The results of the foreign exchange using C-Vine copula demonstrate the student's t copula dominating. The USD's performance against the domestic currencies of Brazil, Poland, India, and South Africa, as well as their respective equities, demonstrates a strong dependence in both regimes. In particular, there is an asymmetric dependence between Brazil and USDBRL in the industrial and basic materials sectors. This implies that any perturbation in the volatility risk of foreign exchange will have a great impact on the industrial, financial, and basic materials sectors of emerging economies in both regimes. We suggest that the decision makers should establish a policy that covers the protection of investors in these markets from currency risk, allowing them to be confident in the of the market's flexibility with strong and stable institutions and developing innovative measures for investors safety.

Systemic risk exists as a result of the knowledge and integration between sectorial equity markets and the USD exchange rate against emerging economies, necessitating investor safety mechanisms. The positive dependence between emerging equity markets (India, South Africa, Poland, and Brazil) and the US dollar exchange rate varies depending on the sector of the economy and the state of the economy (high-risk, low-risk). Higher (lower) equity prices in the specified industries are accompanied by a depreciation (appreciation) of domestic currencies in USD terms. The feature of seeing if the pricing of currency risk differs in different sectors of equity markets (industrial, financial, and basic materials) and the heterogeneous nature of currency pricing in equity markets is a specific focus of this paper. This is visible in all of emerging countries' selected sectors as well as economic states. As a result, emerging-market governments may be able to boost the performance of their native currencies, resulting in better economic growth via the domestic stock market.

## 6. Patents

### Supplementary Materials:

**Author Contributions:** the contribution of each author is as follows: Conceptualization, J.W. Muteba Mwamba; methodology, J.W. Muteba Mwamba, and Benjamin Mudiangombe Mudiangombe; software, Benjamin Mudiangombe Mudiangombe; validation, J.W. Muteba Mwamba; formal analysis, Benjamin Mudiangombe Mudiangombe; investigation, J.W. Muteba Mwamba, and Benjamin Mudiangombe Mudiangombe; resources, Benjamin Mudiangombe Mudiangombe; data curation, Benjamin Mudiangombe Mudiangombe; writing—original draft preparation, Benjamin Mudiangombe Mudiangombe; writing—review and editing, J.W. Muteba Mwamba; visualization, Benjamin Mudiangombe Mudiangombe; supervision, J.W. Muteba Mwamba; project administration, Benjamin Mudiangombe Mudiangombe; funding acquisition, Not Applicable. All authors have read and agreed to the published version of the manuscript.

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**Data Availability Statement:** The dataset consisting of daily stock prices are taken from Thompson Reuter's database and Yahoo finance. Data available at: https://eikon.thomsonreuters.com/index.html and https://finance.yahoo.com/ respectively.

**Conflicts of Interest:** The authors declare no conflict of interest. The authors certify that they have no affiliations with or involvement in any organization or entity with any financial or non-financial interest in the subject matter or materials discussed in this manuscript.

## Appendix A

Table A1. Markov-Switching estimates transition probabilities for equity markets

| SECTORS | | INDUSTRIALS | | FINANCIALS | | BASIC-MATERIALS | |
|---|---|---|---|---|---|---|---|
| | | Regime 1 | Regime 2 | Regime 1 | Regime 2 | Regime 1 | Regime 2 |
| coeff. | | | | | | | |
| United States | $\theta$ | -0.1622** | 0.1019*** | -0.1716* | 0.0742*** | 0.0996*** | -0.1504** |
| | | 0.0686 | 0.0148 | (0.1039) | (0.0155) | (0.0182) | (0.0751) |

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| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | $\theta_1$ | -0.1026*** | 0.0049 | -0.1399*** | -0.0560*** | -0.0108 | -0.0902*** |
| | | 0.0299 | 0.0157 | (0.0321) | (0.0185) | (0.0201) | (0.0295) |
| | $\theta_2$ | 0.0598** | -0.0461 | 0.0696** | -0.0194 | -0.0317 | 0.0334 |
| | | 0.0303 | 0.0191 | (0.0325) | (0.0183) | (0.0198) | (0.0297) |
| Transition Prob | $p_{1i}$ | 0.9501 | 0.0187 | 0.9444 | 0.0171 | 0.9823 | 0.0445 |
| | $p_{2i}$ | 0.0499 | 0.9813 | 0.0556 | 0.9829 | 0.0177 | 0.9555 |
| | ED | 20.04 | 53.48 | 17.99 | 58.48 | 56.50 | 22.52 |
| Brazil | $\theta$ | -0.0799** | 0.0322 | 0.1070*** | -0.3155** | -0.3472 | 0.0706** |
| | | (0.5481) | (0.0285) | (0.0312) | (0.1572) | (0.2751) | (0.0349) |
| | $\theta_1$ | -0.2254** | -0.0387*** | 0.0134 | -0.1101*** | -0.1759*** | -0.0067 |
| | | (0.0946) | (0.0136) | (0.0176) | (0.0346) | (0.0463) | (0.0151) |
| | $\theta_2$ | 0.0328 | -0.0068 | -0.0214 | 0.0291 | -0.0639 | -0.0087 |
| | | (0.0752) | (0.0125) | (0.0182) | (0.0355) | (0.0473) | (0.0162) |
| Transition Prob. | $p_{1i}$ | 0.8290 | 0.0109 | 0.9825 | 0.0664 | 0.9286 | 0.0101 |
| | $p_{2i}$ | 0.1710 | 0.9891 | 0.0175 | 0.9336 | 0.0714 | 0.9899 |
| | ED | 5.85 | 91.74 | 57.14 | 15.07 | 14.01 | 99.01 |
| India | $\theta$ | 0.1080*** | -0.2298*** | 0.1122*** | -0.2132** | -0.1907** | 0.1105*** |
| | | (0.0223) | (0.0890) | (0.0246) | (0.1052) | (0.0957) | (0.0233) |
| | $\theta_1$ | 0.1642*** | 0.0840*** | 0.1117*** | 0.0998*** | 0.0721** | 0.1194*** |
| | | (0.0200) | (0.0304) | (0.0194) | (0.0315) | (0.0316) | (0.0192) |
| | $\theta_2$ | 0.0190 | 0.0111 | 0.0171 | -0.0317 | 0.0481 | 0.0042 |
| | | (0.0203 | (0.0291) | (0.0199) | (0.0325) | (0.0322) | (0.0194) |
| Transition Prob. | $p_{1i}$ | 0.9711 | 0.0758 | 0.9838 | 0.0475 | 0.9471 | 0.0179 |
| | $p_{2i}$ | 0.0289 | 0.9242 | 0.0162 | 0.9525 | 0.0529 | 0.9821 |
| | ED | 34.60 | 13.19 | 61.73 | 21.05 | 18.90 | 55.87 |
| Poland | $\theta$ | 0.0529** | -0.2482** | 0.0559** | -0.1772 | 0.0761** | -0.1176 |
| | | (0.0229) | (0.1018) | (0.0247) | (0.1156) | (0.0303) | (0.1053) |
| | $\theta_1$ | 0.0727*** | 0.1113*** | 0.0604*** | 0.1048*** | 0.0831*** | 0.0705** |
| | | (0.0674) | (0.0351) | (0.0135) | (0.0234) | (0.0191) | (0.0293) |
| | $\theta_2$ | 0.0403** | 0.0208 | 0.0123 | -0.0039 | 0.0293 | 0.0039 |
| | | (0.0185) | (0.0376) | (0.0175) | (0.1828) | (0.0196) | (0.0126) |
| Transition Prob. | $p_{1i}$ | 0.9780 | 0.0795 | 0.9917 | 0.0297 | 0.9894 | 0.0274 |
| | $p_{2i}$ | 0.0220 | 0.9205 | 0.0083 | 0.9703 | 0.0106 | 0.9726 |
| | ED | 45.45 | 12.58 | 120.48 | 33.67 | 94.34 | 36.50 |
| South Africa | $\theta$ | -0.1562 | 0.0526** | 0.0595** | -0.1753 | -0.2545 | 0.0360 |
| | | (0.1017) | (0.0262) | (0.0263) | (0.1107) | (0.2104) | (0.0254) |
| | $\theta_1$ | 0.0372 | 0.2962*** | 0.0539*** | 0.0585* | 0.0080 | 0.0444*** |
| | | (0.0319) | (0.0187) | (0.0191) | (0.0332) | (0.1207) | (0.0168) |
| | $\theta_2$ | 0.0217 | 0.0054 | -0.0108 | -0.0102 | 0.0693 | -0.0195 |

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| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | (0.0310) | (0.0173) | (0.0172) | (0.0327) | (0.0438) | (0.0151) |
| Transition Prob | $p_{1i}$ | 0.9597 | 0.0125 | 0.9868 | 0.0447 | 0.9156 | 0.0114 |
| | $p_{2i}$ | 0.0403 | 0.9875 | 0.0132 | 0.9553 | 0.0844 | 0.9886 |
| | ED | 24.81 | 80 | 75.76 | 22.37 | 11.85 | 87.72 |

Note: This table exhibits the estimates parameters of MS $\theta$ as the regime dependent intercept, and $\theta_1, \theta_2$ the autoregressive coefficients, the transition probabilities ($p_{i1\ and}\ p_{j2}$) with $i = 1,2\ and\ j = 1,2$ representing the states of regimes, and the expected durations (ED) of the MS for industrials, financials and basic materials sectors of emerging countries.

Table A2. estimates parameters for C-Vine copulas between US, sectorial equity markets of emerging economies and the US foreign exchange against domestic currencies.

| Regime 1 | | | | | | Regime 2 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| US_INDIA_USDINR | | | | | | US_INDIA_USDINR | | | | | |
| Edge | Industrials | Edge | Financials | Edge | Basic materials | Edge | Industrials | Edge | Financials | Edge | Basic materials |
| | Parameter | | Parameter | | Parameter | | Parameter | | Parameter | | Parameter |
| 2,1 | 6.7267*** | 2,1 | 4.6439*** | 2,1 | 6.5079*** | 2,1 | 6.2764*** | 2,1 | 4.6845*** | 2,1 | 7.3054*** |
| | (0.869) | | (0.074) | | (0.222) | | (0.107) | | (0426) | | (0.001) |
| 3,2 | 14.5622*** | 3,2 | 12.5812*** | 3,2 | 10.930*** | 3,2 | 14.0136*** | 3,2 | 10.8169*** | 3,2 | 11.3499*** |
| | (0.677) | | (0.123) | | (1.365) | | (1.903) | | (2.023) | | (2.290) |
| | AIC: -132.72 | | AIC: -226.28 | | AIC: -161.30 | | AIC: -135.05 | | AIC: -225.13 | | AIC: -136.10 |
| | BIC: -113.68 | | BIC: -207.23 | | BIC: -142.25 | | BIC: -115.99 | | BIC: -206.08 | | BIC: -117.10 |
| US_SOUTH AFRICA_USDZA | | | | | | US_SOUTH AFRICA_USDZA | | | | | |
| | Parameter | | Parameter | | Parameter | | Parameter | | Parameter | | Parameter |
| 2,1 | 6.1503*** | 2,1 | 4.4917*** | 1,2 | 5.1183*** | 2,1 | 4.4789*** | 2,1 | 4.5546*** | 1,2 | 5.0982*** |
| | (0529) | | (0.133) | | (0171) | | (0.037) | | (0.118) | | (0.507) |
| 3,2 | 11.1495*** | 3,2 | 18.4345*** | 3,1 | 15.2419*** | 3,2 | 19.1421*** | 3,2 | 17.2930*** | 3,1 | 14.4390*** |
| | (0.512) | | (0.116) | | (0.274) | | (0.677) | | (0.333) | | (3.902) |
| | AIC: -141.47 | | AIC: -230.66 | | AIC: -219.35 | | AIC: -247.65 | | AIC: 231.39 | | AIC: -223.94 |
| | BIC: -122.43 | | BIC: -211.62 | | BIC: -200.30 | | BIC: -228.60 | | BIC: -212.34 | | BIC: -204.89 |
| US_POLAND_USDPLN | | | | | | US_POLAND_USDPLN | | | | | |
| | Parameter | | Parameter | | Parameter | | Parameter | | Parameter | | Parameter |
| 2,1 | 5.8990*** | 2,1 | 4.2086*** | 2,1 | 5.3442*** | 2,1 | 6.1603*** | 2,1 | 4.1492*** | 2,1 | 5.3656*** |
| | (0.251) | | (0.261) | | (0.526) | | (1.716) | | (0.113) | | (0.560) |
| 3,2 | 8.3545*** | 3,2 | 7.8932*** | 3,2 | 9.0750*** | 3,2 | 9.8951*** | 3,2 | 7.7306*** | 3,2 | 8.8198*** |
| | (0.279) | | (0.256) | | (0.987) | | (0.430) | | (1.355) | | (0.014) |
| | AIC: -241.97 | | AIC: -296.15 | | AIC: -216.04 | | AIC: -170.53 | | AIC: -302.22 | | AIC: -217.60 |
| | BIC: -222.93 | | BIC: -277.10 | | BIC: -196.99 | | BIC: -151.49 | | BIC: -283.18 | | BIC: -198.56 |
| US_BRAZIL_USDBRL | | | | | | US_BRAZIL_USDBRL | | | | | |
| | Parameter | | Parameter | | Parameter | | Parameter | | Parameter | | Parameter |
| 3,1 | 8.2191*** | 2,1 | 4.3492*** | 2,1 | 7.2931*** | 2,1 | 7.0812*** | 2,1 | 4.3450*** | 2,1 | 4.0908*** |
| | (1.440) | | (0.226) | | (1.145) | | (0.001) | | (0.105) | | (0.841) |
| 3,2 | 13.9276*** | 3,2 | 11.0419*** | 3,2 | 32.4389*** | 3,2 | 12.1450*** | 3,2 | 11.0938*** | 3,2 | 11.3829*** |
| | (3.929) | | (0.645) | | (1.777) | | (2.439) | | (0.317) | | (0.343) |
| | AIC: -75.96 | | AIC: -542.74 | | AIC: -124.69 | | AIC: -254.48 | | AIC: -541.68 | | AIC: - 782.59 |
| | BIC: -56.92 | | BIC:-523.69 | | BIC: -105.64 | | BIC: -235.43 | | BIC: -522.64 | | BIC: - 763.54 |

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Notes: This table exhibits the estimates C-Vine copulas for industrials, financials and the basic materials sectors of the equity markets of US, Brazil, India, Poland and South Africa, and the USD against the domestic currencies, corresponding to the first tree, the edge linked the bivariate student's t copula with their respective parameters, "***", "**" and "*" indicate respectively the level of significance at 1%, 5% and 10%

## Appendix B

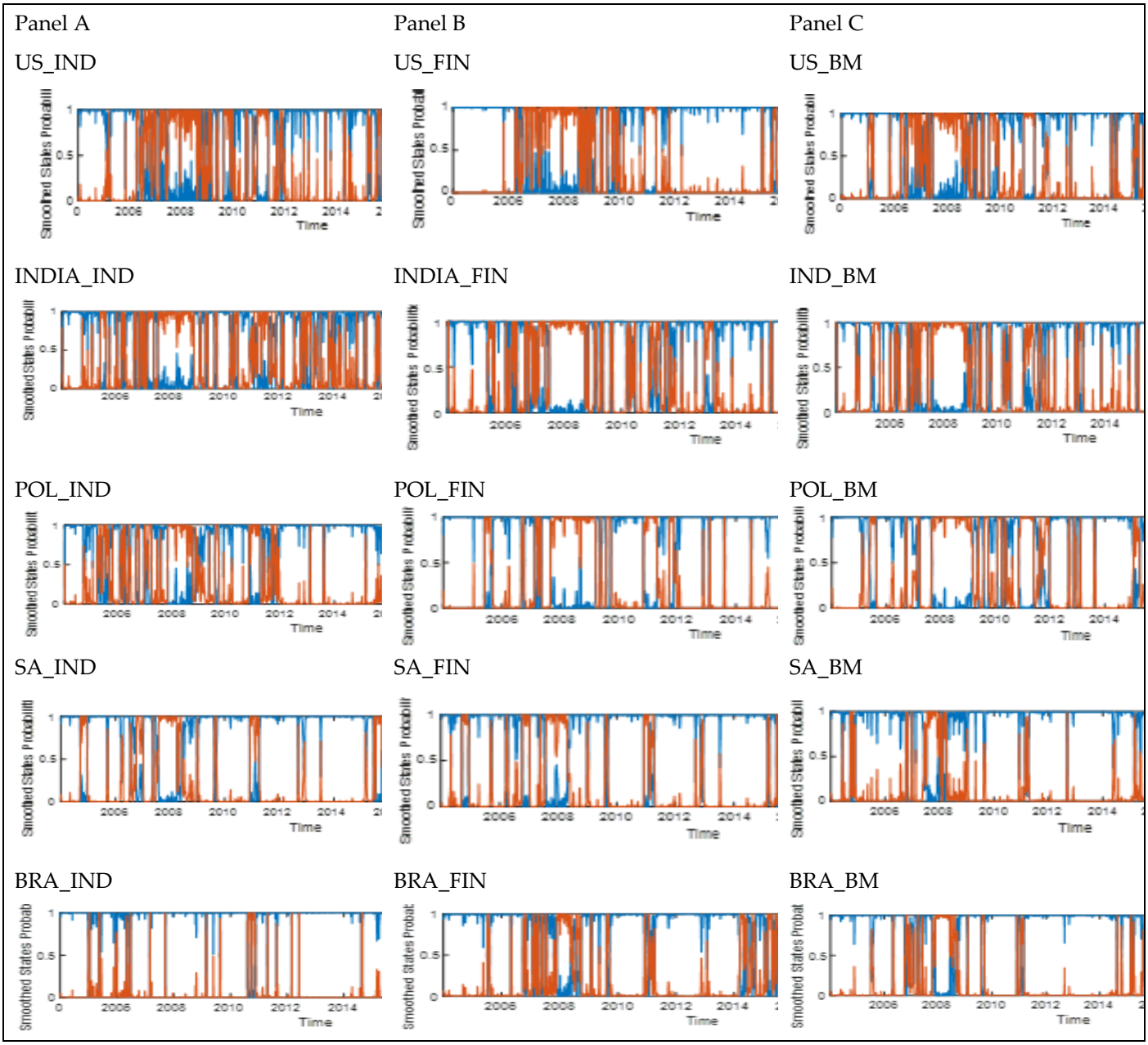


Figure B1 presents the plots of smoothed probabilities of industrials in panel A, financials in panel B and basic materials in panel C based in state 1 and state 2 of US, India, SA, Poland and Brazil.

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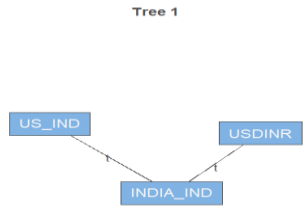
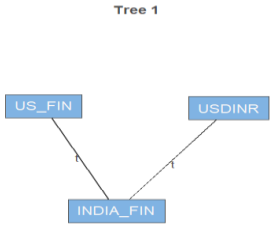
Regime 1: US_INDIA_USDINR

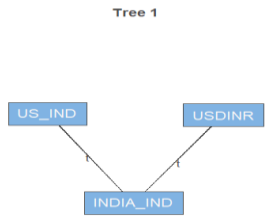
Industrials



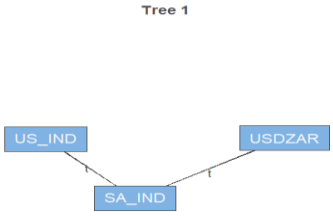

Financials

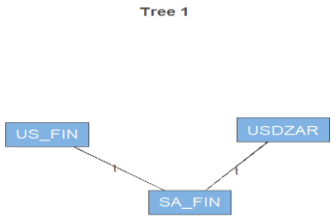


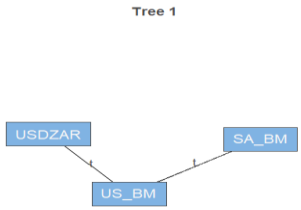

Basic Materials



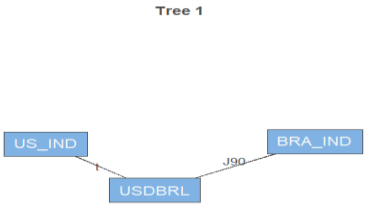

US_SOUTH AFRICA_USDZAR

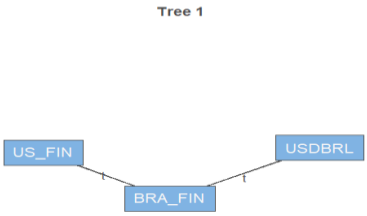


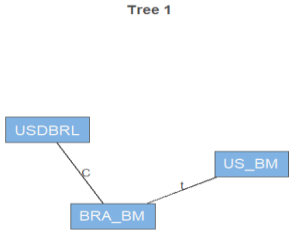



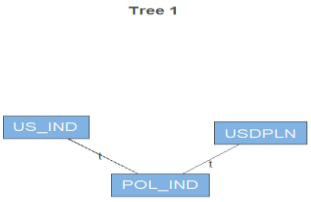

US_BRAZIL_USDBRL

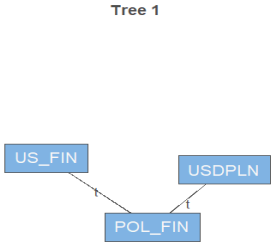



US_POLAND_USDPLN



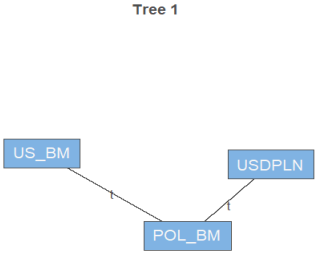




Figure B2 presents the first tree structure of regime 1 of C-Vine copula model and the corresponding bivariate copulas for US, USD foreign exchange against domestic currencies for Brazil, India, Poland and South Africa and their sectorial equity markets.

Regime 2: US_INDIA_USDINR

Industrials Financials Basic Materials

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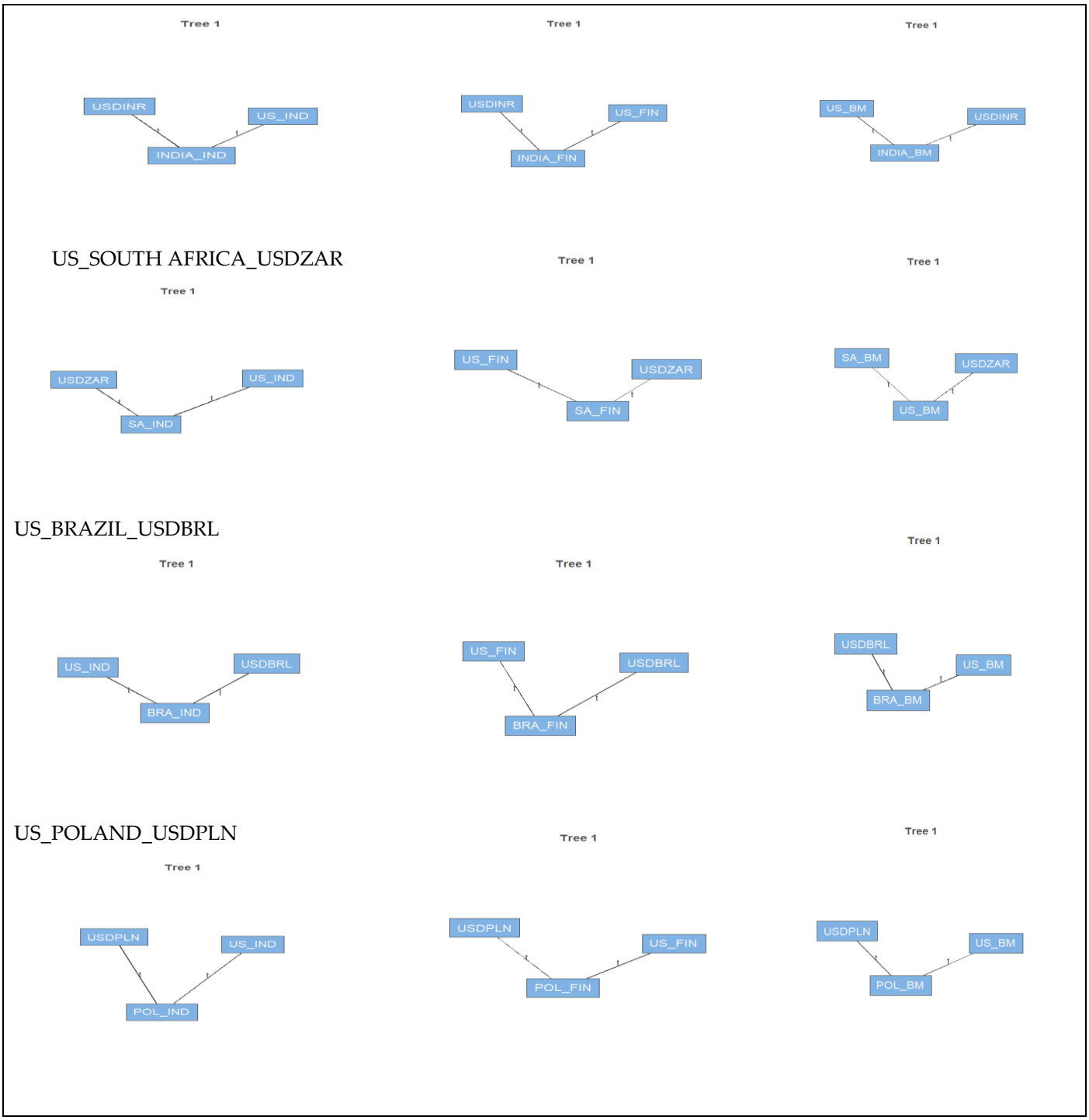


Figure B3 presents the first tree structure of regime 2 of C-Vine copula model and the corresponding bivariate copulas for US, USD foreign exchange against domestic currencies for Brazil, India, Poland and South Africa and their sectorial equity markets.

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