REPUBLIC OF TÜRKİYE

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GRADUATE SCHOOL OF SCIENCE AND ENGINEERING

ANALYSIS OF THE DEPENDENCIES OF EMERGING COUNTRIES' STOCK MARKETS WITH NOVEL TIME VARYING FLEXY COPULA APPROACH

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DOCTOR OF PHILOSOPHY THESIS

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Tugay KARADAĞ

Signature

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Dedicated to my family

and my best friend

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LIST OF SYMBOLS

$M(u)$	Comotone Copula
$C(u,v)$	Copula function
ρ	Correlation parameter of Gaussian and Student t Copula
$W(u)$	Countermonotone Copula
v	Degrees of freedom parameter of Student t Copula
θ	First parameter of Archimedean Copulas
$\varphi(t)$	Generator function of Archimedean Copulas
τ	Kendall's tau
δ	Second Parameter of mixed Copulas

LIST OF ABBREVIATIONS

AC	After crisis
ADF	Augmented Dickey-Fuller
AIC	Akaike information criteria
ARCH	Autoregressive conditional heteroskedasticity
Asym	Asymmetric
BB1	Clayton-Gumbel copula
BB6	Joe-Gumbel Copula
BB7	Joe-Clayton Copula
BB8	Joe-Frank Copula
BC	Before Crisis
BIC	Bayesian information criteria
BRIC	The acronyms of Brazil, Russia, India, and China
BRICS	The acronyms of Brazil, Russia, India, China, and South Africa
BRICS+	BRICS countries and newly included countries
BRICS-T	BRICS countries with Türkiye
CMLE	Canonical Maximum Likelihood Estimation
CoVaR	Conditional Value-at-risk
d.r.	degrees rotated
DC	During crisis
GARCH	Generalized ARCH
GDP	Gross domestic product
IBOV	Main Brazilian stock index
IMF	International Monetary Fund
KPSS	Kwiatkowski–Phillips–Schmidt–Shin
KS	Kolmogorov-Smirnov
LL	Log-likelihood
LM	Lagrange Multiplier
MLE	Maximum Likelihood Estimation
NBER	National Bureau of Economic Research
NIFTY	National Stock Exchange of India
Only Lw	Only lower
Only Up	Only upper
PHEIC	Public Health Emergency of International Concern

PP	Phillips–Perron
RTSI	Russia Trading System Index
SA40	South Africa 40 Index
SSE	Shanghai Stock Exchange index
Symm.	Symmetric
TD	Tail dependency
TVFC	Time-varying flexy copula
TVOC	Time-varying optimal copula
VaR	Value-at-risk
VIX	Volatility Index
WHO	World Health Organization
XU100	Main index of Turkish stock market

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ABSTRACT

Analysis of the Dependencies of Emerging Countries' Stock Markets with Novel Time Varying Flexy Copula Approach

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Statistics Program

Doctor of Philosophy Thesis

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In this thesis, a time-varying flexy copula (TVFC) approach was proposed and performed to investigate the dependence structures of BRICS-T stock markets as representatives of emerging countries in the presence of financial shocks. For this purpose, four different crisis periods were selected, including the crises of 2001, 2008, and COVID-19 and the Ukraine-Russia war period. In addition, to examine the risk spillovers between the country stock markets, Conditional Value-at-Risk (CoVaR) copula and delta-CoVaR copula analyses were applied, and the risk spillovers and risk contributions of the country stock markets were analyzed. According to the results for the crisis periods, the TVFC method provided a satisfactory model fit compared to all other single, time-varying single, and time-varying optimal copula methods based on both log-likelihood values and Akaike information criteria. When all crisis periods were examined, it was found that China had the lowest dependency value compared to the other BRICS-T countries. Considering all periods, it was concluded that the dependency values of the Türkiye-Russia pair were relatively higher than other pairs. In terms of risk spillovers and risk contributions, it was found that China was the country least exposed to risk spillovers from the other BRICS-T countries, while Türkiye was the country most exposed to risk spillovers.

Keywords: Copula, emerging countries, financial crises, time-varying copula

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ÖZET

Gelişmekte Olan Ülke Borsalarının Bağımlılıklarının Yeni Zamanla Değişen Esnek Kopula Yaklaşımı ile Analizi

Tugay KARADAĞ

İstatistik Anabilim Dalı

Doktora Tezi

Danışman: Prof. Dr. Gülhayat GÖLBAŞI ŞİMŞEK

Bu tezde BRICS-T ülke borsalarının finansal şokların varlığındaki bağımlılık yapılarını araştırmak amacıyla zamanla değişen esnek kopula (ZDEK) yaklaşımı önerilmiş ve uygulanmıştır. Bu amaçla, 2001, 2008 krizleri, COVID-19 dönemi ve Ukrayna-Rusya savaş dönemi dahil olmak üzere dört farklı kriz dönemi belirlenmiştir. Ayrıca, ülke borsaları arasındaki risk yayılmalarını incelemek için Koşullu Riske Maruz Değer (KRMD) kopula ve delta-KRMD kopula analizleri uygulanmış ve ülke borsa piyasalarının risk yayılmaları ve risk katkıları analiz edilmiştir. Kriz dönemlerine ilişkin sonuçlara göre, ZDEK yöntemi hem log-olabilirlik değerleri hem de Akaike bilgi kriterleri bakımından diğer tüm tek, zamanla değişen tek ve zamanla değişen optimal kopula yöntemlerine kıyasla tatmin edici bir model uyumu sağlamıştır. Tüm kriz dönemleri incelendiğinde, Çin'in diğer BRICS-T ülkelerine göre en düşük bağımlılık değerine sahip olduğu bulunmuştur. Ayrıca, tüm dönemler göz önüne alındığında Türkiye-Rusya ikilisinin diğer çiftlere göre nispeten daha yüksek bağımlılık değerlerine sahip olduğu sonucuna varılmıştır. Risk yayılımları ve risk katkısı açısından, Çin'in diğer BRICS-T ülkelerinden risk yayılımına en az maruz kalan ülke olduğu, Türkiye'nin ise en fazla risk yayılımına maruz kalan ülke olduğu bulunmuştur.

Anahtar Kelimeler: Kopula, gelişmekte olan ülkeler, finansal krizler, zamanla değişen kopula

1

INTRODUCTION

Stock exchanges provide individuals with limited savings the opportunity to become shareholders in large companies. Consequently, they have become one of the most popular options among individual investors in recent years. By investing small amounts in stock exchanges, it is possible to make small investments in large and profitable companies that have been publicly traded. However, not every company can achieve high profitability. Some companies go bankrupt and withdraw from the stock market, while others fail to yield returns to investors for extended periods. Yet, some can provide extraordinary returns to investors. Therefore, investors typically do not rely on a single stock; instead, they diversify their portfolios in stock exchanges to spread their risks. Additionally, portfolio management companies create investment funds to manage the investments of individuals unfamiliar with financial markets. These portfolio management companies may choose to invest in foreign stock exchanges as well as their own country's exchanges to obtain returns from various stock markets. Consequently, portfolio managers need to be familiar with the dynamics of the stock market in the country where investments are made when forming their portfolios.

One of the most important aspects brought about by the globalized world is that all financial assets are influenced to some extent by each other. Furthermore, stock markets can be affected by each country's political issues. Among all this complexity, one of the most important and widely used methods used to determine the relationships between financial assets is the copula method (Jlassi et al., 2023; Makhanya et al., 2024; Mudiangombe & Muteba Mwamba, 2023; Zhao et al., 2023; Zhao & Park, 2024).

In addition to understanding the relationships between individual stocks, it is also essential to analyze broader market trends through indices which are calculated to represent the gains or losses of countries' stock markets over a certain period. For instance, to represent the chemical sector in a country's stock market, the average price movements of chemical companies (weighted or weight-limited) are calculated to create a chemical index. Similarly, an index can be created by calculating the average price movements of the largest 100 companies to represent them. Each stock market has created its own indices in a similar manner. Consequently, comparative analyses can be conducted among different exchange indices.

1.1 BRICS Countries

The initials of Brazil, Russia, India, China, and South Africa constitute the term BRICS. In Figure 1.1, the locations of BRICS countries on the world map are depicted. The concept of BRICS was first proposed by Jim O'Neill, who served as a director at Goldman Sachs in 2001. At that time, due to South Africa's absence from this formation, the acronym BRIC was used. However, with the inclusion of South Africa in 2010, the formation adopted the name BRICS.



Figure 1.1 Locations of BRICS countries (source: www.istockphoto.com)

The BRICS formation, which prioritizes transparent and open dialogue and cooperation among developing countries, aims to serve the interests of individuals and nations living within their territories and to create a peaceful and harmonious world with shared prosperity. On January 1, 2024, Argentina, Egypt, Ethiopia, Iran, Saudi Arabia, and the United Arab Emirates were also included in the BRICS formation (Zaidan & de Oliveira, 2024). Many developments have occurred regarding the inclusion of Türkiye in the BRICS formation, which has many key features in terms of geographical location, population, and landmass. In this dissertation, the term BRICS represents the founding countries, while the expression BRICS+ symbolizes both the founding countries and the newly included countries in the formation.

BRICS is a global organization that is effective in the international arena. They attract attention due to their economic and demographic characteristics. They draw interest because

of their economic and population traits. Moreover, they have many similarities, like being rapidly developing countries with some of the biggest economies in their areas. China has the largest economy in Asia and is part of the G8. India has the third-largest economy in Asia, while South Africa has the second-largest economy in Africa. Lastly, Brazil has the largest economy in South America (Ajayi, 2019). Therefore, in recent times, BRICS countries have attracted significant media and academic interest (Azevedo et al., 2018; Zakarya et al., 2015). Forecasts suggest that by 2050, there is a strong likelihood that BRICS countries will be economically stronger than the world's leading developed countries and the European Union. (Gusarova, 2019).

According to World Bank data in May 2024, the total Gross Domestic Product (GDP) of BRICS countries in 2022 amounted to $25.9 billion, corresponding to 25.7% of the global total. Similarly, based on population data from 2022, the total population of BRICS countries accounts for 40.8% of the world population. In terms of surface area, BRICS countries constitute 28.2% of the total surface area worldwide (World Development Indicators, 2024).

1.2 Türkiye and BRICS Countries

Türkiye's first significant contact with BRICS countries occurred towards the end of July 2018. Türkiye was invited as a special guest and represented at the presidential level at the 10th summit of BRICS countries held in South Africa (Jianguo et al., 2023; Presidency of the Republic of Türkiye, 2018). Similarly, following the BRICS summit held in China in June 2022, Purnima Anand, the president of the BRICS International Forum, expressed hope for Türkiye's inclusion in the process and emphasized that the participation process would not take much time (Klimentyev, 2022, July 14).

In academic literature, the abbreviation BRICS-T is used to evaluate various aspects involving BRICS countries and Türkiye. The "T" in BRICS-T represents Türkiye. While the BRICS-T concept has been the subject of many studies, there has been a significant increase in research focusing on developing countries, particularly after Türkiye was invited as a special guest to meetings. Comparative analyses have been conducted on BRICS-T countries, considering various indicators related to these nations (Hashmi et al., 2023; Jianguo et al., 2023; Samour et al., 2023; Ullah et al., 2024).

BRICS-T countries share the major characteristic of all being classified as developing nations. Various institutions classify countries into different categories based on their economic status. Perhaps one of the most reputable of these institutions is the International Monetary Fund

(IMF), which publishes the "World Economic Outlook Projections" report twice a year in April and October, sharing countries' levels of development based on their economies. In the report released in April 2024, 41 countries, including the United States, Japan, and Germany, are classified as "developed countries," while 155 countries, including Türkiye, Brazil, Russia, India, China, and South Africa, are referred to as "emerging markets and developing countries" (International Monetary Fund, 2024).

The GDP of BRICS-T countries accounts for 26.6% of the world total, while their total population constitutes 41.9% of the global population. Similarly, the total land area of BRICS-T countries corresponds to 28.8% of the world total. With Türkiye's participation in this formation, there will be an increase of 0.9% in the total GDP, 1.1% in the total population, and 0.6% in the total land area.

1.3 Literature

The BRICS formation has gained significant attention in academic literature due to its impact on global markets. Within the scope of this thesis, relevant literature has been examined under four main headings: (1) studies evaluating BRICS countries among themselves, (2) studies evaluating BRICS countries in conjunction with other nations, (3) studies assessing BRICS countries together with Türkiye (BRICS-T), and (4) studies evaluating BRICS countries using time-varying copula approaches.

(1) The collaborations among the countries included in the BRICS formation have led to a close relationship among their stock markets (Joo et al., 2024). The inclusion of these five countries among the developing nations has been the focus of many studies in terms of representing developing countries (BenSaïda, 2023; De Paulo et al., 2017; Fernandes et al., 2021; Kumar et al., 2023). Particularly, examining the dependencies among national stock markets or the risk spillovers among them is common in the literature. Due to the time frame examined or the methodology used, there are also some controversial findings. Cheng et al. (2021) investigated the dependency structures of the Chinese stock market with other BRICS country markets before and after the COVID-19 pandemic using weekly closing data. Based on the results, they stated that the Chinese and South African stock markets became more interdependent after the declaration of the COVID-19 pandemic. In another study, Karadag and Golbasi Simsek (2023) examined BRICS country stock markets using daily closing data before and after COVID-19. They found that the Chinese and South African stock markets were less interdependent after the COVID-19 pandemic declaration. Studies focusing on the

stock market index also show that the Chinese stock market is dominant in many aspects compared to other BRICS countries. Kulikova et al. (2024) investigated the weak-form market efficiency in BRICS countries using monthly data covering the period from 1995 to 2020, and according to the findings, they determined that only the Chinese stock market was not affected by the 2008 and COVID-19 recessions. Another study highlighting China's dominance over other BRICS countries is the research conducted by Lu et al. (2023), which applies Liang causality analysis to rare events such as sudden stock market crashes, unexpected political events, terrorist attacks, etc., in BRICS countries. According to the findings of the study, it has been revealed that there is almost no Liang causality between the Chinese stock market and the stock markets of other BRICS countries.

(2) In studies examining BRICS countries and other country stock exchanges, the dominance of the Chinese stock market remains prominent. McIver and Kang (2020) examined the spillover between the stock exchanges of the United States and BRICS countries using weekly closing data covering the period from 1998 to 2016. This study indicated that in addition to the United States and China, the Brazilian stock market was a net transmitter. Additionally, it was interpreted that the stock markets of Russia, India, and South Africa were net receivers. However, Shi (2021) examined the spillovers between the stock markets of BRICS countries using daily data spanning from 2002 to 2019. Unlike McIver and Kang (2020), Shi (2021) indicated that Brazilian stock market is a receiver, whereas Indian stock market is not receiver but transmitter. The point where study of Shi (2021) aligns with the findings of McIver and Kang (2020) is the conclusion that the Chinese stock market is transmitter. However, Panda et al. (2021) examined the volatility spillovers of stock indices between developed countries and BRICS countries during crisis periods and indicated that Brazilian stock market is receiver, South African stock market is receiver, while China, Russia, and India are both receivers and transmitters depending on the crisis period.

(3) Türkiye's integration with BRICS countries, named as BRICS-T, is observed in the academic literature. Numerous studies in the literature examine the impact of various instruments or indicators on BRICS-T stock indices. Bayrakdaroğlu and Kaya (2021) investigated the effect of the Volatility Index (VIX), exchange rate, consumer confidence index, and freedom index on the stock markets of BRICS-T countries, indicating a significant negative relationship between exchange rates and the VIX fear index with stock market indices. Caporale et al. (2022) analyzed BRICS-T stock indices by sector to examine the sectoral impact of exchange rates and oil prices on BRICS-T country stock markets. The

findings indicated that oil prices had a negative impact on the industrial sectors of all countries except Türkiye. Köycü and Kayali (2021), on the other hand, investigated the impact of foreign direct investment and portfolio investments on BRICS-T stock indices, finding a positive and significant relationship between portfolio investments and stock returns, while stating that there was no significant relationship between foreign direct investments and stock returns. Studies examining the stock markets of BRICS-T countries using different instruments are also available in the literature (Demir & Terzi, 2019; Güzel & İltaş, 2022; Kök & Nazlıoğlu, 2022). BRICS-T countries have not only been the subject of researchers through stock indices. Gültekin and Emsen (2023) focused on income, health, per capita income, democracy, and education in BRICS-T countries, while Şenol and Onaran (2023) investigated unemployment rates and economic growth in BRICS-T countries. Durmuş and Yıldırım (2023) analyzed BRICS-T countries to determine the economic determinants of life satisfaction in developing countries. They stated that inflation and GDP have a positive effect on life satisfaction, while unemployment has a negative effect. Sanni and Erenay (2023) evaluated BRICS-T countries based on economic indicators, while Samour et al. (2023), Ullah et al. (2024), Jianguo et al. (2023) ve Padhan et al. (2023) examined these countries focusing on renewable energy. Yiğiteli (2023) explored the current technological adaptation of BRICS-T countries, while Hashmi et al. (2023) investigated whether globalization and good governance contribute to these countries' attainment of carbon neutrality. Baskak (2023) and Yaman Songur (2023) conducted causal analyses on various indicators. Overall, there is a comprehensive literature on BRICS-T countries, with each study focusing on a specific and unique aspect.

(4) Ji et al. (2020) used a time-varying single copula to analyze the dependence structures between oil returns and market returns of BRICS countries. They selected the time frame from February 1996 to December 2016, with a window length of twenty-four. Yang et al. (2018) employed a time-varying single copula combined with wavelet analysis to investigate the dependence structures between G7 countries and BRICS countries' Credit Default Swap spreads across various time scales, utilizing daily data from January 2009 to December 2017. They recommended the use of a time-varying copula for improved results compared to a time-invariant copula. Similarly, Kumar et al. (2019) utilized a time-varying single copula in their research, focusing on the dependence structures between BRICS stock and foreign exchange markets using the dependence-switching copula model. Their dataset covered daily closing prices from July 21, 2015, to December 29, 2017, categorized under four market conditions:

rising stock–appreciating currency, falling stock–depreciating currency, rising stock–depreciating currency, and falling stock–appreciating. Jiang et al. (2020) aimed to explore the risk spillover effect of oil on BRICS countries' stock markets using Copula-Conditional Value-at-Risk-Maximal overlapped discrete wavelet transform, based on daily stock prices from January 1, 1997, to June 15, 2018. They employed a time-varying single copula to identify the tail-related structure of markets during shocks.

1.4 Objective of the Thesis

The time-varying copula approach is frequently utilized in the literature. Compared to time-invariant copula methods, the time-varying copula approach yields better results. This is because asset prices are continuously changed, resulting in constantly evolving dependence structures when working with time series data (Yang et al., 2018). Many studies have examined the dependencies in the stock markets of BRICS countries using the time-varying copula approach (Cheng et al., 2021; Ji et al., 2020; Jiang et al., 2020; Kumar et al., 2019; Yang et al., 2018). However, in these studies, while only allowing for changes in values, changes in copula families are not allowed. In this thesis, the time-varying flexy copula (TVFC) approach, where both values and copula families change over time, is employed to achieve well-fitting structures compared to other time-varying copula methods. Additionally, BRICS-T countries have been the subject of research, representing developing nations, and the dependency structures of their stock market indices have been examined in the presence of crises in the 21st century. Furthermore, the risk spillovers of BRICS-T countries have also been investigated using the CoVaR-Copula approach.

Because BRICS formation has an effective role in global markets, Türkiye's process of joining this formation has attracted significant media and academic attention. In this context, many researchers have analyzed the past relationship between BRICS countries and Türkiye using various indicators. Although the topics covered in these studies vary widely, conducting a complex dependency analysis of BRICS-T countries' stock indices is highly necessary. This is because a detailed examination of the stock market dependency structure before Türkiye's accession to this formation would contribute significantly to the literature. At this point, this thesis will be a pioneering study in comparing the changing dependency structures of BRICS-T countries' stock markets over time.

1.5 Hypothesis

In this study, it was evaluated whether the TVFC approach yields promising results, considering the stock market indices of BRICS-T countries in determined crisis periods, compared to other time-varying copula methods in the literature.

2
METHODS

2.1 Copula Methodology

The copula method has recently gained considerable attention among researchers in the literature. This method is used to analyze multivariate extreme events and the dependency structure between specified variables (Hamma et al., 2018). The concept of copula was introduced to the literature by Sklar (1959) and is widely used in financial applications to analyze tail dependencies. Let $F(x_1, x_2)$ denote the joint cumulative distribution function of two random variables, x_1 and x_2. Accordingly, the copula function is as follows:

$$F(x_1, x_2) = C\big(F_1(x_1), F_2(x_2)\big) = C(u, v) \tag{2.1}$$

Here, $u = F_1(x_1)$ ve $v = F_2(x_2)$ are the marginal distributions of variables that have a uniform distribution on the interval [0,1].

2.1.1 Fréchet-Hoeffding Bounds

There are three types of pseudo copula families: countermonotone, comonotone, and independent copula. When an appropriate copula family cannot be selected between two variables, this is referred to as an independence copula. Additionally, cases where the relationships are perfectly positive or perfectly negative are referred to as the Fréchet-Hoeffding upper bound and the Fréchet-Hoeffding lower bound, respectively. The Fréchet-Hoeffding lower and upper bounds for two variables can be expressed as follows:

$$W(u) \leq C(u) \leq M(u), u \in [0,1]^2$$

Here, W is countermonotone copula, while M is a comotone copula. When one series increases (decreases), and the other series decreases (increases), it indicates perfect negative dependence. This situation corresponds to the Fréchet-Hoeffding lower bound. Conversely, when one series increases (decreases), and the other series also increases (decreases), it indicates perfect positive dependence. This situation corresponds to the Fréchet-Hoeffding upper bound (Hofert et al., 2018).

2.1.2 Copula Families

Copulas represent the dependence type between two variables by incorporating lower and upper tail dependence coefficients. The tail dependence coefficients in copulas enrich the depth of the model, particularly during periods of financial crisis. In the presence of negative shocks, if there is a correlation between two variables, there exists a lower tail dependence coefficient between these variables. Similarly, in the presence of positive shocks, if there is a correlation between two variables, there exists an upper tail dependence coefficient between these variables. Lastly, if two variables have both lower and upper tail dependence coefficients and these values are equal, this condition is referred to as symmetric dependence. (Yang et al., 2015). In addition to commonly used copula families such as Gaussian, Student t, Frank, Joe, Clayton, and Gumbel, there are also copula families formed by the combination of two copula families. Moreover, copula families rotated by 90 and 270 degrees are used to indicate relationships in the opposite direction (Joe, 1997). The names of copula families and the types of tail dependence are listed in Table 2.1 (Karadag & Golbasi Simsek, 2023).

Table 2.1 The names of copula families and their tail dependence types

Copula Family Name	No TD	Symm. TD	Only Lw TD	Only Up TD	Asym TD
Independence	+				
Gaussian	+				
Student t		+			
Clayton			+		
Gumbel				+	
Frank	+				
Joe				+	
BB1					+
BB6				+	
BB7					+
BB8				+	
180 d.r. Clayton				+	
180 d.r. Gumbel			+		
180 d.r. Joe			+		
180 d.r. BB1					+
180 d.r. BB6			+		
180 d.r. BB7					+
180 d.r. BB8			+		
90 d.r. Clayton	+				
90 d.r. Gumbel	+				
90 d.r. Joe	+				
90 d.r. BB1	+				
90 d.r. BB6	+				
90 d.r. BB7	+				
90 d.r. BB8	+				
270 d.r. Clayton	+				
270 d.r. Gumbel	+				
270 d.r. Joe	+				
270 d.r. BB1	+				
270 d.r. BB6	+				
270 d.r. BB7	+				
270 d.r. BB8	+				
Tawn type 1				+	
180 d.r. Tawn type 1			+		
90 d.r. Tawn type 1	+				
270 d.r. Tawn type 1	+				
Tawn type 2				+	
180 d.r. Tawn type 2			+		
90 d.r. Tawn type 2	+				
270 d.r. Tawn type 2	+				

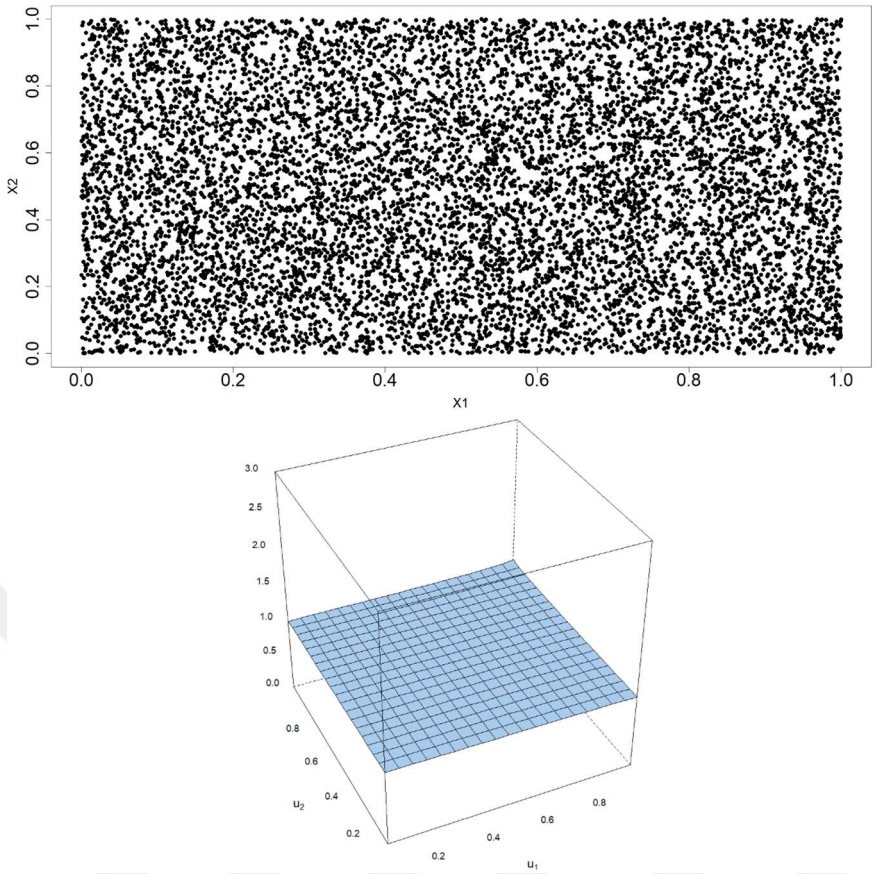
BB1: Clayton-Gumbel; BB6: Joe-Gumbel; BB7: Joe-Clayton; BB8: Joe-Frank; d.r.: degrees rotated; Symm.: Symmmetric; Only Lw: Only Lower; Only Up: Only Upper; Asym: Asymmetric

It is reasonable to classify copula families into elliptical, Archimedean, and others. The most commonly used copula classes in the literature are elliptical copula and Archimedean copula classes. Gaussian (normal) and Student t copula families belong to the elliptical copula class, while Frank, Joe, Gumbel, and Clayton copula families belong to the Archimedean copula class. Other copula families generally consist of combinations and rotated versions of copula families in the Archimedean copula class. Archimedean copulas are based on generator functions, meaning that each Archimedean copula has a generator function. Additionally,

Hofert et al. (2018) have included the Tawn copula family in a class called the extreme value copula class. In the remaining sections of the second chapter, visual graphs and mathematical notations related to some copula families will be provided. Detailed mathematical notations for all copula families have been extensively explained by Joe (1997) and Hofert et al. (2018).

2.1.3 Independence Copula

When there is no dependence between two series, this absence of dependence is defined as the independence copula family. Especially when other copula family structures are not suitable for these variables, the independence copula family becomes the most suitable copula family for these two series. For a visual representation, a simulation was conducted with 10,000 observations for two variables, assuming an independence copula structure between them. The scatter plot, density plot, and dependency values related to the obtained data are presented in Figure 2.1. The graph at the top of Figure 2.1 represents the scatter plot, while the one below represents the density plot. As can be seen, the distribution between the two series is somewhat chaotic. Therefore, there is no possibility of any relationship. Hence, Kendall's Tau, lower tail, and upper tail dependency coefficients are obtained as 0. In real-life problems, independence copula families encountered do not exhibit such perfect absence of dependence. However, these graphs are still important in representing the independence copula family.



Kendall's Tau= 0
Lower Tail Dependency=0
Upper Tail Dependency=0

Figure 2.1 A simulation of an independence copula family (n=10000) with dependency values: The top plot displays the scatter plot, while the plot below shows the density plot.

2.1.4 Elliptical Copulas

Elliptical copulas consist of Gaussian and Student t copula families. While the Gaussian copula has only one parameter, the Student t copula has two parameters.

2.1.4.1 Gaussian (Normal) Copula

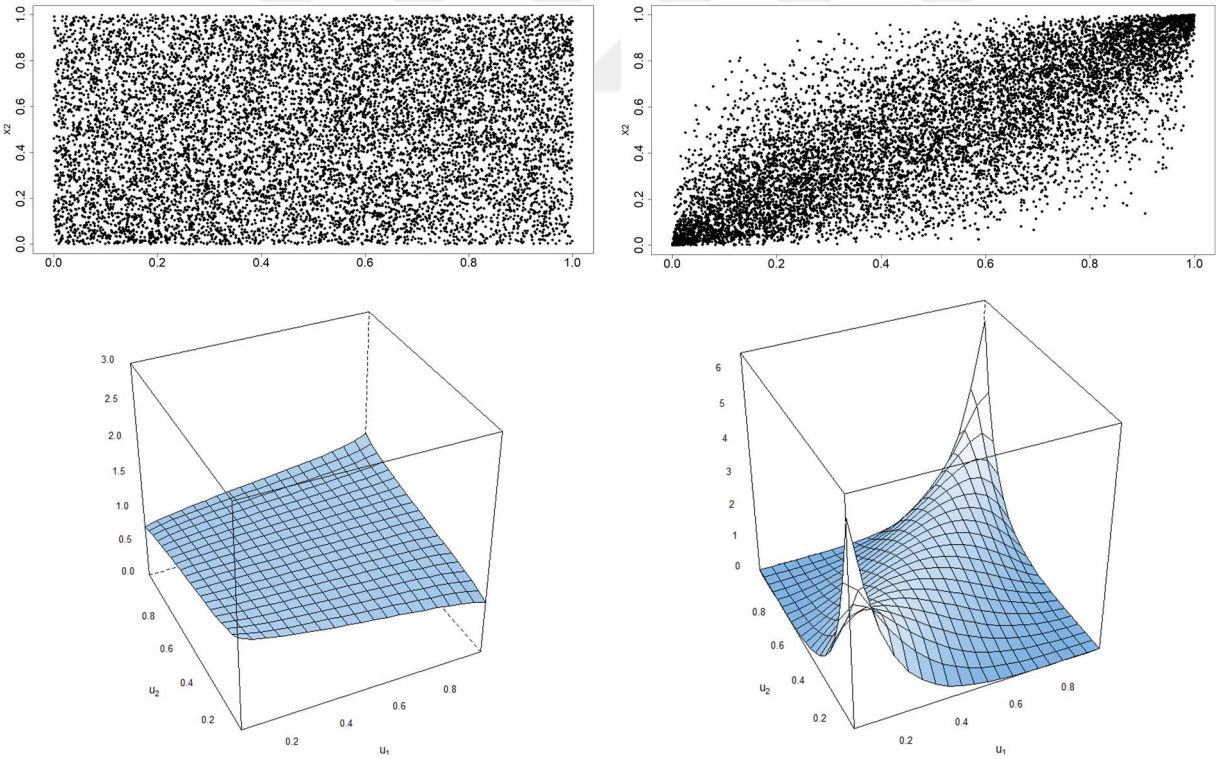
Gaussian copula, which resembles a normal distribution, consists of a single parameter. Additionally, it does not exhibit lower or upper tail dependence. The bivariate Gaussian copula has a distribution function as follows (Şahin, 2023):

$$\emptyset_\rho\left(\emptyset^{-1}(u), \emptyset^{-1}(v)\right) = \int_{-\infty}^{\emptyset^{-1}(u)} \int_{-\infty}^{\emptyset^{-1}(v)} \frac{1}{2\pi\sqrt{1-\rho^2}} \exp\left(-\frac{s^2 - 2\rho st + t^2}{2(1-\rho^2)}\right) dsdt \quad (2.2)$$

Since the Gaussian copula is composed of a single parameter, ρ in the equation (2.2) above represents the parameter of the Gaussian copula. Additionally, this parameter is the linear

correlation coefficient. Therefore, ρ varies in the range (-1,1). As the parameter of the Gaussian copula approaches 1, it converges to the Fréchet-Hoeffding upper bound. Conversely, as this parameter approaches -1, it converges to the Fréchet-Hoeffding lower bound. Moreover, approaching ρ to 0 implies approaching the independence copula.

Figure 2.2 displays two different simulation outputs. On the left side of the graph, an output is presented for a relationship with a low Kendall's Tau dependency coefficient (0.07), while on the right side of the graph, a structure with a relatively high Kendall's Tau dependency coefficient (0.59) is provided. The graph at the top of Figure 2.2 represents the scatter plot, while the one just below it represents the density plot. In the scatter plot on the right side of Figure 2.2, where the dependency coefficient is 0.59, a pattern resembling a normal distribution curve is quite evident. When the dependency structure between two series resembles this pattern, it is said that the Gaussian copula family is the most suitable copula family. The Gaussian copula, similar to the classic Gaussian distribution, exhibits distribution around the center and is rarely encountered in financial analyses due to the lack of dependency in the tails (Şahin, 2023).



Kendall's Tau= 0.07
Lower Tail Dependency=0
Upper Tail Dependency=0

Kendall's Tau= 0.59
Lower Tail Dependency=0
Upper Tail Dependency=0

Figure 2.2 A simulation of a Gaussian copula family (n=10000) with dependency values: The top plot displays the scatter plot, while the plot below shows the density plot.

2.1.4.2 Student t Copula

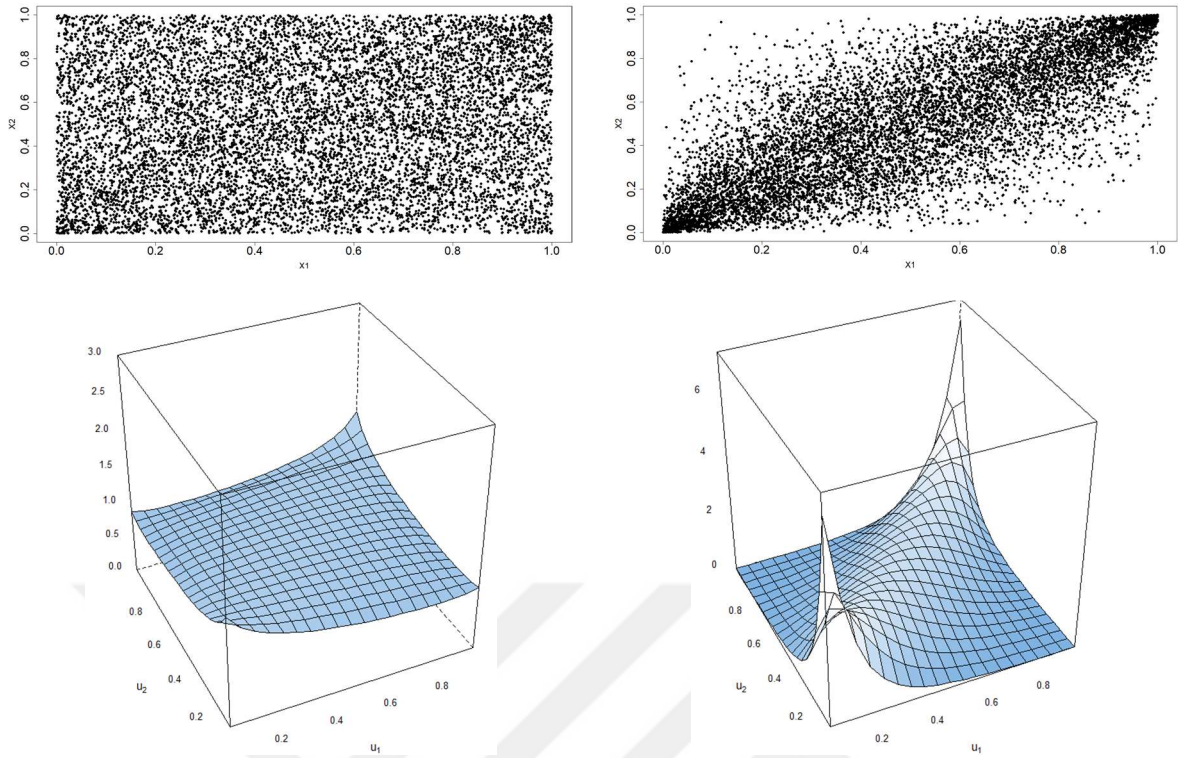
The Student t copula, which belongs to the elliptical copula family along with the Gaussian copula, is a copula family that exhibits both upper and lower tail dependence, unlike the Gaussian copula. Similar to how the Gaussian copula is derived from the Gaussian distribution, the Student t copula is derived from the Student t distribution. The bivariate Student t copula is given as follows (Bağrıaçık, 2021):

$$C_{p,\nu}^{t} = t_{p,\nu}\left(t_{\nu}^{-1}(u), t_{\nu}^{-1}(v)\right) = \int_{-\infty}^{t_{\nu}^{-1}(u)} \int_{-\infty}^{t_{\nu}^{-1}(v)} \frac{1}{2\pi\sqrt{1-\rho^2}} \left(1 + \frac{s^2 + t^2 - 2\rho st}{\nu(1-\rho^2)}\right)^{-\frac{\nu+2}{2}} dsdt \qquad (2.3)$$

In equation (2.3), $t_{p,\nu}$ represents the Student t distribution with mean 0, correlation ρ, which is the first parameter, and degrees of freedom ν, which is the second parameter. t_{ν}^{-1} denotes the inverse of the standard Student t distribution. As ν approaches infinity, the Student t copula converges to the Gaussian copula. The main distinction between the Student t copula and the Gaussian copula is its tail dependence. Due to equal tail dependences, the values of lower and upper tail dependence are equal in the Student t copula. Accordingly, the lower and upper tail dependence coefficients for the Student t distribution are as follows:

$$\lambda_{\text{Lower TD}}\left(C_{p,\nu}^{t}\right) = \lambda_{\text{Upper TD}}\left(C_{p,\nu}^{t}\right) = 2t_{\nu+1}\left(-\sqrt{\frac{(\nu+1)(1-\rho)}{1+\rho}}\right) \qquad (2.4)$$

The output graphs of two simulated dependency structures related to the Student t copula are provided in Figure 2.3. Since the t copula family has two parameters, the second parameter is set to 10 for both simulations. The scatter and density plots on the left side of Figure 2.3 depict a relationship with Kendall's Tau dependency coefficient of 0.06 and lower and upper tail dependency coefficients of 0.01. While there may not be much difference observed in the scatter plot compared to the Gaussian copula, this distinction can be identified through the density plot. In the density plot related to the Student t copula, it is observed that there is more density in the tails compared to the Gaussian copula. Additionally, it can be clearly seen from the density plots that the distribution is wider compared to the Gaussian copula. The visuals on the right side of Figure 2.3, representing the t copula family with relatively higher dependency, generally reveal the structure of this copula family.



Kendall's Tau= 0.06
Lower Tail Dependency=0.01
Upper Tail Dependency=0.01

Kendall's Tau= 0.60
Lower Tail Dependency=0.30
Upper Tail Dependency=0.30

Figure 2.3 A simulation of a t copula family (n=10000) with dependency values: The top plot displays the scatter plot, while the plot below shows the density plot.

2.1.5 Archimedean Copulas

The Archimedean copula class consists of the Clayton, Gumbel, Frank, and Joe copula families. These copula families have a generator function and a single parameter.

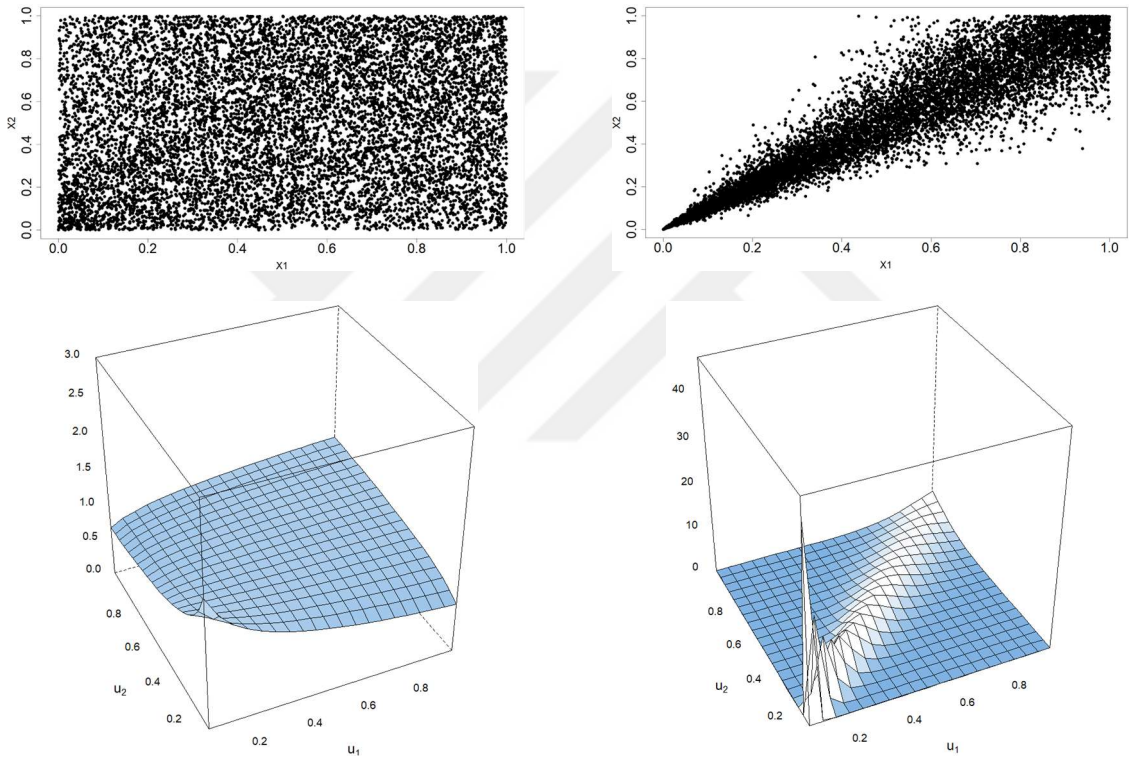
2.1.5.1 Clayton Copula

The Clayton copula, with a generator function $\varphi(t) = \frac{1}{\theta}\left(t^{-\theta} - 1\right)$, has only lower tail dependence and does not exhibit upper tail dependence. The mathematical representation of the bivariate Clayton copula is as follows:

$$C(u, v; \theta) = (u^{-\theta} + v^{-\theta} - 1)^{-1/\theta} \tag{2.5}$$

In equation (2.5), θ is the dependency parameter and is defined in the range of (0,∞) (Hofert et al., 2018). In Clayton copula as θ approaches ∞, it converges to the Fréchet-Hoeffding upper bound. When the parameter value is 0, it corresponds to the independence copula.

Figure 2.4 presents graphical representations of two different simulations of Clayton copulas. On the left side of the graph, scatter plots (top) and density plots (bottom) with a Kendall's Tau dependency coefficient of 0.09 and a lower tail dependency coefficient of 0.03 are shown. It can be observed that even with a low dependency coefficient, there is a significant density on the lower tail side. On the right side of Figure 2.4, a graph with a higher dependency coefficient is presented. Here, a simulation output with Kendall's Tau coefficient of 0.80 and a lower tail dependency coefficient of 0.92 is provided. The Clayton copula's theoretical shape is more clearly demonstrated by the scatter and density plots on the right side of Figure 2.4. The Clayton copula only exhibits lower tail dependency.



Kendall's Tau= 0.09
Lower Tail Dependency=0.03
Upper Tail Dependency=0

Kendall's Tau= 0.80
Lower Tail Dependency=0.92
Upper Tail Dependency=0

Figure 2.4 A simulation of a Clayton copula family (n=10000) with dependency values: The top plot displays the scatter plot, while the plot below shows the density plot.

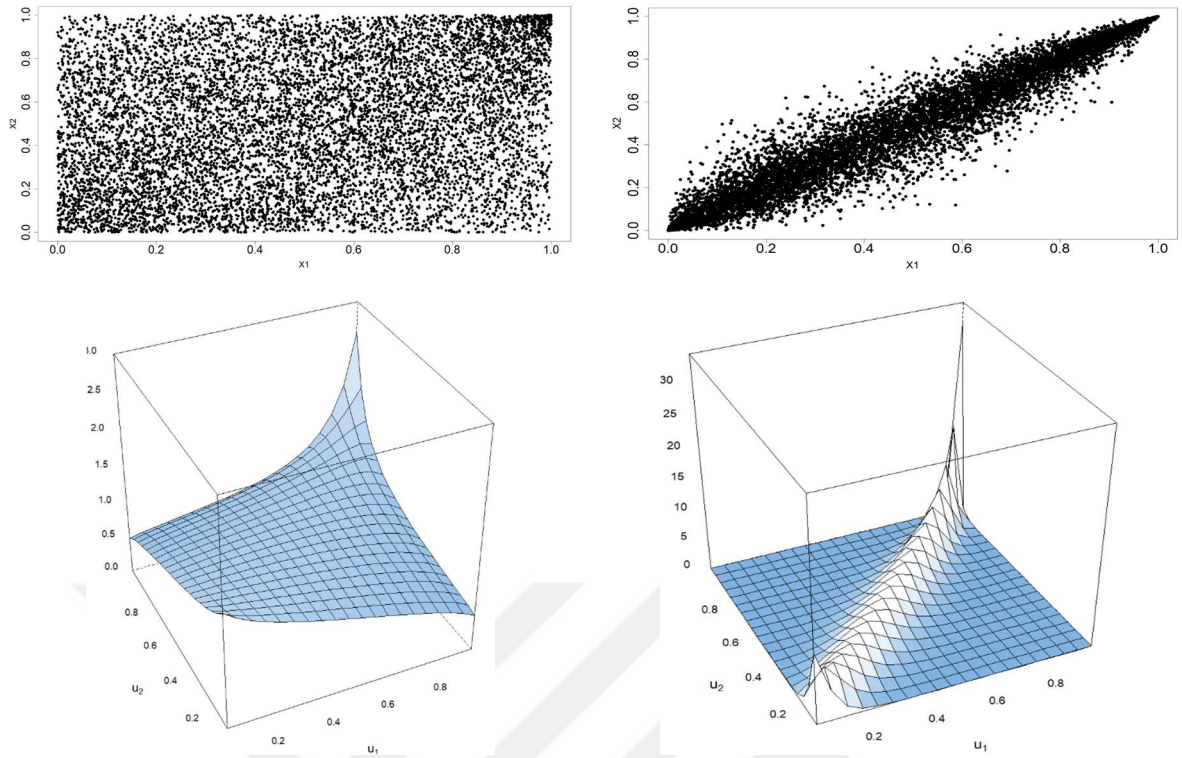
2.1.5.2 Gumbel Copula

The Gumbel copula, with generator function $\varphi(t) = (-logt)^{\theta}$, exhibits only upper tail dependency, and its mathematical representation is as follows:

$$C(u, v; \theta) = exp\left[-\left((lnu)^{\theta} + (-lnv)^{\theta}\right)^{\frac{1}{\theta}}\right] \quad (2.6)$$

In the Gumbel copula, the dependency parameter θ can take values in the range [1, ∞). As θ approaches infinity, it tends towards the Fréchet-Hoeffding upper bound. When the parameter value is 1, it corresponds to the independence copula. Additionally, the Gumbel copula allows for negative dependency between variables.

Figure 2.5 presents graphs depicting two different simulations of the Gumbel copula. On the left side of the graph, there is a scatter plot (top) and a density plot (bottom) with Kendall's Tau dependency coefficient of 0.16 and an upper tail dependency coefficient of 0.21. It is evident that there is density on the upper tail side. On the right side of Figure 2.5, a graph with a higher dependency coefficient is presented. Here, a simulation output with Kendall's Tau coefficient of 0.84 and an upper tail dependency coefficient of 0.88 is provided. The theoretical understanding of how the Gumbel copula takes shape is better illustrated by the scatter and density plots on the right side of Figure 2.5. The Gumbel copula only exhibits upper tail dependency.



Kendall's Tau= 0.16
Lower Tail Dependency=0
Upper Tail Dependency=0.21

Kendall's Tau= 0.84
Lower Tail Dependency=0
Upper Tail Dependency=0.88

Figure 2.5 A simulation of a Gumbel copula family (n=10000) with dependency values: The top plot displays the scatter plot, while the plot below shows the density plot.

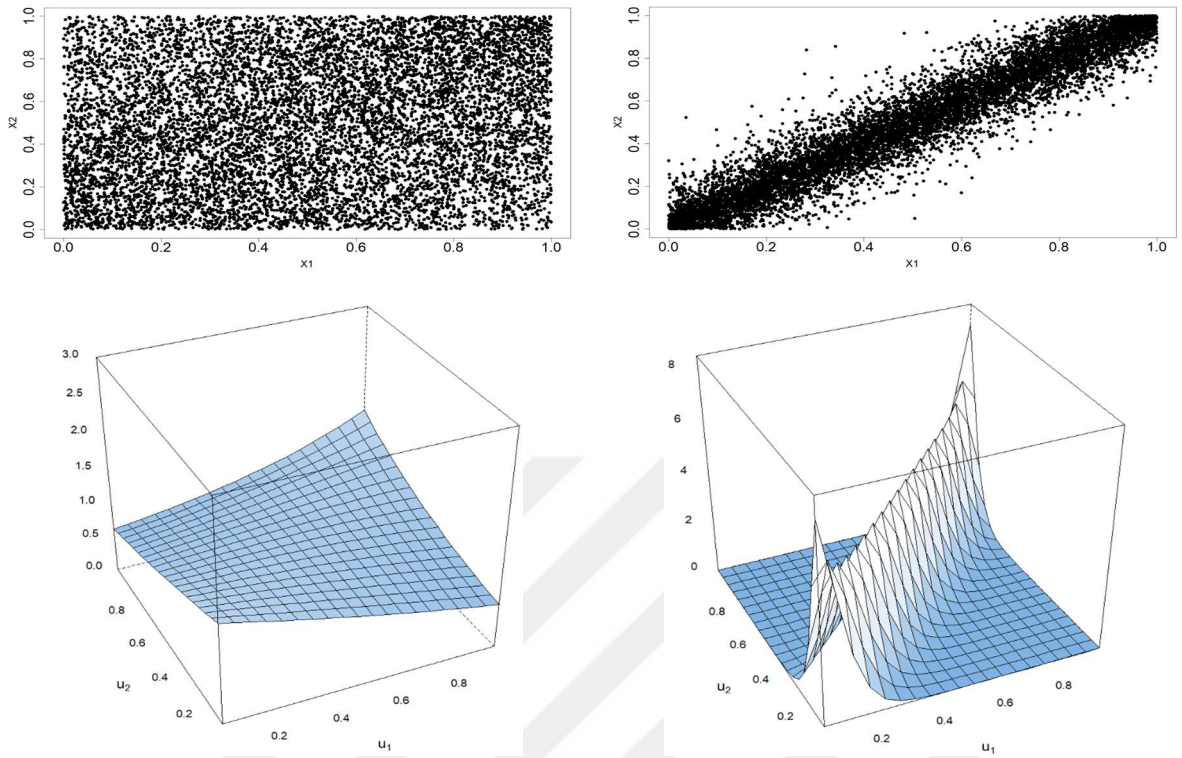
2.1.5.3 Frank Copula

The bivariate mathematical representation of the Frank copula, with generator function $\varphi(t) = -\log\left(\frac{e^{-\theta}-1}{e^{-\theta}-1}\right)$, is as follows:

$$C(u,v;\theta) = \frac{-1}{\theta} ln\left[1 + \frac{(e^{(-\theta u)}-1)(e^{(-\theta v)}-1)}{e^{(-\theta)}-1}\right] \tag{2.7}$$

The parameter value of the Frank copula can take values in the range (-∞,∞). As θ approaches ∞, it converges to the Fréchet-Hoeffding upper bound, and as θ approaches -∞, it converges to the Fréchet-Hoeffding lower bound. As the parameter value approaches 0, it approaches the independence copula family. In Figure 2.6, graphs depicting two different simulations of the Frank copula are provided. On the left side of the graph, there is a scatter plot (top) and a density plot (bottom) with a Kendall's Tau dependency coefficient of 0.12. On the right side of Figure 2.6, a graph with a higher dependency coefficient of 0.81 is presented. The scatter and density plots on the right side of Figure 2.6 provide a clearer representation of how the Frank

copula takes shape theoretically. According to these simulated examples, both the lower and upper tail dependency coefficients in the Frank copula are obtained as 0.



Kendall's Tau= 0.12
Lower Tail Dependency=0
Upper Tail Dependency=0

Kendall's Tau= 0.81
Lower Tail Dependency=0
Upper Tail Dependency=0

Figure 2.6 A simulation of a Frank copula family (n=10000) with dependency values: The top plot displays the scatter plot, while the plot below shows the density plot

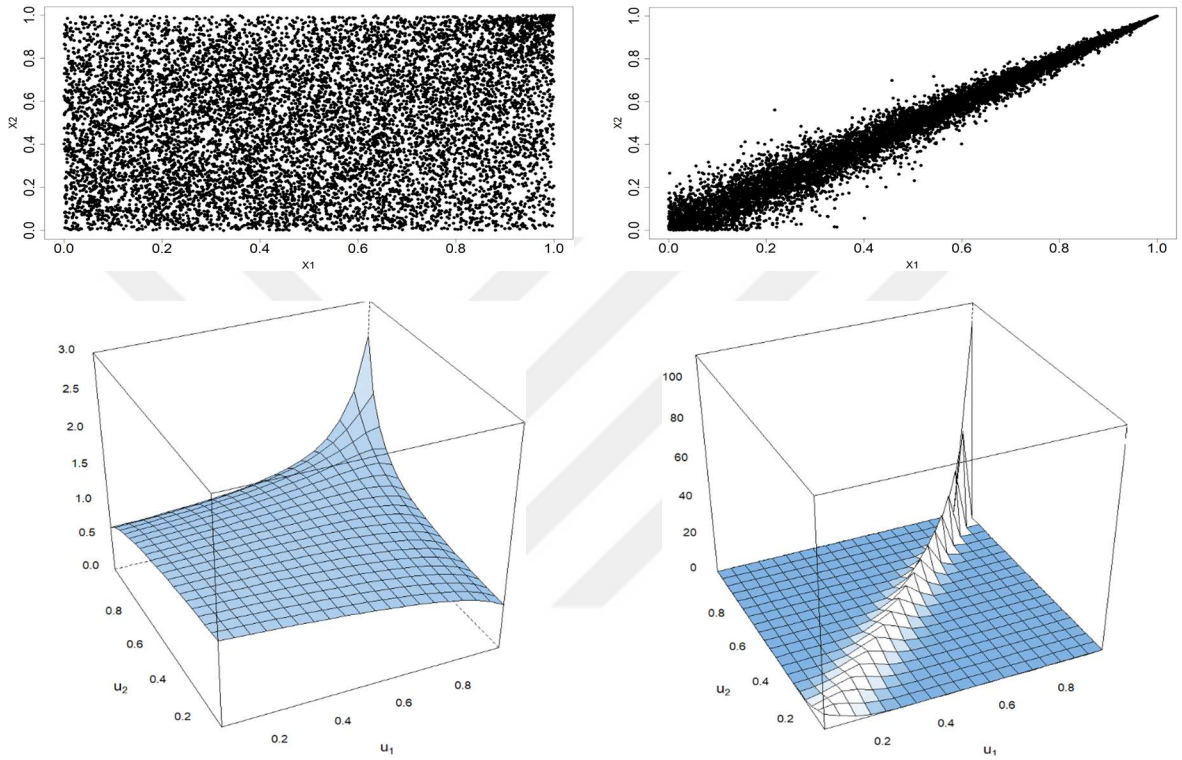
2.1.5.4 Joe Copula

Joe copula only allows for lower tail dependence. The generator function is $\varphi(t) = -\log(1-(1-t)^{\theta})$, and the bivariate mathematical expression of the Joe copula, where the upper tail dependence coefficient is 0, is as follows:

$$C(u,v;\theta) = 1-((1-u)^{\theta}+(1-v)^{\theta}-(1-u)^{\theta}(1-v)^{\theta})^{1/\theta} \tag{2.8}$$

Here the dependence parameter θ can take values in the range [1, ∞). When the parameter value equals 1, it indicates an independence copula. In addition, when the parameter approaches ∞, it implies approaching the Fréchet-Hoeffding upper bound, while approaching -∞ signifies approaching the Fréchet-Hoeffding lower bound. In other words, the Joe copula allows for negative dependence.

Figure 2.7 presents graphs for two different simulations of the Joe copula. On the left side of the graph, there is a scatter plot (top) and a density plot (bottom) with a Kendall's Tau dependence coefficient of 0.11. On the right side of Figure 2.7, a graph with a higher dependence coefficient is provided, where Kendall's Tau coefficient is 0.81. The scatter and density plots on the right side of Figure 2.7 actually provide a clearer representation of how the Joe copula takes shape theoretically.



Kendall's Tau= 0.11
Lower Tail Dependency=0
Upper Tail Dependency=0.24

Kendall's Tau= 0.90
Lower Tail Dependency=0
Upper Tail Dependency=0.96

Figure 2.7 A simulation of a Joe copula family (n=10000) with dependency values: The top plot displays the scatter plot, while the plot below shows the density plot.

2.1.5.5 Other Copula Families

Copula families formed by the combination of Frank, Joe, Clayton, and Gumbel copula families are also Archimedean copulas. In addition to these copulas, there are also rotated versions of copula families at 90 degrees, 180 degrees, and 270 degrees, along with Tawn Type-1 and Tawn Type-2 copula families. For a copula family to have a rotated version, its tail dependence structures must not be symmetric (Mudiangombe & Muteba Mwamba, 2023). Additionally, copulas rotated by 180 degrees are also referred to as survival copulas. The survival version of a copula is not an Archimedean copula (Şahin, 2023).

- **Clayton-Gumbel Copula**

Clayton-Gumbel copula, with a generator function $\varphi_{\theta,\delta}(t) = \left(1 + t^{1/\delta}\right)^{-1/\theta}$, is also known as BB1 in the literature. Its bivariate representation is as follows:

$$C_{\theta,\delta}(u,v) = \left(1 + \left[\left(u^{-\theta} - 1\right)^{\delta} + \left(v^{-\theta} - 1\right)^{\delta}\right]^{1/\delta}\right)^{-1/\theta} \tag{2.9}$$

The parameter δ can take values in the range [1, ∞), while the parameter θ can take values in the range (0, ∞). As δ approaches 1, it tends towards Clayton copulas, and as θ approaches 0, it tends towards Gumbel copulas.

- **Joe-Gumbel Copula**

Joe-Gumbel copula, with a generator function $\varphi_{\theta,\delta}(t) = 1 - \left(1 - \exp\left(-t^{1/\delta}\right)\right)^{1/\theta}$, is also known as BB6 in the literature. Its bivariate representation is as follows:

$$C_{\theta,\delta}(u,v) = 1 - \left(1 - exp - \left[\left(-\log\left(1 - (1-u)^{\theta}\right)\right)^{\delta} + \left(-\log\left(1 - (1-v)^{\theta}\right)\right)^{\delta}\right]^{1/\delta}\right)^{1/\theta} \tag{2.10}$$

The parameter δ can take values in the range [1, ∞), while the parameter θ can take values in the range [1, ∞). As δ approaches 1, it tends towards Joe copulas, and as θ approaches 1, it tends towards Gumbel copulas.

- **Joe-Clayton Copula**

The Joe-Clayton copula, with a generator function $\varphi_{\theta,\delta}(t) = 1 - \left(1 - (1+t)^{-1/\delta}\right)^{1/\theta}$, is also known as BB7 in the literature. Its bivariate representation is as follows:

$$C_{\theta,\delta}(u,v) = 1 - \left(1 - \left(\left(1 - (1-u)^{\theta}\right)^{-\delta} + \left(1 - (1-v)^{\theta}\right)^{-\delta} - 1\right)^{-1/\delta}\right)^{1/\theta} \tag{2.11}$$

The parameter δ can take values in the range (0, ∞), while the parameter θ can take values in the range [1, ∞). As δ approaches 0, it tends towards Joe copulas, and as θ approaches 1, it tends towards Clayton copulas.

- **Joe-Frank Copula**

The Joe-Frank copula, with a generator function $\varphi_{\theta,\delta}(t) = \frac{1}{\delta}\left(1 - \left(1 - \left(1 - (1 - \delta)^{\theta}\right)e^{-s}\right)^{1/\theta}\right)$, is also known as BB8 in the literature. Its bivariate representation is as follows:

$$C_{\theta,\delta}(u,v) = \delta^{-1}\left(1-\left(1-\left(1-(1-\delta)^{\theta}\right)^{-1}\left(1-(1-\delta u)^{\theta}\right)\left(1-(1-\delta v)^{\theta}\right)\right)^{1/\theta}\right) \quad (2.12)$$

The parameter δ can take values in the range (0,1], while the parameter θ can take values in the range [1, ∞). As δ approaches 1, it tends towards Joe copulas, and as θ approaches ∞, it tends towards Frank copulas.

2.2 Copula Estimation and Model Selection

Several methods are available for estimating copula models. Maximum Likelihood Estimation (MLE), which is a parametric method, works by maximizing the log-likelihood function with respect to all parameters and the hyperparameters of the marginals. Consider that we observe n independent realizations from a multivariate distribution, $\{(X_{i1},\dots,X_{ip})^{T}: i = 1,\dots,n\}$. Assume this multivariate distribution has a cumulative distribution function F_i and a probability distribution function f_i for $i = 1,\dots,p$, and a copula with density c. Let β represent the vector of marginal parameters and α represent the vector of copula parameters. The vector of parameters to be estimated is Θ. The log-likelihood function is expressed as follows (Yan, 2007):

$$l(\theta) = \sum_{i=1}^{n} \log c\left\{F_1(X_{i1};\beta),\dots,F_p(X_{ip};\beta);\alpha\right\} + \sum_{i=1}^{n}\sum_{j=1}^{p} log f_i(X_{ij};\beta) \quad (2.13)$$

The MLE of θ is as follows:

$$\hat{\theta}_{ML} = argmax l(\theta), \theta \epsilon \Theta \quad (2.14)$$

Here, Θ represents the parameter space.

The Canonical Maximum Likelihood Estimation (CMLE) method, which is semi-parametric, does not require specifying the marginal distributions of the copula. This method determines the CMLE value using the specified log-likelihood function. In CMLE, rather than estimating the hyperparameters, the empirical cumulative distribution function $\hat{F}_j$ is calculated for each random variable, and the observations (x) are converted into uniform variables (u).

$$\forall 1 \le i \le n, \forall 1 \le j \le d, u_{ij} = \hat{F}_j(x_{ij}) \quad (2.15)$$

Then, the estimation of the copula parameter is performed by maximizing the log-likelihood on the transformed data:

$$\hat{\theta} = argmax_{\theta} \sum_{i=1}^{n} log\ c(u_{i1}, \dots, u_{id}; \theta) \quad (2.16)$$

One of the non-parametric methods for copula model estimation is the non-parametric estimator by Genest and Rivest (1993). A key advantage of this approach is that, unlike parametric and semi-parametric methods, it does not require specifying the marginal distributions. Let c represent the number of concordant pairs in the sample and d represent the number of discordant pairs in the sample. The sample version of Kendall's tau is given as follows:

$$\hat{\tau} = \frac{c-d}{c+d} \quad (2.17)$$

Using this estimate and the relationship between the copula parameter and Kendall's tau, if a closed-form expression for this relationship exists, the non-parametric estimate can be easily obtained. If a closed-form expression is not available, the copula parameter can still be estimated using the general form of Kendall's tau for Archimedean copulas (equation 2.18):

$$\tau_C = 1 + 4 \int_0^1 \frac{\varphi(t)}{\varphi'(t)} dt \quad (2.18)$$

A notable disadvantage of this estimator is that it can only be applied to a limited number of single-parameter models (Manner, 2007).

When selecting the dependency structure between two assets, choosing different copula families can directly affect the results of the calculations. Therefore, when selecting the copula family between two entities for any data range, it may be necessary to try different copula families. By trying different copula families for the same data range, comparisons can be made according to certain criteria. The most commonly used criteria in the literature are log-likelihood, as well as Akaike Information Criterion (AIC), the Bayesian Information Criterion (BIC) derived from the maximum likelihood function (Yıldırım Bölen, 2022). The AIC information criterion is a value calculated based on the maximum likelihood function and is calculated using the following formula:

$$AIC = -2\ln(L) + 2k \tag{2.19}$$

where k is the number of estimated parameters and L is the maximum value of the likelihood function. The BIC criterion is calculated using the following formula:

$$BIC = -2\ln(L) + kln(n) \tag{2.20}$$

where k is the number of estimated parameters, L is the maximum value of the likelihood function, and n is the number of observations.

2.3 Copula Applications in Financial Analysis

Copula families are utilized in financial literature with various approaches. In this section, these approaches are evaluated by categorizing them into two distinct groups. Among the copula approaches employed in finance, the first is the single copula, and the second is the time-varying copula. Time-varying copulas are also divided into two categories. The first one consists of time-varying single copulas, while the second category comprises time-varying non-single copulas. The time-varying flexy copula (TVFC) proposed in this thesis and time-varying optimal copula (TVOC) approaches are time-varying non-single copulas.

2.3.1 Single Copula

When only one copula family is selected for a period covering the entirety of a study, this structure is referred to as a single or static copula. Therefore, only one copula family will have been chosen for the relevant period. This approach is called a single copula (Liu et al., 2017a; Wen et al., 2019). For instance, let's consider opting for the single copula approach to examine the pre-crisis and post-crisis dependency structures of assets X and Y. The scenario of selecting the most appropriate copula family for pre and post-crisis periods exemplifies single copulas. For instance, if there are 100 time points (days or weeks, for example) before the crisis, a single copula family is chosen for these 100 values. Similarly, if there are also 100 time points after the crisis, and a single copula family is chosen for this period, then the single copula approach is utilized. Single copulas, which exhibit time-invariant structures, are commonly used in the literature (Grégoire et al., 2008; Rašiová & Árendáš, 2023; Sukcharoen & Leatham, 2016; Zhao et al., 2023).

2.3.2 Time-varying Copula

In financial research, copula analysis is often evaluated under a time-invariant structure. Therefore, the results obtained from copula analysis remain unchanged over time. However, when working with time series data, it is important to consider that dependency values may continuously change. Especially in cases where transactions are conducted on a second-by-second basis, such as in stock market indices, the instantaneous change in dependency values should not be overlooked. Hence, copula approaches that change over time have been widely utilized in the literature in recent years (Ji et al., 2018; Lee et al., 2018; Zhang & Zhao, 2021). The first study to employ a time-varying copula approach is conducted by Ozun and Cifter (2007).

2.3.2.1 Time-varying Single Copula

In time-varying copula approaches, a time window length is determined, and within this window, the selected copula family and parameters are calculated. For example, a copula is calculated for a time period starting at *t-m* and ending at *t*. Then, the window is shifted by one day, and the copula is recalculated for the period starting at *t-m+1* and ending at *t+1*. This process continues until the last time point in the dataset is reached. In time-varying single copulas, these calculations are performed using a single copula family throughout the entire process, meaning that another copula family is not allowed to be chosen. For instance, if the Student t copula family is chosen, the Student t copula is calculated for the entire period, and the window is shifted by one step. However, the disadvantage of this approach is that if there is another copula family that fits the data better for any time period, it will be overlooked, preventing the achievement of an optimal result.

2.3.2.2 Time-varying Flexy Copula

When conducting time-varying copula analysis, different copula families are applied for a specified time interval, and the best copula family is selected based on the information criterion value. The TVOC approach by Liu et al. (2017b) selects the optimal copula from three sets of copulas based on the dependency structure between two variables. If the variables show significant negative dependence, the copula family is chosen from normal, t, 90° rotated Clayton, 270° rotated Clayton, 90° rotated Gumbel, and 270° rotated Gumbel copulas. For significant positive dependence, the selection is from normal, t, Clayton, 180° rotated Clayton, Gumbel, and 180° rotated Gumbel copulas. If neither condition is met, the copula family is selected from a broader set including normal, t, Clayton, 90° rotated Clayton, 180° rotated Clayton, 270° rotated Clayton, Gumbel, 90° rotated Gumbel, 180° rotated

Gumbel, and 270° rotated Gumbel copulas. Unlike the commonly used copula approaches, time-varying flexy copula (TVFC) aims for a better structure based on a natural selection achieved in a single step, selecting the most appropriate copula from the extended set of copulas included in the R package VineCopula (Nagler et al., 2023), namely independence, normal, t, Clayton, Gumbel, Frank, Joe, BB1, BB6, BB7, BB8, 180° rotated Clayton, 180° rotated Gumbel, 180° rotated Joe, 180° rotated BB1, 180° rotated BB6, 180° rotated BB7, 180° rotated BB8, 90° rotated Clayton, 90° rotated Gumbel, 90° rotated Joe, 90° rotated BB1, 90° rotated BB6, 90° rotated BB7, 90° rotated BB8, 270° rotated Clayton, 270° rotated Gumbel, 270° rotated Joe, 270° rotated BB1, 270° rotated BB6, 270° rotated BB7, 270° rotated BB8, Tawn type 1, 180° rotated Tawn type 1, 90° rotated Tawn type 1, 270° rotated Tawn type 1, Tawn type 2, 180° rotated Tawn type 2, 90° rotated Tawn type 2, and 270° rotated Tawn type 2 copulas for each window. In this way, TVFC aims not only to extend the selection set of the copula family but also to let the algorithm decide on the most appropriate copula family and, therefore, the direction of the dependency. This allows for the copula family to change suddenly when the window shifts by one time point. Therefore, the aim is to achieve more optimal results with TVFC.

After the data is prepared for analysis, the copula families, Kendall's Tau dependency values, and tail dependency values for each day are computed through a 65-day rolling-window approach. Let T denote the time span determined for the study. Consequently, T copula families need to be identified for the two series. This determination is conducted via an algorithm comprising the subsequent steps:

1. Obtain the filtered values of the variables.
2. Convert these values into values with a uniform distribution on [0,1].
3. Apply all existing copula families one by one to day t (current day) and the previous 64 days, obtain the information for day t, and get the log-likelihood (LL) and Akaike information criteria (AIC) values for each copula family.
4. Determine the most appropriate copula based on the best LL and AIC values.
5. Move to the next day (t=t+1) and return to step 3. Stop the process when the analyses for the last day are complete.

The procedure is iterated for each pair to obtain the most optimal output. Figure 2.8 illustrates a graphical representation summarizing step 3, step 4, and step 5.

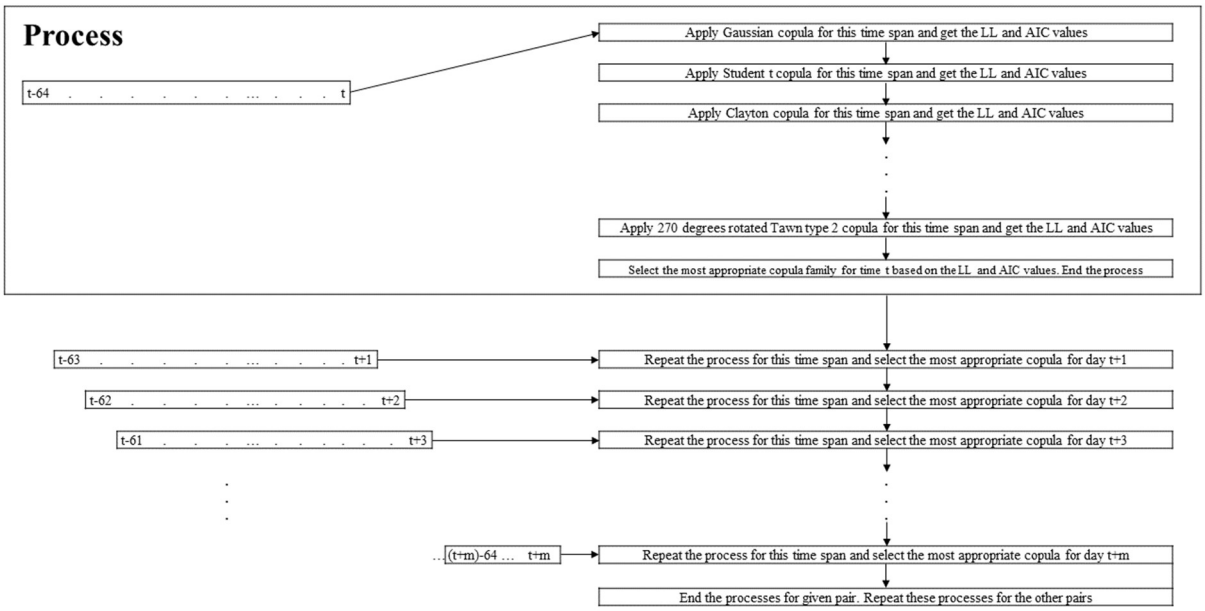


Figure 2.8 A graphical visualization of the main steps of the TVFC approach (Karadag & Golbasi Simsek, 2023)

2.4 Conditional Value-at-Risk

Value-at-risk (VaR) is a method used to measure the potential loss in the value of an asset, investment, or portfolio at a certain confidence level. It represents the maximum loss that an asset, investment, or portfolio could be exposed to under normal market conditions. VaR is typically expressed as a percentage and is commonly used in the literature for risk measurement. However, the VaR value of an asset, investment, or portfolio alone does not reflect systemic risk. Therefore, to measure tail dependencies and risk spillovers among financial assets, the conditional Value-at-Risk (CoVaR) method, proposed by Adrian and Brunnermeier (2011) and generalized by Girardi and Ergün (2013), is proposed. The conditional Value-at-Risk (CoVaR) is the VaR value of an index A given that another index, typically in financial distress, is taken into consideration. It quantifies the downside or upside risk of index A relative to index B. Let r_t^A represent the return of index A at time *t*, and r_t^B represent the return of index B at time *t*, the downside (or upside) risk spillover from A to B can be expressed as (Jin, 2018):

$$\Pr\left(r_t^B \leq CoVaR_{\beta,t}^B \middle| r_t^A \leq VaR_{\alpha,t}^A\right) = \beta \tag{2.21}$$

Here, $r_t^B \leq CoVaR_{\beta,t}^B$Is the CoVaR value of index B at the confidence level of $1-\beta$. The $VaR_{\alpha,t}^A$ expression represents the index returns in the α-quantile of the A index. The upside risk spillover is expressed as follows:

$$\Pr\left(r_t^B \geq CoVaR_{\beta,t}^B \middle| r_t^A \geq VaR_{1-\alpha,t}^A\right) = \beta \tag{2.22}$$

Here, $r_t^B \geq CoVaR_{\beta,t}^B$ represents the CoVaR value for the B index at a confidence level of $1-\beta$. The main benefit of using copulas to obtain CoVaR values is that it allows for separate modeling of the marginal distribution and dependency structures, considering various tail dependencies, whether symmetrical or asymmetrical (Cao, 2021). Therefore, the CoVaR-Copula method has been widely used in many studies in the literature (Cheng et al., 2021; Hu et al., 2024; Ji et al., 2018; Jin, 2018; Kumar et al., 2021; Reboredo & Ugolini, 2015; Shen et al., 2020; Sun et al., 2020; Xu et al., 2021; Yang et al., 2020; Zhao & Park, 2024). By utilizing copula notation, equations (2.21) and (2.22) can be expressed respectively as:

$$C\left(F_{r_t^B}\left(CoVaR_{\beta,t}^B\right), F_{r_t^A}\left(VaR_{\alpha,t}^A\right)\right) = \alpha\beta \tag{2.23}$$

$$1 - F_{r_t^B}\left(CoVaR_{\beta,t}^B\right) - F_{r_t^A}\left(VaR_{1-\alpha,t}^A\right) + C\left(F_{r_t^B}\left(CoVaR_{\beta,t}^B\right), F_{r_t^A}\left(VaR_{1-\alpha,t}^A\right)\right) = \alpha\beta \tag{2.24}$$

In this thesis, the copula family that provided the best results based on information criteria is selected to calculate the values for each window, similar to the time-varying flexible copula approach. In addition, the Kolmogorov-Smirnov (KS) bootstrap test, proposed by Abadie (2002), is used to test the difference between upside and downside risk spillovers from the VaR value. The hypothesis for the downside risk spillovers is given as: $H_0: CoVaR = VaR$ and $H_1: CoVaR < VaR$. Likewise, the hypothesis for upside risk spillovers is as follows: $H_0: CoVaR = VaR$ and $H_1: CoVaR > VaR$.

The systemic risk contribution of one asset to another can be calculated using ΔCoVaR. The formula for ΔCoVaR is as follows (Adrian & Brunnermeier, 2011):

$$\Delta CoVaR_{\beta,t}^{B|A} = \left(CoVaR_{\beta,t}^{B|A} - CoVaR_{\beta,t}^{B|A,\alpha=0.50}\right) \tag{2.25}$$

Here, $CoVaR_{\beta,t}^{B|A}$ is the VaR of index B in the β-quantile, conditional on the VaR of index A in the α-quantile. $CoVaR_{\beta,t}^{B|A,\alpha=0.50}$ is the VaR of index B in the β-quantile, conditional on the

VaR of index A in the median quantile. Eventually, $\Delta CoVaR_{\beta,t}^{B|A}$ shows how much index A adds to the VaR of index B when A moves from its median state to its alpha state. In this thesis, CoVaR is used to investigate the BRICS-T countries' stock markets' risk spillovers, and ΔCoVaR is used to measure the systemic risk contributions of the countries' stock markets.

3
APPLICATION

3.1 Data

The dataset of the thesis consists of the values obtained from the main stock indices of BRICS-T countries from the year 2000 to the present day. The daily index closing data for Bovespa (IBOV) represents the Brazilian stock market, RTSI (RTS) represents the Russian stock market, Nifty 50 (NIFTY) represents the Indian stock market, Shanghai Composite (SSE) represents the Chinese stock market, South Africa Top 40 (SA40) representing the South African stock market, and BIST100 (XU100) representing the Turkish stock market are included within the scope of the thesis. The daily natural logarithmic return calculation of stock markets is calculated to obtain the daily returns data.

3.2 Crisis Periods

In this thesis, the periods covered include the 2001 and 2008 crises, the COVID-19 pandemic, and the Russia-Ukraine war. The crisis data for the 2001 and 2008 crises are based on National Bureau of Economic Research (NBER) data (Federal Reserve Bank of St. Louis, 2024), while the COVID-19 pandemic period is defined according to the World Health Organization's (WHO) Public Health Emergency of International Concern (PHEIC) declaration date (World Health Organization, 2020). The Russia-Ukraine war period is defined based on the official start date of the war.

The NBER (Federal Reserve Bank of St. Louis, 2024) recession indicator is widely used to determine the start and end dates of global crises (Daly & Marks, 2014; Giannone et al., 2020; Owyang et al., 2005; Sun et al., 2021). Therefore, the start and end dates of the 2001 and 2008 crisis periods included in this thesis are based on the NBER economic recession indicator. For the COVID-19 crisis, the start date is considered to be January 30, 2020, the day when the World Health Organization declared PHEIC. Additionally, February 24, 2022, the start date of the Russia-Ukraine war, is included in the analysis to represent the periods before and after the Russia-Ukraine war. The details of the defined periods are as follows:

According to the NBER, the 2001 crisis lasted for eight months. Therefore, three periods, each lasting eight months, have been defined as follows:

- Pre-2001 Crisis Period: August 2, 2000 – March 31, 2001 (179 business days)
- During the 2001 Crisis Period: April 2, 2001 – November 30, 2001 (179 business days)
- Post-2001 Crisis Period: December 3, 2001 – August 5, 2002 (179 business days)

According to the NBER, the 2008 crisis lasted for 17 months. Similar to the 2001 crisis, three periods, each lasting 17 months, have been defined as follows:

- Pre-2008 Crisis Period: June 30, 2006 – December 31, 2007 (394 business days)
- During the 2008 Crisis Period: January 1, 2008 – June 30, 2009 (394 business days)
- Post-2008 Crisis Period: July 1, 2009 – December 29, 2010 (394 business days)

According to the NBER recession indicator, the 2020 COVID-19 pandemic recession lasted for two months. Initially, three periods of 2 months each were to be created: before the pandemic, during the pandemic, and after the pandemic, totaling six months of data. However, since two months of data is insufficient for analysis, unlike the 2001 and 2008 crises, only two periods were created for this example: before and after COVID-19. Additionally, the start date of the COVID-19 crisis is based on the WHO's PHEIC declaration date. Therefore, the periods defined for the COVID-19 pandemic are defined as follows:

- Pre-COVID-19 Period: January 30, 2019 – January 30, 2020 (262 business days)
- Post-COVID-19 Period: January 31, 2020 – January 29, 2021 (262 business days)

In addition to the crisis periods, the impact of the Russia-Ukraine war will also be examined. Therefore, the periods for the Russia-Ukraine war are defined as follows:

- Pre-Russia-Ukraine War Period: February 23, 2021 – February 23, 2022 (262 business days)
- Russia-Ukraine War Period: February 24, 2022 – February 24, 2023 (262 business days)

3.3 Results

Table 3.1 presents the summary statistics of the indices. The whole data covers the period from May 5, 2000, which is 64 days before the start of the Pre-2001 Crisis Period, to February 24, 2023, marking the end of the Russia-Ukraine War Period. The minimum return of Türkiye's BIST100 index was during the 2001 crisis, while the minimum returns of Brazil's BOVESPA and South Africa's Top 40 indices occurred during the 2008 crisis. Additionally, the minimum returns of India's Nifty 50 and China's Shanghai Composite indices were

observed to be on COVID-19 pandemic days, and the minimum value for Russia's RTSI index was observed at the start of the Russia-Ukraine war.

The maximum return of Türkiye's BIST100 and China's Shanghai Composite indices were during the 2001 crisis, while the maximum returns of Brazil's BOVESPA, India's Nifty 50, and South Africa's Top 40 indices occurred during the 2008 crisis. The maximum value for Russia's RTSI index was observed during the Russia-Ukraine war.

The skewness and kurtosis coefficients indicate that all variables exhibit skewness and significant leptokurtosis. The Jarque-Bera test checks if sample data have the skewness and kurtosis of a normal distribution. It tests the null hypothesis that the data are normally distributed. High Jarque-Bera values indicate that the data are not normal, leading to the rejection of the null hypothesis (Bera & Jarque, 1981). The Jarque-Bera test values reject the null hypothesis of normality for the variables. The Augmented Dickey-Fuller (ADF) test checks for a unit root in a time series sample to determine if the series is non-stationary (Cheung & Lai, 1995). It improves the basic Dickey-Fuller test by including lags of the differenced series to handle higher-order serial correlation. Rejecting the null hypothesis means the series is stationary. The Phillips-Perron (PP) test also checks for a unit root in a time series but uses a non-parametric method to correct for serial correlation and heteroskedasticity in the error terms (Phillips & Perron, 1988). Like the ADF test, rejecting the null hypothesis indicates the series is stationary. The Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test checks for stationarity in a time series (Kwiatkowski et al., 1992). Unlike the ADF and PP tests, the KPSS test's null hypothesis is that the series is stationary around a deterministic trend. Not rejecting the null hypothesis means the series is stationary. The results of the ADF and PP tests led us to reject the null hypothesis of a unit root for all indices. Additionally, the KPSS test results did not reject the null hypothesis of stationarity for any variable. Collectively, the ADF, PP, and KPSS tests confirm that the variables are stationary. The Ljung-Box test checks for autocorrelation in a time series by examining correlations at different lags (Ljung & Box, 1978). Its null hypothesis is that there is no autocorrelation. Rejection of the null hypothesis indicates autocorrelation. The Ljung-Box Q statistics revealed the presence of autocorrelation in all variables and heteroskedasticity, except for Brazil. The Lagrange Multiplier (LM) test, also known as the ARCH test, checks for autoregressive conditional heteroskedasticity (ARCH) effects in a time series (Breusch & Pagan, 1980). It looks for autocorrelation in the squared residuals from a regression model, indicating time-varying volatility. Rejection of the null hypothesis suggests the presence of

ARCH effects, and models like GARCH may be suitable. The Lagrange Multiplier (LM) test results showed an ARCH (autoregressive conditional heteroskedasticity) effect in all series. Considering the descriptive statistics, the GARCH(1,1) (generalized ARCH) model was deemed appropriate for filtering the returns data and accounting for heavy tails (Necula, 2010).

Table 3.1 Descriptive Statistics

Statistics	Brazil	Russia	India	China	South_Africa	Türkiye
Mean	0	0	0	0	0	0
Standard Deviation	0.024	0.022	0.015	0.015	0.018	0.026
Minimum	-0.192	-0.483	-0.151	-0.093	-0.239	-0.329
Maximum	0.22	0.232	0.199	0.094	0.115	0.221
Skewness	-0.331	-2.115	-0.356	-0.435	-0.767	-0.57
Kurtosis	9.062	52.711	14.252	8.737	12.975	14.838
Jarque-Bera	9310*	623107*	31821*	8428*	25497*	35405*
ADF	-29.99*	-28.71*	-29.11*	-28.59*	-30.20*	-30.95*
PP	-6043*	-5759*	-5796*	-6161*	-5688*	-5790*
KPSS	0.273	0.794	0.84	0.255	0.723	0.086
Q(6)	7.162	19.8*	50.1*	32.1*	25.97*	20.61*
Q2(6)	2467*	380.7*	785.3*	734.6*	1582.4*	1026.3*
Lagrange Multiplier	1459*	7414*	3721.7*	2933.7*	1753.1*	3076.4*

Jarque-Bera: Test for normality; ADF: Augmented Dickey–Fuller test; PP: Phillips–Perron test; KPSS: Kwiatkowski–Phillips–Schmidt–Shin test; Q(6): Ljung-Box statistics order of 6; *: < .01

3.3.1 Evaluating the Copula Results for All Periods

3.3.1.1 Evaluating the Copula Results of 2001 Crisis

In this section, the performance of the TVFC approach proposed in this thesis is evaluated against commonly used time-varying copula approaches and the TVOC approach. Table 3.2 presents the LL and AIC values for the entire 2001 crisis period. According to Table 3.2, the TVFC approach proposed in this thesis shows remarkable results compared to other approaches for the 2001 crisis period. Among others, the TVOC approach generally provides better results. The other time-varying single copula approaches included in Table 3.2 are those frequently used in the literature.

Table 3.2 Log-likelihood and Akaike Information Criterion values of chosen copula families (2001 Crisis)

	Br-Ru		**Br-In**		**Br-Ch**		**Br-So**		**Br-Tu**		**Ru-In**		**Ru-Ch**		**Ru-So**	
	LL	**AIC**	**LL**	**AIC**	**LL**	**AIC**	**LL**	**AIC**	**LL**	**AIC**	**LL**	**AIC**	**LL**	**AIC**	**LL**	**AIC**
TVFC	**2.91**	**-3.82**	**3.09**	**-3.71**	**2.20**	**-1.99**	**3.98**	**-5.61**	**3.07**	**-4.17**	**2.79**	**-3.86**	**0.97**	**-0.71**	**5.49**	**-8.51**
TVOC	2.48	-3.39	1.55	-1.95	1.38	-1.31	3.36	-4.75	2.53	-3.51	2.28	-3.40	0.33	-0.23	5.01	-8.01
Normal	1.64	-1.28	1.23	-0.46	0.73	0.54	1.83	-1.67	1.75	-1.49	1.91	-1.82	0.35	1.30	3.97	-5.93
t	2.63	-1.26	1.65	0.69	1.52	0.97	2.98	-1.96	2.32	-0.64	2.33	-0.66	0.51	2.97	4.98	-5.97
Clayton	1.80	-1.59	1.13	-0.26	0.20	1.60	2.53	-3.06	1.94	-1.88	1.89	-1.78	0.12	1.75	3.98	-5.97
Gumbel	1.63	-1.26	0.73	0.54	0.27	1.45	1.49	-0.98	1.44	-0.88	1.70	-1.41	0.08	1.84	3.89	-5.79
Frank	1.58	-1.15	1.46	-0.93	0.73	0.53	1.55	-1.10	1.68	-1.36	1.64	-1.29	0.47	1.06	3.68	-5.37
BB7	2.32	-0.63	1.27	1.47	0.40	3.20	3.02	-2.04	2.43	-0.86	2.40	-0.80	0.19	3.62	4.92	-5.84
R-Gumbel	1.94	-1.88	1.06	-0.12	0.28	1.45	2.56	-3.13	2.07	-2.14	2.11	-2.21	0.11	1.78	4.50	-6.99
R-BB7	2.28	-0.57	1.19	1.62	0.36	3.27	3.26	-2.52	2.68	-1.36	2.56	-1.12	0.18	3.65	5.00	-5.99
	Ru-Tu		**In-Ch**		**In-So**		**In-Tu**		**Ch-So**		**Ch-Tu**		**So-Tu**			
	LL	**AIC**	**LL**	**AIC**	**LL**	**AIC**	**LL**	**AIC**	**LL**	**AIC**	**LL**	**AIC**	**LL**	**AIC**		
TVFC	**4.69**	**-6.40**	**1.52**	**-1.21**	**2.47**	**-3.27**	**3.57**	**-4.97**	**1.41**	**-1.26**	**1.26**	**-0.97**	**3.19**	**-4.25**		
TVOC	3.81	-5.56	0.64	-0.44	2.15	-2.98	3.10	-4.53	0.71	-0.72	0.69	-0.55	2.55	-3.65		
Normal	2.74	-3.48	0.54	0.92	1.42	-0.84	2.20	-2.40	0.70	0.59	0.40	1.20	1.95	-1.89		
t	3.84	-3.69	0.93	2.15	2.15	-0.31	3.09	-2.18	0.84	2.31	1.00	1.99	2.28	-0.57		
Clayton	2.34	-2.68	0.25	1.50	1.64	-1.29	1.74	-1.48	0.36	1.28	0.28	1.44	1.89	-1.79		
Gumbel	3.07	-4.14	0.20	1.61	1.47	-0.94	1.91	-1.82	0.32	1.36	0.52	0.97	1.84	-1.67		
Frank	2.42	-2.84	0.56	0.88	1.45	-0.91	2.21	-2.42	0.66	0.68	0.31	1.38	1.81	-1.62		
BB7	3.68	-3.36	0.30	3.39	2.29	-0.57	2.34	-0.67	0.56	2.89	0.77	2.46	2.64	-1.29		
R-Gumbel	2.91	-3.82	0.26	1.47	1.64	-1.27	1.99	-1.97	0.36	1.28	0.30	1.40	2.03	-2.06		
R-BB7	3.75	-3.50	0.32	3.36	2.20	-0.40	2.40	-0.79	0.55	2.90	0.66	2.67	2.72	-1.44		

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye; LL: Log-likelihood;
AIC: Akaike Information Criterion; TVFC: Time-Varying Flexy Copula; TVOC: Time-Varying Optimal Copula;
BB7: Joe-Clayton Copula; R-Gumbel: 180 degreed rotated Gumbel Copula; R-BB7: 180 degrees rotated Joe-Clayton Copula

3.3.1.2 Evaluating the Copula Results of 2008 Crisis

Time-varying copula approaches were also applied to the 2008 crisis period data, and the LL and AIC criteria values are presented in Table 3.3. According to the outputs in Table 3.3, the results that stand out are again obtained with the TVFC approach proposed in this thesis. The TVOC approach also appears to be noteworthy, but it does not always outperform other methods for all pairs. For example, according to the LL criterion, the BB7 and 180 degrees rotated BB7 copula families give better results than the TVOC approach for the Brazil-Russia pair. However, according to the AIC criterion, the TVOC approach provides better results for this pair than the other two copula families. A similar situation is observed for the Russia-Türkiye pair in Table 3.3.

Table 3.3 Log-likelihood and Akaike Information Criterion values of chosen copula families (2008 Crisis)

	Br-Ru		**Br-In**		**Br-Ch**		**Br-So**		**Br-Tu**		**Ru-In**		**Ru-Ch**		**Ru-So**	
	LL	**AIC**	**LL**	**AIC**	**LL**	**AIC**	**LL**	**AIC**	**LL**	**AIC**	**LL**	**AIC**	**LL**	**AIC**	**LL**	**AIC**
TVFC	**6.95**	**-11.1**	**5.60**	**-8.5**	**2.58**	**-3.12**	**18.3**	**-33.8**	**13.2**	**-23.6**	**10.5**	**-18.2**	**3.34**	**-4.49**	**17.9**	**-33.2**
TVOC	6.35	-10.5	4.99	-7.8	1.62	-2.12	17.7	-33.1	12.6	-22.9	9.76	-17.4	2.54	-3.64	17.4	-32.7
Normal	5.46	-8.92	3.78	-5.5	1.20	-0.40	16.5	-31.0	11.3	-20.6	8.55	-15.1	1.93	-1.86	16.3	-30.6
t	6.12	-8.25	4.94	-5.8	1.41	1.17	17.5	-31.0	12.3	-20.6	9.24	-14.5	2.41	-0.82	16.9	-29.8
Clayton	5.50	-9.00	3.58	-5.1	1.14	-0.28	15.1	-28.3	10.2	-18.5	8.83	-15.7	2.20	-2.41	15.1	-28.3
Gumbel	5.05	-8.10	3.74	-5.4	1.12	-0.23	15.3	-28.6	10.8	-19.6	7.40	-12.8	1.62	-1.24	14.7	-27.4
Frank	4.65	-7.30	3.33	-4.6	1.03	-0.06	15.1	-28.2	10.2	-18.5	7.96	-13.9	1.75	-1.51	15.3	-28.5
BB7	6.57	-9.13	4.73	-5.4	1.75	0.51	17.9	-31.7	12.6	-21.3	9.75	-15.5	2.63	-1.27	17.4	-30.7
R-Gumbel	5.86	-9.72	4.02	-6.0	1.18	-0.36	16.7	-31.5	11.5	-21.1	9.27	-16.5	2.21	-2.42	16.6	-31.1
R-BB7	6.54	-9.09	4.81	-5.6	1.76	0.49	17.7	-31.4	12.7	-21.4	9.72	-15.4	2.68	-1.35	17.4	-30.7
	Ru-Tu		**In-Ch**		**In-So**		**In-Tu**		**Ch-So**		**Ch-Tu**		**So-Tu**			
	LL	**AIC**	**LL**	**AIC**	**LL**	**AIC**	**LL**	**AIC**	**LL**	**AIC**	**LL**	**AIC**	**LL**	**AIC**		
TVFC	**17.1**	**-31.3**	**3.82**	**-5.3**	**9.43**	**-16.3**	**8.97**	**-15.4**	**2.94**	**-3.79**	**2.88**	**-3.53**	**20.1**	**-37.7**		
TVOC	16.5	-30.7	3.10	-4.5	8.92	-15.7	8.63	-15.1	2.10	-2.87	2.06	-2.67	19.5	-36.9		
Normal	15.3	-28.5	2.71	-3.4	8.19	-14.4	7.79	-13.6	1.66	-1.31	1.50	-1.01	18.6	-35.1		
t	16.1	-28.1	2.95	-1.9	8.79	-13.6	8.45	-12.9	1.91	0.19	2.04	-0.07	19.1	-34.3		
Clayton	14.5	-27.0	2.63	-3.2	6.93	-11.9	6.98	-12.0	1.70	-1.40	1.63	-1.26	16.0	-30.0		
Gumbel	13.9	-25.9	2.14	-2.2	7.87	-13.7	7.17	-12.3	1.28	-0.56	1.18	-0.36	17.2	-32.4		
Frank	14.1	-26.3	2.41	-2.8	7.79	-13.6	7.42	-12.8	1.50	-1.01	1.42	-0.84	17.8	-33.7		
BB7	16.6	-29.3	3.05	-2.1	8.82	-13.6	8.41	-12.8	2.06	-0.12	1.96	0.08	19.1	-34.2		
R-Gumbel	15.8	-29.6	2.66	-3.3	7.94	-13.9	7.65	-13.3	1.76	-1.52	1.68	-1.35	18.1	-34.3		
R-BB7	16.6	-29.1	3.02	-2.0	8.83	-13.7	8.32	-12.6	2.20	-0.39	2.01	-0.02	19.1	-34.2		

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye; LL: Log-likelihood;
AIC: Akaike Information Criterion; TVFC: Time-Varying Flexy Copula; TVOC: Time-Varying Optimal Copula;
BB7: Joe-Clayton Copula;R-Gumbel: 180 degreed rotated Gumbel Copula; R-BB7: 180 degrees rotated Joe-Clayton Copula

3.3.1.3 Evaluating the Copula Results of 2020 COVID-19 Pandemic

Time-varying copula approaches were applied to the 2020 COVID-19 pandemic period, and the results are presented in Table 3.4. According to these results, the TVFC approach proposed in this thesis again provided noticeable results compared to other approaches when considering the LL and AIC criteria. Consistent with the results obtained for the 2001 and 2008 crisis periods, the TVFC approach also gave satisfactory results for the 2020 COVID-19 pandemic period.

Table 3.4 Log-likelihood and Akaike Information Criterion values of chosen copula families (2020 COVID-19 Pandemic)

	Br-Ru		Br-In		Br-Ch		Br-So		Br-Tu		Ru-In		Ru-Ch		Ru-So	
	LL	AIC	LL	AIC	LL	AIC	LL	AIC	LL	AIC	LL	AIC	LL	AIC	LL	AIC
TVFC	**3.47**	**-4.33**	**3.88**	**-5.45**	**2.14**	**-2.31**	**10.7**	**-19.2**	**4.16**	**-5.82**	**6.34**	**-10.3**	**2.53**	**-3.18**	**7.18**	**-11.94**
TVOC	2.52	-3.39	3.45	-5.01	1.22	-1.30	10.1	-18.2	3.33	-4.72	5.57	-9.34	1.84	-2.45	6.86	-11.58
Normal	2.37	-2.75	2.64	-3.28	0.94	0.12	9.56	-17.1	2.27	-2.54	4.27	-6.53	1.73	-1.46	5.94	-9.87
t	2.44	-0.88	3.00	-2.01	1.36	1.28	9.83	-15.7	2.86	-1.72	5.00	-6.00	1.73	0.53	6.90	-9.79
Clayton	2.16	-2.31	3.08	-4.17	1.09	-0.17	8.83	-15.7	2.82	-3.63	5.47	-8.94	1.68	-1.36	5.28	-8.56
Gumbel	1.79	-1.58	2.01	-2.02	0.83	0.34	8.37	-14.7	1.66	-1.33	3.44	-4.88	1.36	-0.73	6.00	-10.00
Frank	2.16	-2.31	2.46	-2.92	0.81	0.39	9.57	-17.1	2.33	-2.66	3.94	-5.88	1.71	-1.43	5.53	-9.06
BB7	2.48	-0.97	3.40	-2.80	1.41	1.18	9.89	-15.8	3.13	-2.26	5.90	-7.80	2.04	-0.08	6.88	-9.77
R-Gumbel	2.24	-2.49	3.18	-4.36	1.02	-0.04	9.52	-17.0	2.72	-3.45	5.35	-8.69	1.71	-1.41	6.03	-10.06
R-BB7	2.45	-0.89	3.55	-3.10	1.40	1.21	9.79	-15.6	3.04	-2.09	5.90	-7.80	2.05	-0.10	6.85	-9.70
	Ru-Tu		**In-Ch**		**In-So**		**In-Tu**		**Ch-So**		**Ch-Tu**		**So-Tu**			
	LL	AIC	LL	AIC	LL	AIC	LL	AIC	LL	AIC	LL	AIC	LL	AIC		
TVFC	**4.31**	**-6.18**	**3.58**	**-4.59**	**7.91**	**-13.3**	**5.11**	**-7.45**	**5.86**	**-9.23**	**2.61**	**-2.90**	**7.58**	**-12.4**		
TVOC	3.88	-5.80	2.59	-3.34	7.43	-12.7	4.51	-6.73	5.27	-8.70	1.98	-2.25	6.65	-11.3		
Normal	3.14	-4.29	2.06	-2.12	6.83	-11.7	3.67	-5.34	4.96	-7.91	1.31	-0.61	5.73	-9.47		
t	3.66	-3.33	2.48	-0.95	7.20	-10.4	4.52	-5.04	5.06	-6.12	1.82	0.36	6.45	-8.89		
Clayton	2.72	-3.45	1.95	-1.90	6.38	-10.8	3.40	-4.80	3.96	-5.93	1.14	-0.28	4.62	-7.24		
Gumbel	2.97	-3.93	1.84	-1.68	5.95	-9.9	3.64	-5.27	4.81	-7.62	1.25	-0.50	5.96	-9.91		
Frank	2.87	-3.73	1.88	-1.76	6.56	-11.1	3.51	-5.02	4.42	-6.84	1.39	-0.79	5.26	-8.52		
BB7	3.76	-3.51	2.59	-1.17	7.41	-10.8	4.30	-4.59	5.51	-7.03	1.73	0.55	6.72	-9.45		
R-Gumbel	2.94	-3.89	2.02	-2.04	6.88	-11.8	3.75	-5.50	4.49	-6.98	1.28	-0.56	5.35	-8.70		
R-BB7	3.64	-3.28	2.47	-0.94	7.35	-10.7	4.23	-4.45	5.41	-6.81	1.76	0.48	6.63	-9.25		

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye; LL: Log-likelihood;
AIC: Akaike Information Criterion; TVFC: Time-Varying Flexy Copula; TVOC: Time-Varying Optimal Copula;
BB7: Joe-Clayton Copula;R-Gumbel: 180 degreed rotated Gumbel Copula; R-BB7: 180 degrees rotated Joe-Clayton Copula

3.3.1.4 Evaluating the Copula Results of Russia-Ukraine War Period

Time-varying copula approaches were applied to two years of data, covering one year before and after the start of the Russia-Ukraine war. The averages of the LL and AIC information criteria obtained for the approaches are given in Table 3.5. As with the 2001 crisis, 2008 crisis, and the 2020 COVID-19 pandemic periods, the TVFC approach yielded remarkable results in terms of LL and AIC criteria during the Russia-Ukraine war period.

The TVFC approach allows both the returns values to vary over time and the copula families to change over time. The main reason why the TVFC approach yields better results according to information criteria compared to other time-varying copula approaches is actually this flexibility. In conclusion, using the TVFC method, which has a time-varying structure, in examining the dependency structures of two return series provides favourable results.

Table 3.5 Log-likelihood and Akaike Information Criterion values of chosen copula families (Russia-Ukraine War Period)

	Br-Ru		Br-In		Br-Ch		Br-So		Br-Tu		Ru-In		Ru-Ch		Ru-So	
	LL	AIC	LL	AIC	LL	AIC	LL	AIC	LL	AIC	LL	AIC	LL	AIC	LL	AIC
TVFC	**7.34**	**-11.7**	**3.48**	**-4.74**	**2.84**	**-3.54**	**12.3**	**-21.7**	**4.94**	**-7.49**	**7.09**	**-11.4**	**3.67**	**-5.01**	**15.1**	**-27.6**
TVOC	6.77	-11.1	3.06	-4.26	1.73	-2.29	11.8	-21.2	3.92	-6.36	6.46	-10.6	2.98	-4.29	14.8	-27.1
Normal	5.10	-8.20	1.93	-1.86	1.06	-0.11	10.2	-18.4	2.92	-3.85	5.09	-8.19	2.42	-2.84	13.0	-24.1
t	6.63	-9.26	3.11	-2.22	1.67	0.65	11.4	-18.9	3.75	-3.51	6.32	-8.64	2.82	-1.63	14.5	-24.9
Clayton	4.45	-6.89	2.30	-2.60	1.16	-0.32	9.4	-16.8	3.79	-5.58	4.69	-7.39	2.06	-2.13	12.1	-22.3
Gumbel	5.49	-8.98	1.84	-1.68	1.10	-0.20	9.9	-17.7	2.39	-2.79	5.28	-8.56	2.49	-2.98	12.2	-22.3
Frank	4.53	-7.06	1.52	-1.03	0.86	0.29	9.1	-16.3	2.54	-3.08	4.97	-7.93	2.22	-2.44	12.3	-22.5
BB7	6.40	-8.81	2.87	-1.74	1.76	0.47	11.7	-19.4	4.06	-4.12	6.21	-8.41	3.12	-2.24	14.2	-24.5
R-Gumbel	5.30	-8.60	2.47	-2.93	1.24	-0.48	10.6	-19.3	3.73	-5.45	5.18	-8.36	2.24	-2.47	13.6	-25.2
R-BB7	6.61	-9.22	2.98	-1.95	1.80	0.40	12.0	-20.0	4.20	-4.39	5.96	-7.91	2.91	-1.82	14.5	-24.9
	Ru-Tu		**In-Ch**		**In-So**		**In-Tu**		**Ch-So**		**Ch-Tu**		**So-Tu**			
	LL	AIC	LL	AIC	LL	AIC	LL	AIC	LL	AIC	LL	AIC	LL	AIC		
TVFC	**6.88**	**-11.4**	**6.15**	**-10.0**	**8.90**	**-15.3**	**6.71**	**-11.1**	**7.88**	**-13.2**	**3.90**	**-5.50**	**9.53**	**-16.3**		
TVOC	6.40	-11.0	5.66	-9.44	8.67	-14.9	6.18	-10.5	7.37	-12.6	3.09	-4.76	8.48	-15.2		
Normal	5.75	-9.49	4.47	-6.95	6.57	-11.1	4.93	-7.85	6.60	-11.2	2.70	-3.40	7.39	-12.8		
t	6.41	-8.81	4.97	-5.94	8.26	-12.5	5.62	-7.24	6.88	-9.76	3.18	-2.35	7.85	-11.7		
Clayton	5.42	-8.84	5.07	-8.14	7.45	-12.9	5.78	-9.55	5.91	-9.82	2.35	-2.70	7.80	-13.6		
Gumbel	5.53	-9.05	3.67	-5.34	6.13	-10.3	3.93	-5.87	5.96	-9.91	2.48	-2.95	6.47	-10.9		
Frank	5.21	-8.42	4.12	-6.24	6.47	-10.9	4.58	-7.16	5.90	-9.80	2.40	-2.79	6.34	-10.7		
BB7	6.68	-9.36	5.67	-7.33	8.26	-12.5	6.21	-8.41	7.53	-11.1	3.08	-2.16	8.86	-13.7		
R-Gumbel	5.93	-9.86	5.18	-8.36	7.88	-13.8	5.79	-9.58	6.31	-10.6	2.65	-3.31	7.93	-13.9		
R-BB7	6.56	-9.11	5.88	-7.76	8.22	-12.4	6.24	-8.48	7.37	-10.7	3.12	-2.24	8.78	-13.6		

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye; LL: Log-likelihood;
AIC: Akaike Information Criterion; TVFC: Time-Varying Flexy Copula; TVOC: Time-Varying Optimal Copula;
BB7: Joe-Clayton Copula;R-Gumbel: 180 degreed rotated Gumbel Copula; R-BB7: 180 degrees rotated Joe-Clayton Copula

3.3.2 Results of 2001 Crisis

3.3.2.1 Time-Varying Copula Results of 2001 Crisis

According to the analysis of the 2001 crisis, the number of copula families obtained using the TVFC approach before the 2001 crisis (BC), during the 2001 crisis (DC), and after the 2001 crisis (AC) are presented in Table 3.6. The results in Table 3.6 show that the most notable changes occurred in the Brazil-Russia pair. The number of Independence copulas increased from 13 in the BC period to 35 in the DC period and further to 113 in the AC period. These results clearly indicate that the dependency between Brazil and Russia decreased in the AC period. Another significant finding is observed in the Russia-China pair. The number of Independence copulas increased from 105 before the crisis to 115 during the crisis and then decreased to 99 after the crisis. Table 3.6 shows that the highest number of Independence

copulas among all pairs belongs to this pair. Therefore, the dependency coefficient for this pair is expected to be lower than for other pairs. The values related to dependency coefficients will be provided in the following tables, where this situation will also be discussed.

One of the best features of the TVFC approach is its flexibility in choosing the copula family between two return series. For example, if a single copula approach such as normal, Student t, or Clayton had been selected for the 2001 crisis period, as shown in Table 3.2, all calculations for the 2001 crisis would have been made using that chosen copula family. If only the Student t copula family had been selected, all calculations for the Brazil-Russia pair during the 2001 crisis would have been based on this copula family. However, in Table 3.6, the number of times the Student t copula family was chosen for the Brazil-Russia pair was 70 in the BC period, 5 in the DC period, and 0 in the AC period. This means that in the AC period, the Student t copula was never selected as the suitable copula family for the Brazil-Russia pair. If a time-varying single copula approach had specified the Student t family, it would have restricted the data to the Student t copula family throughout all time points, preventing the selection of a more suitable copula family. Therefore, the TVFC approach allows for the selection of the most appropriate copula family at many time points without restricting the data, leading to better results.

Table 3.6 Selected copula families with their frequencies (2001 crisis)

		Br-Ru			Br-In			Br-Ch			Br-So			Br-Tu		
Name	**TD STR**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**
Independence	No	13	35	113	52	15	47	66	45	51	1		58	52	35	52
Gaussian	No	2	5	3	3			10	6			4			8	
Student t	Symm.	70	5		14	15			76	28	32	35		28		11
Clayton	Only Lw		15	33		3	21				17		8		1	2
Gumbel	Only Up	4	9	6							1	12			5	
Frank	No		32	2	17	45	22	37		1				4	11	20
Joe	Only Up		14	1	10		1		5		2	8				3
BB1	Asym															
BB6	Only Up															
BB7	Asym		4								1	2			1	
BB8	Only Up		4												4	
180 d.r. Clayton	Only Up	4									2	6			4	31
180 d.r. Gumbel	Only Lw	19	12	3		10				5	12	4	25	5	29	
180 d.r. Joe	Only Lw	38	2	1	8	8	5		1		64	104	40	81	52	9
180 d.r. BB1	Asym															
180 d.r. BB6	Only Lw															
180 d.r. BB7	Asym											4			3	
180 d.r. BB8	Only Lw					2	1				2					
90 d.r. Clayton	No				9	4			16							
90 d.r. Gumbel	No			2												
90 d.r. Joe	No			3	1		11									
90 d.r. BB1	No															
90 d.r. BB6	No															
90 d.r. BB7	No								4							
90 d.r. BB8	No															
270 d.r. Clayton	No							8								
270 d.r. Gumbel	No					4										
270 d.r. Joe	No		7							14	14					2
270 d.r. BB1	No															
270 d.r. BB6	No															
270 d.r. BB7	No															
270 d.r. BB8	No															
Tawn type 1	Only Up		12	1	10		2			7	28					6
180 d.r. Tawn type 1	Only Lw	9	1	2		9				26			19	1	21	
90 d.r. Tawn type 1	No			3			13	20	3	14						1
270 d.r. Tawn type 1	No		1		8	8	2		4	1	3		4		2	
Tawn type 2	Only Up		13	1	34			1		3						
180 d.r. Tawn type 2	Only Lw	20	3		4	16	54						16	2	3	37
90 d.r. Tawn type 2	No			2	7	40		23	9	23			7	6		
270 d.r. Tawn type 2	No		5	3	2			14	10	6			2			5

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye; BC: Before 2001 Crisis; DC: During 2001 Crisis; AC: After 2001 Crisis; TD STR: Tail Dependency Structure; BB1: Clayton-Gumbel; BB6: Joe-Gumbel; BB7: Joe-Clayton; BB8: Joe-Frank; d.r.: degrees rotated; Symm.: Symmmetric; Only Lw: Only Lower; Only Up: Only Upper; Asym: Asymmetric

Table 3.6. Selected copula families with their frequencies (2001 crisis) (continued)

		Ru-In			Ru-Ch			Ru-So			Ru-Tu			In-Ch		
Name	**TD STR**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**
Independence	No	28	91	58	105	115	99		5	76	9		14	88	53	93
Gaussian	No	4	3					10	1	1	1	7	10	3	4	
Student t	Symm.		1	1	8			49	23	1	24	36	30	14		14
Clayton	Only Lw		8			1			28		2	7				2
Gumbel	Only Up	3	1	34					15	4	7	8	12			
Frank	No	7			32	5	9	2		24			18	1	13	3
Joe	Only Up		4	15			3	19	17		9	20	4			
BB1	Asym															
BB6	Only Up															
BB7	Asym							8	6		9					
BB8	Only Up								11							
180 d.r. Clayton	Only Up	7		23								6	10			
180 d.r. Gumbel	Only Lw	40	28	2				14	34	30		23	10	8		
180 d.r. Joe	Only Lw	19	8	33		9		20	9	20	10	64		2		4
180 d.r. BB1	Asym															
180 d.r. BB6	Only Lw															
180 d.r. BB7	Asym		8						4			3	1			
180 d.r. BB8	Only Lw	4														
90 d.r. Clayton	No				6											
90 d.r. Gumbel	No				18									3		1
90 d.r. Joe	No		16		2											9
90 d.r. BB1	No															
90 d.r. BB6	No															
90 d.r. BB7	No						1									
90 d.r. BB8	No															
270 d.r. Clayton	No				8										28	1
270 d.r. Gumbel	No															5
270 d.r. Joe	No		7			13									3	24
270 d.r. BB1	No															
270 d.r. BB6	No															
270 d.r. BB7	No														9	
270 d.r. BB8	No															
Tawn type 1	Only Up	6	1			19	12	16	17				13		9	
180 d.r. Tawn type 1	Only Lw	31		2				41		6	31	5	8	6	1	
90 d.r. Tawn type 1	No			1			27						12	1	4	
270 d.r. Tawn type 1	No	15				11									3	17
Tawn type 2	Only Up	6	3	7		1				1	70		37	1		
180 d.r. Tawn type 2	Only Lw	8				5	1		9		7			37	27	6
90 d.r. Tawn type 2	No									13				1	6	
270 d.r. Tawn type 2	No	1		3			27			3				14	19	

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye; BC: Before 2001 Crisis; DC: During 2001 Crisis; AC: After 2001 Crisis; TD STR: Tail Dependency Structure; BB1: Clayton-Gumbel; BB6: Joe-Gumbel; BB7: Joe-Clayton; BB8: Joe-Frank; d.r.: degrees rotated; Symm.: Symmmetric; Only Lw: Only Lower; Only Up: Only Upper; Asym: Asymmetric

Table 3.6. Selected copula families with their frequencies (2001 crisis) (continued)

		In-So			In-Tu			Ch-So			Ch-Tu			So-Tu		
Name	**TD STR**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**
Independence	No	30	48	97	73	3	62	92	71	84	96	80	86	52	34	25
Gaussian	No		3			3	10	11	3	5			1	6		18
Student t	Symm.	23	19	2	7	65	7		3		40	6	1	2	5	4
Clayton	Only Lw	2	42	12		9			12	11				17		
Gumbel	Only Up	22		6			17		3	1	3	8		43		3
Frank	No		8	37	11		21		8	7	2				19	1
Joe	Only Up	28	28	11	3		15		15			2	45	5		7
BB1	Asym						4									
BB6	Only Up															
BB7	Asym	6														
BB8	Only Up	4											2			3
180 d.r. Clayton	Only Up	17	2	1	3		20		20	6			3			41
180 d.r. Gumbel	Only Lw	1		4	5	14	5		1			9			18	7
180 d.r. Joe	Only Lw	28	17		14	12		23		5		12		17	74	7
180 d.r. BB1	Asym						3									
180 d.r. BB6	Only Lw															
180 d.r. BB7	Asym								1				1			
180 d.r. BB8	Only Lw															
90 d.r. Clayton	No															
90 d.r. Gumbel	No							3			10					
90 d.r. Joe	No				16	40						16				
90 d.r. BB1	No															
90 d.r. BB6	No															
90 d.r. BB7	No															
90 d.r. BB8	No															
270 d.r. Clayton	No							25								
270 d.r. Gumbel	No							3			4					
270 d.r. Joe	No		5								13		5			
270 d.r. BB1	No															
270 d.r. BB6	No															
270 d.r. BB7	No															
270 d.r. BB8	No															
Tawn type 1	Only Up	8	1	5	2					10	2	15	23	1	7	19
180 d.r. Tawn type 1	Only Lw	8	5			13	1		7	22		26	1	2	21	8
90 d.r. Tawn type 1	No				13			6					1			
270 d.r. Tawn type 1	No		1					8		1		2				
Tawn type 2	Only Up	1			10		13		19	21	3			32	1	35
180 d.r. Tawn type 2	Only Lw	1		2	15				13	5	3		8	2		1
90 d.r. Tawn type 2	No			2	7	20	1	6			3	3				
270 d.r. Tawn type 2	No							2	3	1			2			

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye; BC: Before 2001 Crisis; DC: During 2001 Crisis; AC: After 2001 Crisis; TD STR: Tail Dependency Structure; BB1: Clayton-Gumbel; BB6: Joe-Gumbel; BB7: Joe-Clayton; BB8: Joe-Frank; d.r.: degrees rotated; Symm.: Symmmetric; Only Lw: Only Lower; Only Up: Only Upper; Asym: Asymmetric

The percentages of the copula families based on tail dependency types for the periods related to the 2001 crisis are shown in Table 3.6. Essentially, Table 3.6 can be considered a summary of Table 3.6. In Table 3.6, values with the same tail dependency structure from Table 3.6 are aggregated and presented as percentages. For example, it was noted that the number of independence copula families for the Brazil-Russia pair was 13 in the BC period, 35 in the DC period, and 113 in the AC period. However, the independence copula family is not the

only one with "No tail dependence." Values for other copula families with a "No tail dependency" structure were also summed, divided by the total value for that period, and the percentages are presented in Table 3.6.

According to Table 3.6, the "no tail dependency" structure for the Brazil-Russia pair increased from 8% in the BC period to 47% in the DC period and then to 73% in the AC period. Therefore, the decrease in dependency between the Brazil-Russia stock indices is clearly demonstrated in this table.

The "no tail dependency" percentage for the Russia-China pair during the 2001 crisis periods is also notable. In the BC period, the Russia-China pair has a "no tail dependency" structure for almost the entire period (96%). Although this percentage drops in the DC period, it remains quite high at 80%. In the AC period, it rises again to 91%. These values show that the Russia-China stock indices had almost no dependency during the 2001 crisis periods. Another notable result is observed in the Brazil-Türkiye pair. The percentage of "only lower tail dependency," which shows dependency during negative shocks, was 50% in the BC period, 59% in the DC period, and 27% in the AC period. These results suggest that the Brazil and Türkiye stock indices were more dependent on each other during negative shocks in the BC and DC periods compared to the AC period.

The values for the India-South Africa pair show that the dependency structure between these two stock markets decreased over the periods. The percentage of copula families with no tail dependency was 17% in the BC period, increased to 36% in the DC period, and rose significantly to 76% in the AC period.

Table 3.6 shows that China has the highest “no tail dependency” with other countries. The percentage of no tail dependency between the Chinese and Brazilian stock markets is 99%, 54%, and 61% for the BC, DC, and AC periods, respectively. For the Chinese and Russian stock markets, these values are 96%, 80%, and 91%. Similarly, the percentages with the Indian stock market are 62%, 79%, and 85%, and with the South African stock market, they are 87%, 47%, and 55%. For the Turkish stock market, the values are 72%, 56%, and 53%. These results indicate that the Chinese stock market has a lower dependency on other countries' stock markets compared to other pairs.

Table 3.7 The percentages of the tail dependence types for each pair (2001 crisis)

	Br-Ru			Br-In			Br-Ch			Br-So			Br-Tu		
	BC	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**
No	8%	47%	73%	55%	65%	53%	99%	54%	61%	10%	2%	40%	35%	31%	45%
Symm.	39%	3%		8%	8%			42%	16%	18%	20%		16%		6%
Only Lw	48%	18%	22%	7%	27%	45%		1%	17%	53%	60%	60%	50%	59%	27%
Only Up	4%	29%	5%	30%		2%	1%	3%	6%	18%	15%			7%	22%
Asym		2%								1%	3%			2%	
	Ru-In			**Ru-Ch**			**Ru-So**			**Ru-Tu**			**In-Ch**		
	BC	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**
No	31%	65%	35%	96%	80%	91%	7%	3%	65%	6%	4%	30%	62%	79%	85%
Symm.		1%	1%	4%			27%	13%	1%	13%	20%	17%	8%		8%
Only Lw	57%	25%	21%		8%	1%	42%	45%	31%	28%	55%	10%	30%	16%	7%
Only Up	12%	5%	44%		11%	8%	20%	34%	3%	48%	19%	42%	1%	5%	
Asym		4%					4%	6%		5%	2%	1%			
	In-So			**In-Tu**			**Ch-So**			**Ch-Tu**			**So-Tu**		
	BC	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**
No	17%	36%	76%	67%	37%	53%	87%	47%	55%	72%	56%	53%	32%	30%	25%
Symm.	13%	11%	1%	4%	36%	4%		2%		22%	3%	1%	1%	3%	2%
Only Lw	22%	36%	10%	19%	27%	3%	13%	18%	24%	2%	26%	5%	21%	63%	13%
Only Up	45%	17%	13%	10%		36%		32%	21%	4%	14%	41%	45%	4%	60%
Asym	3%					4%		1%				1%			

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye; BC: Before 2001 Crisis; DC: During 2001 Crisis; AC: After 2001 Crisis; Symm.: Symmmetric; Only Lw: Only Lower; Only Up: Only Upper; Asym: Asymmetric

In the 2001 crisis periods, lower tail dependence values, upper tail dependence values, and Kendall's Tau values for BRICS countries' stock indices are provided in Table 3.8. Accordingly, it is determined that China has the lowest dependency coefficients among country stock markets during the 2001 crisis periods.

When examining the lower tail dependence values representing dependency during negative financial shocks, it is observed that the dependency coefficient of the Brazil-Russia pair decreases over time. This result is consistent with the interpretations made for this pair in Tables 201 and 202. The dependency structure, which was 0.20 in the BC period, decreased to 0.06 in the DC period. Thus, the dependency coefficient of the Brazil-Russia pair, which had a high lower tail dependence value of 0.20 in the BC period, decreased to 0.06 during the crisis period. In the AC period, this coefficient did not rise again; instead, it dropped to 0.03. Therefore, the 2001 crisis led to Brazilian and Russian stock markets having less lower tail dependence. The opposite situation has occurred for the Brazil stock market concerning the Brazil-China pair. The lower tail dependence coefficient, which was 0 before the 2001 crisis, rose to 0.09 during the crisis and decreased to 0.07 after the crisis. Thus, the lower tail dependence structure between these two countries increased even more compared to the BC

period. Another noteworthy result is obtained for the South Africa-Türkiye pair. The lower tail dependence coefficient, which was 0.04 in the BC period, significantly increased to 0.23 in the DC period. In the AC period, it returned to a low value of 0.03. Thus, it is observed that the South Africa and Türkiye stock markets were more affected by negative financial shocks during the 2001 crisis compared to other periods.

During crisis periods, as there is increased exposure to negative financial shocks compared to other periods, slightly higher lower tail dependences than normal are expected. When examining the 15 pairs in Table 3.8, it is observed that the lower tail dependence coefficients of the Brazil-India, Brazil-China, Brazil-South Africa, Brazil-Türkiye, Russia-China, Russia-Türkiye, India-South Africa, India-Türkiye, and South Africa-Türkiye pairs increased in the DC period compared to the BC period.

When examining the upper tail dependence coefficients that represent the degree of dependence in the presence of positive financial shocks, it was found that India's upper tail dependence coefficients with South Africa were 0.15, 0.07, and 0.03 in the BC, DC, and AC periods, respectively. As can be seen, there has been a steady decrease in the upper tail dependence coefficient over time. Conversely, for the India-Türkiye pair, the upper tail dependence coefficient increased over time, with values of 0.01, 0.05, and 0.14 in the BC, DC, and AC periods, respectively. Thus, during the 2001 crisis periods, it was concluded that India's dependence with South Africa decreased while its dependence with Türkiye increased in the presence of positive financial shocks. However, it was observed that India's upper tail dependence value with China remained at 0.01 for all three periods. This indicates that during these periods, there was neither an increase nor a decrease in the upper tail dependence coefficient for the India-China pair. Indeed, when Table 3.6 is examined, it is seen that China had low upper tail dependence coefficients with other countries, especially in the BC period. In the BC period, China's upper tail dependence coefficients with Brazil, Russia, and China were all 0. No other pair had an upper tail dependence coefficient of 0 in the BC period.

When examining Kendall's Tau values, it was concluded that the dependence degrees of the Russia-South Africa and Russia-Türkiye pairs were higher than those of other pairs. However, it was observed that Russia's dependence coefficient with South Africa decreased from 0.26 in the BC period and 0.23 in the DC period to 0.07 in the AC period. The dependence coefficient for the Russia-Türkiye pair was found to be 0.16 in the BC period, 0.22 in the DC period, and 0.14 in the AC period.

The negative dependencies present in pairs involving China are also quite significant. The China-Russia pair, with negative dependence coefficients of -0.06 and -0.03 in the BC and AC periods, respectively, had a dependence coefficient of 0 in the DC period. Additionally, while the China-Brazil pair had a dependence coefficient of -0.08 in the BC period, it became 0 in the DC period and 0.01 in the AC period. The negative dependence coefficient of -0.04 for the China-South Africa pair in the BC period turned positive, reaching 0.06 in the DC and AC periods. Therefore, it is concluded that the negative dependence of the China-South Africa pair before the 2001 crisis turned positive during and after the crisis. The opposite situation occurred for the China-India pair. The positive dependence value (0.02) of the pair in the BC period became -0.03 in the DC period and -0.02 in the AC period. Thus, it is seen that the positive dependence of the China-India pair before the 2001 crisis turned negative during and after the crisis.

Table 3.8 Lower tail dependence, upper tail dependence, and Kendall's Tau values (2001 Crisis)

	Brazil			**Russia**			**India**			**China**			**South Africa**			**Türkiye**		
	BC	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**
	Lower tail dependence values																	
Brazil	1	1	1															
Russia	.20	.06	.03	1	1	1												
India	.02	.10	.06	.16	.11	.07	1	1	1									
China	.00	.09	.07	.00	.02	.00	.06	.02	.02	1	1	1						
South A.	.21	.29	.14	.26	.21	.07	.07	.16	.03	.03	.01	.04	1	1	1			
Türkiye	.16	.20	.09	.07	.25	.08	.06	.16	.02	.04	.03	.00	.04	.23	.03	1	1	1
	Upper tail dependence values																	
Brazil	1	1	1	.11	.11	.01	.05	.02	.00	.00	.09	.03	.06	.13	.00	.03	.03	.05
Russia				1	1	1	.02	.02	.11	.00	.00	.01	.16	.16	.01	.18	.13	.12
India							1	1	1	.01	.01	.01	.15	.07	.03	.01	.05	.14
China										1	1	1	.00	.05	.02	.05	.03	.09
South A.													1	1	1	.10	.01	.13
Türkiye																1	1	1
	Kendall's Tau values																	
Brazil	1	1	1	.13	.16	.03	.00	.01	.06	-.08	.00	.01	.12	.21	.09	.08	.18	.13
Russia				1	1	1	.14	.08	.11	-.06	.00	-.03	.26	.23	.07	.16	.22	.14
India							1	1	1	.02	-.03	-.02	.12	.12	.07	.03	-.02	.15
China										1	1	1	-.04	.06	.06	-.01	.03	.05
South A.													1	1	1	.11	.16	.15
Türkiye																1	1	1

South A.: South Africa; BC: Before 2001 Crisis; DC: During 2001 Crisis; AC: After 2001 Crisis

3.3.2.2 Risk Spillover Results of 2001 Crisis

- **Kolmogorov–Smirnov Bootstrapping Test Results (2001 Crisis)**

The average VaR and CoVaR values for the 2001 crisis are provided in Table 3.9. Additionally, the results of the Kolmogorov-Smirnov test conducted to examine the presence of risk spillovers are also presented in Table 3.9. According to the Kolmogorov-Smirnov test results, the null hypothesis (H0) for downside risk spillover values for all pairs except for those from Russia to China and from China to Russia has been rejected for all three periods. This indicates that no downside risk spillovers were detected from Russia to China or from China to Russia. Downside risk spillovers were statistically identified for all other BRICS-T countries. When examining upside risk spillover values, no risk spillover was detected from Russia to China for all three periods, from India to China for the DC and AC periods, and from China to Russia for the DC and AC periods. The null hypothesis was rejected for other pairs in all hypothesis tests conducted. Therefore, it is concluded that risk spillovers exist for these pairs.

Table 3.9 Averages of VaR and CoVaR values of the indices and KS bootstrap test results (2001 crisis)

Spillover		Downside Spillovers								
from	to	BC			DC			AC		
		VaR	CoVaR	p-value	VaR	CoVaR	p-value	VaR	CoVaR	p-value
Br	Ru	-0.046	-0.092	*	-0.030	-0.043	*	-0.032	-0.038	*
Br	In	-0.026	-0.028	*	-0.023	-0.031	*	-0.019	-0.029	*
Br	Ch	-0.015	-0.012	*	-0.020	-0.023	*	-0.025	-0.033	*
Br	So	-0.023	-0.040	*	-0.025	-0.047	*	-0.027	-0.040	*
Br	Tu	-0.066	-0.109	*	-0.068	-0.124	*	-0.049	-0.072	*
Ru	Br	-0.035	-0.064	*	-0.044	-0.059	*	-0.041	-0.049	*
Ru	In	-0.026	-0.042	*	-0.023	-0.033	*	-0.019	-0.025	*
Ru	Ch	-0.015	-0.014		-0.020	-0.021		-0.025	-0.020	
Ru	So	-0.023	-0.042	*	-0.025	-0.043	*	-0.027	-0.035	*
Ru	Tu	-0.066	-0.105	*	-0.068	-0.139	*	-0.049	-0.073	*
In	Br	-0.035	-0.038	*	-0.044	-0.057	*	-0.041	-0.058	*
In	Ru	-0.046	-0.079	*	-0.030	-0.044	*	-0.032	-0.043	*
In	Ch	-0.015	-0.022	*	-0.020	-0.024	*	-0.025	-0.027	*
In	So	-0.023	-0.032	*	-0.025	-0.038	*	-0.027	-0.032	*
In	Tu	-0.066	-0.075	*	-0.068	-0.098	*	-0.049	-0.064	*
Ch	Br	-0.035	-0.027	*	-0.044	-0.052	*	-0.041	-0.048	*
Ch	Ru	-0.046	-0.042		-0.030	-0.032		-0.032	-0.025	
Ch	In	-0.026	-0.034	*	-0.023	-0.024	*	-0.019	-0.021	*
Ch	So	-0.023	-0.022	*	-0.025	-0.028	*	-0.027	-0.032	*
Ch	Tu	-0.066	-0.082	*	-0.068	-0.084	*	-0.049	-0.053	*
So	Br	-0.035	-0.060	*	-0.044	-0.085	*	-0.041	-0.060	*
So	Ru	-0.046	-0.094	*	-0.030	-0.058	*	-0.032	-0.044	*
So	In	-0.026	-0.038	*	-0.023	-0.037	*	-0.019	-0.023	*
So	Ch	-0.015	-0.016	*	-0.020	-0.024	*	-0.025	-0.032	*
So	Tu	-0.066	-0.088	*	-0.068	-0.125	*	-0.049	-0.067	*
Tu	Br	-0.035	-0.056	*	-0.044	-0.075	*	-0.041	-0.057	*
Tu	Ru	-0.046	-0.069	*	-0.030	-0.061	*	-0.032	-0.045	*
Tu	In	-0.026	-0.032	*	-0.023	-0.035	*	-0.019	-0.025	*
Tu	Ch	-0.015	-0.019	*	-0.020	-0.023	*	-0.025	-0.027	*
Tu	So	-0.023	-0.031	*	-0.025	-0.041	*	-0.027	-0.035	*

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye; BC: Before 2001 Crisis; DC: During 2001 Crisis; AC: After 2001 Crisis; CoVaR: Conditional Value-at-Risk; VaR: Value-at-Risk; *: $p<0.05$

Table 3.9. Averages of VaR and CoVaR values of the indices and KS bootstrap test results (2001 crisis) (continued)

Spillover		Upside Spillovers								
from	to	BC			DC			AC		
		VaR	CoVaR	p-value	VaR	CoVaR	p-value	VaR	CoVaR	p-value
Br	Ru	0.045	0.068	*	0.030	0.043	*	0.032	0.033	*
Br	In	0.025	0.030	*	0.023	0.020	*	0.019	0.020	*
Br	Ch	0.015	0.012	*	0.020	0.024	*	0.025	0.028	*
Br	So	0.023	0.028	*	0.024	0.032	*	0.026	0.026	*
Br	Tu	0.064	0.079	*	0.066	0.090	*	0.049	0.065	*
Ru	Br	0.034	0.049	*	0.043	0.059	*	0.040	0.042	*
Ru	In	0.025	0.031	*	0.023	0.027	*	0.019	0.027	*
Ru	Ch	0.015	0.014		0.020	0.019		0.025	0.024	
Ru	So	0.023	0.036	*	0.024	0.036	*	0.026	0.027	*
Ru	Tu	0.064	0.125	*	0.066	0.104	*	0.049	0.084	*
In	Br	0.034	0.041	*	0.043	0.038	*	0.040	0.042	*
In	Ru	0.045	0.058	*	0.030	0.036	*	0.032	0.046	*
In	Ch	0.015	0.017	*	0.020	0.019		0.025	0.023	
In	So	0.023	0.033	*	0.024	0.030	*	0.026	0.030	*
In	Tu	0.064	0.070	*	0.066	0.073	*	0.049	0.076	*
Ch	Br	0.034	0.026	*	0.043	0.051	*	0.040	0.042	*
Ch	Ru	0.045	0.041	*	0.030	0.029		0.032	0.032	
Ch	In	0.025	0.027	*	0.023	0.021	*	0.019	0.018	*
Ch	So	0.023	0.019	*	0.024	0.030	*	0.026	0.031	*
Ch	Tu	0.064	0.079	*	0.066	0.078	*	0.049	0.066	*
So	Br	0.034	0.043	*	0.043	0.060	*	0.040	0.040	*
So	Ru	0.045	0.079	*	0.030	0.049	*	0.032	0.034	*
So	In	0.025	0.037	*	0.023	0.028	*	0.019	0.022	*
So	Ch	0.015	0.012	*	0.020	0.030	*	0.025	0.033	*
So	Tu	0.064	0.104	*	0.066	0.080	*	0.049	0.086	*
Tu	Br	0.034	0.039	*	0.043	0.053	*	0.040	0.051	*
Tu	Ru	0.045	0.084	*	0.030	0.048	*	0.032	0.053	*
Tu	In	0.025	0.027	*	0.023	0.025	*	0.019	0.029	*
Tu	Ch	0.015	0.018	*	0.020	0.021	*	0.025	0.035	*
Tu	So	0.023	0.032	*	0.024	0.028	*	0.026	0.040	*

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye; BC: Before 2001 Crisis; DC: During 2001 Crisis; AC: After 2001 Crisis; CoVaR: Conditional Value-at-Risk; VaR: Value-at-Risk;
*: $p<0.05$

- **CoVaR Results (2001 Crisis)**

The graphical representations of the average VaR and CoVaR values obtained from Table 3.9 are provided in Figure 3.1. Particularly, when examining the VaR and CoVaR graphs of the Russia-China pair, it can be observed that the VaR and CoVaR values overlap at many points compared to other graphs. This situation supports the result found for this pair in Table 3.9.

From the graphs in Figure 3.1, it is clearly seen that Türkiye is the country most exposed to risk spillover from other BRICS-T countries. Especially in the plots where Türkiye is located, values are spread towards more extreme points. This finding is also evident from Table 3.9. Among the pairs with the highest risk spillover values, Türkiye is frequently observed. Therefore, it is concluded that Türkiye is the country most exposed to risk spillover from BRICS-T countries during the 2001 crisis.

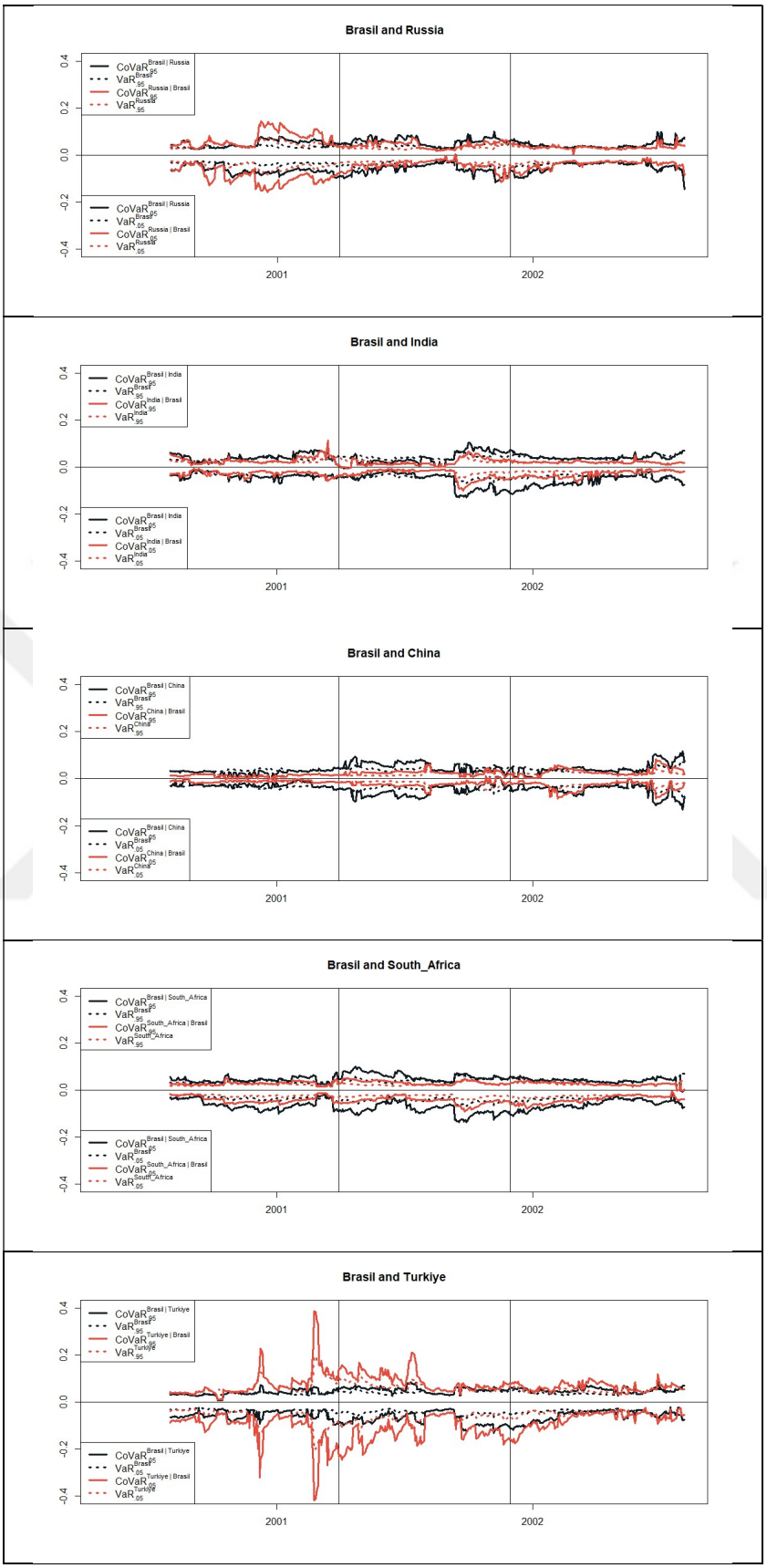


Figure 3.1 Graphic representation of downside and upside VaR and CoVaR estimates of BRICS-T countries (2001 Crisis)

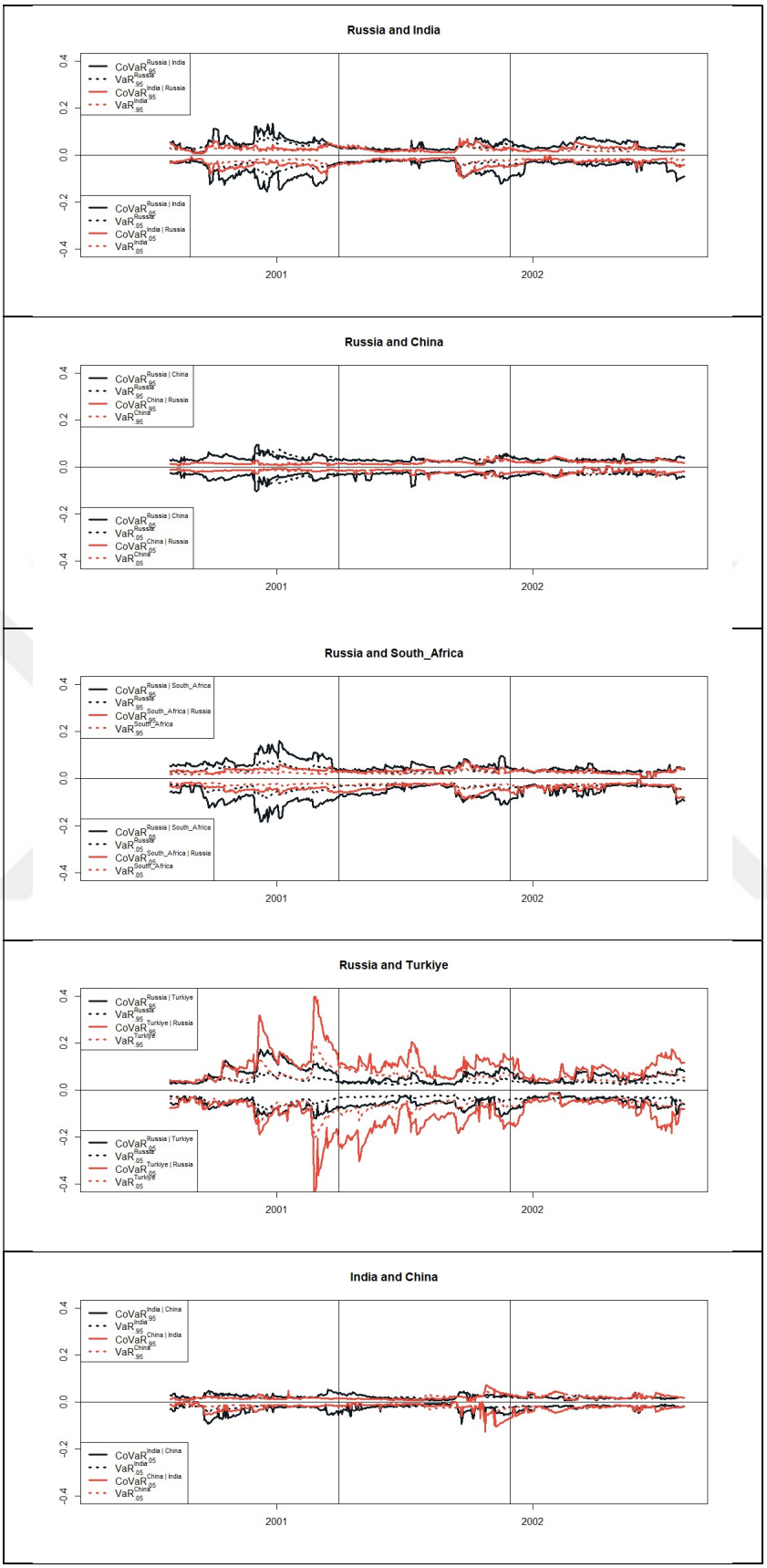


Figure 3.1 Graphic representation of downside and upside VaR and CoVaR estimates of BRICS-T countries (2001 Crisis) (continued)

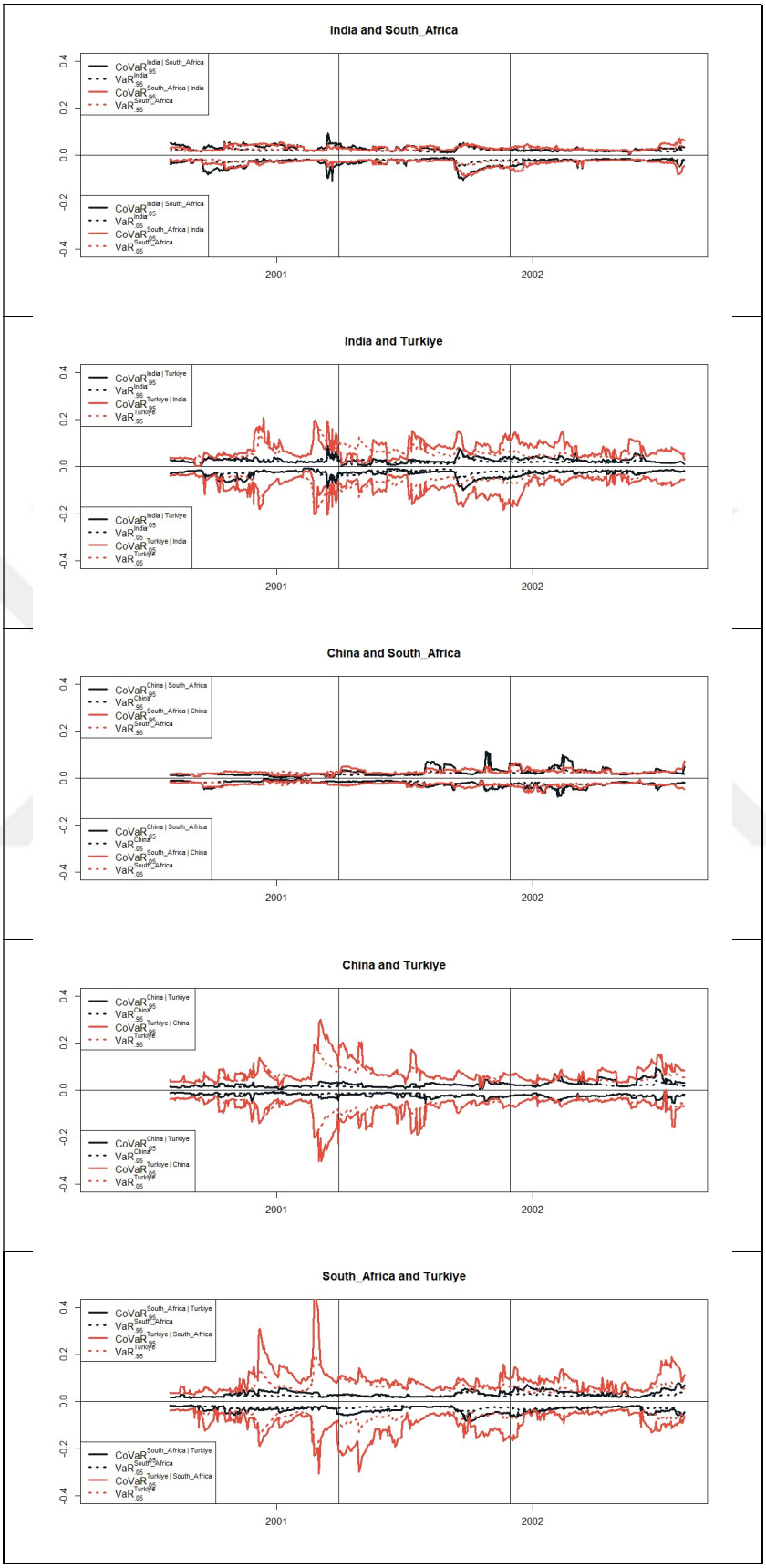


Figure 3.1 Graphic representation of downside and upside VaR and CoVaR estimates of BRICS-T countries (2001 Crisis) (continued)

- **ΔCoVaR Results (2001 Crisis)**

Table 3.10 presents the average downside and upside ΔCoVaR values for BRICS-T countries during the 2001 crisis. Graphical representations of these values are shown in Figure 3.2. According to these results, the downside ΔCoVaR values in the DC period are higher than those in the BC period for the pairs: from Russia to Brazil, from Brazil to Russia, from Russia to India, from India to Russia, from Russia to South Africa, from South Africa to Russia, from China to India, from India to China, and from China to Türkiye. In addition, it was observed that the mutual downside risk contribution values of all other pairs, except India-Brazil, China-Brazil, and China-South Africa, were higher in the AC period than in the BC period. Notably, Türkiye was the most affected by downside risk contributions from other BRICS-T countries during the DC period.

Based on the upside risk contribution results, Türkiye was found to be the most affected by other BRICS-T countries across all three periods of the 2001 crisis, while China was the least affected. Figure 3.2 shows the ΔCoVaR graphs for each country, clearly indicating that China had the lowest values and Türkiye had the highest values overall.

Table 3.10 Averages of ΔCoVaR values (2001 Crisis)

Spillovers		ΔCoVaR downside			ΔCoVaR upside		
from	**to**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**
Russia	Brazil	-0.025	-0.010	-0.006	0.088	0.108	0.085
Brazil	Russia	-0.040	-0.009	-0.005	0.121	0.077	0.066
India	Brazil	-0.003	-0.012	-0.014	0.076	0.084	0.086
Brazil	India	-0.002	-0.007	-0.008	0.056	0.044	0.041
China	Brazil	0.005	-0.008	-0.007	0.058	0.095	0.083
Brazil	China	0.002	-0.003	-0.008	0.025	0.044	0.054
South Africa	Brazil	-0.021	-0.033	-0.015	0.082	0.111	0.085
Brazil	South Africa	-0.013	-0.017	-0.010	0.054	0.062	0.056
Türkiye	Brazil	-0.017	-0.024	-0.012	0.077	0.104	0.096
Brazil	Türkiye	-0.037	-0.045	-0.017	0.151	0.169	0.119
India	Russia	-0.027	-0.012	-0.009	0.110	0.068	0.080
Russia	India	-0.012	-0.008	-0.004	0.060	0.052	0.048
China	Russia	0.001	-0.002	0.005	0.083	0.060	0.062
Russia	China	0.000	-0.001	0.004	0.028	0.039	0.048
South Africa	Russia	-0.039	-0.022	-0.010	0.134	0.085	0.068
Russia	South Africa	-0.015	-0.014	-0.006	0.063	0.065	0.056
Türkiye	Russia	-0.018	-0.025	-0.011	0.134	0.083	0.087
Russia	Türkiye	-0.032	-0.058	-0.019	0.197	0.185	0.137
China	India	-0.007	-0.001	-0.002	0.055	0.044	0.037
India	China	-0.006	-0.003	-0.002	0.033	0.039	0.048
South Africa	India	-0.009	-0.011	-0.003	0.065	0.055	0.042
India	South Africa	-0.006	-0.010	-0.004	0.058	0.058	0.058
Türkiye	India	-0.006	-0.012	-0.003	0.053	0.047	0.050
India	Türkiye	-0.011	-0.035	-0.010	0.135	0.137	0.130
South Africa	China	-0.002	-0.002	-0.005	0.027	0.051	0.059
China	South Africa	-0.001	-0.002	-0.004	0.041	0.056	0.059
Türkiye	China	-0.003	-0.003	0.000	0.033	0.042	0.062
China	Türkiye	-0.016	-0.014	-0.001	0.144	0.148	0.118
Türkiye	South Africa	-0.006	-0.013	-0.005	0.057	0.057	0.069
South Africa	Türkiye	-0.017	-0.047	-0.013	0.175	0.158	0.140

BC: Before 2001 Crisis; DC: During 2001 Crisis; AC: After 2001 Crisis; CoVaR: Conditional Value-at-Risk

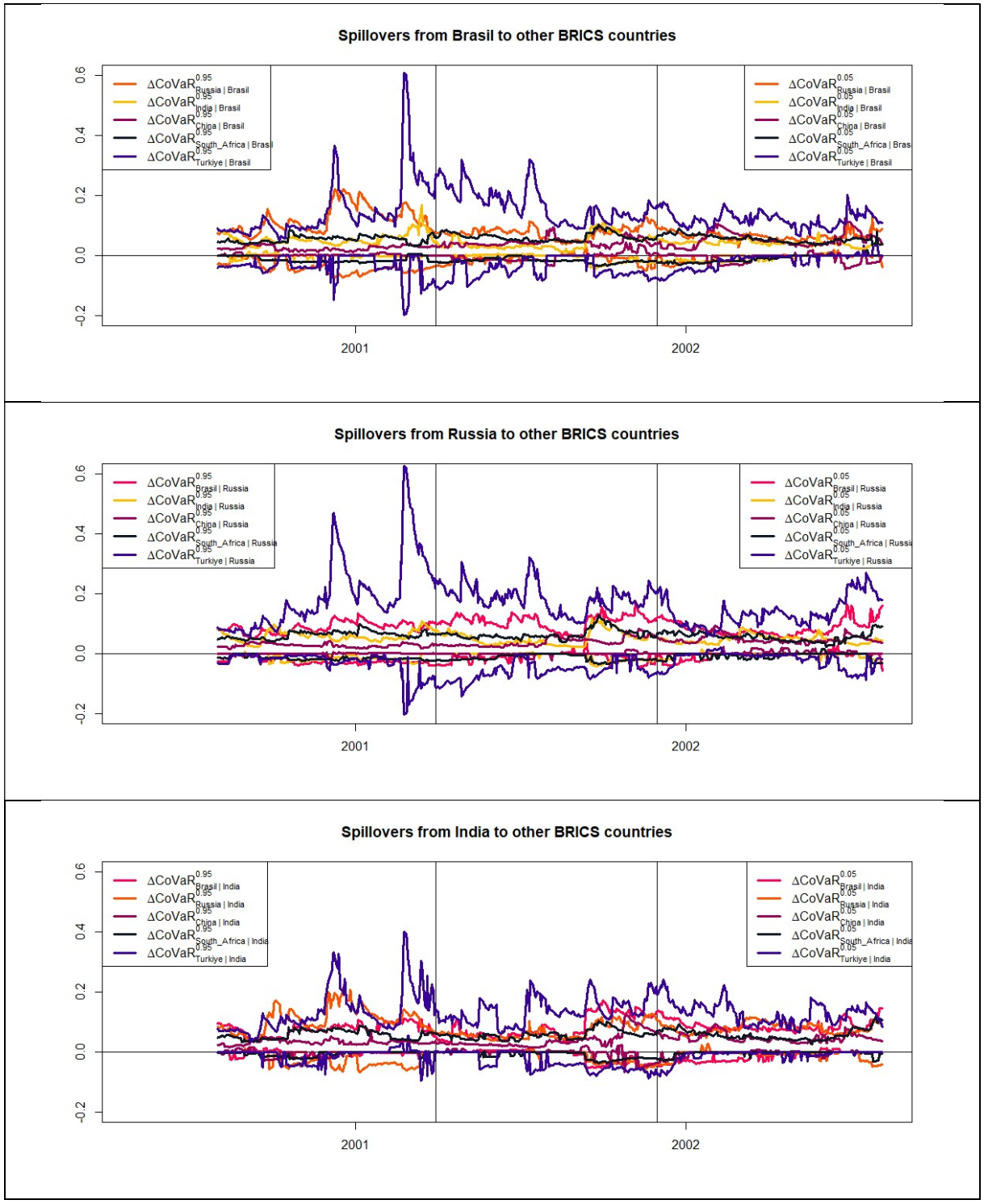


Figure 3.2 Graphical representations of the downside and upside ΔCoVaR estimates of BRICS countries (2001 crisis)

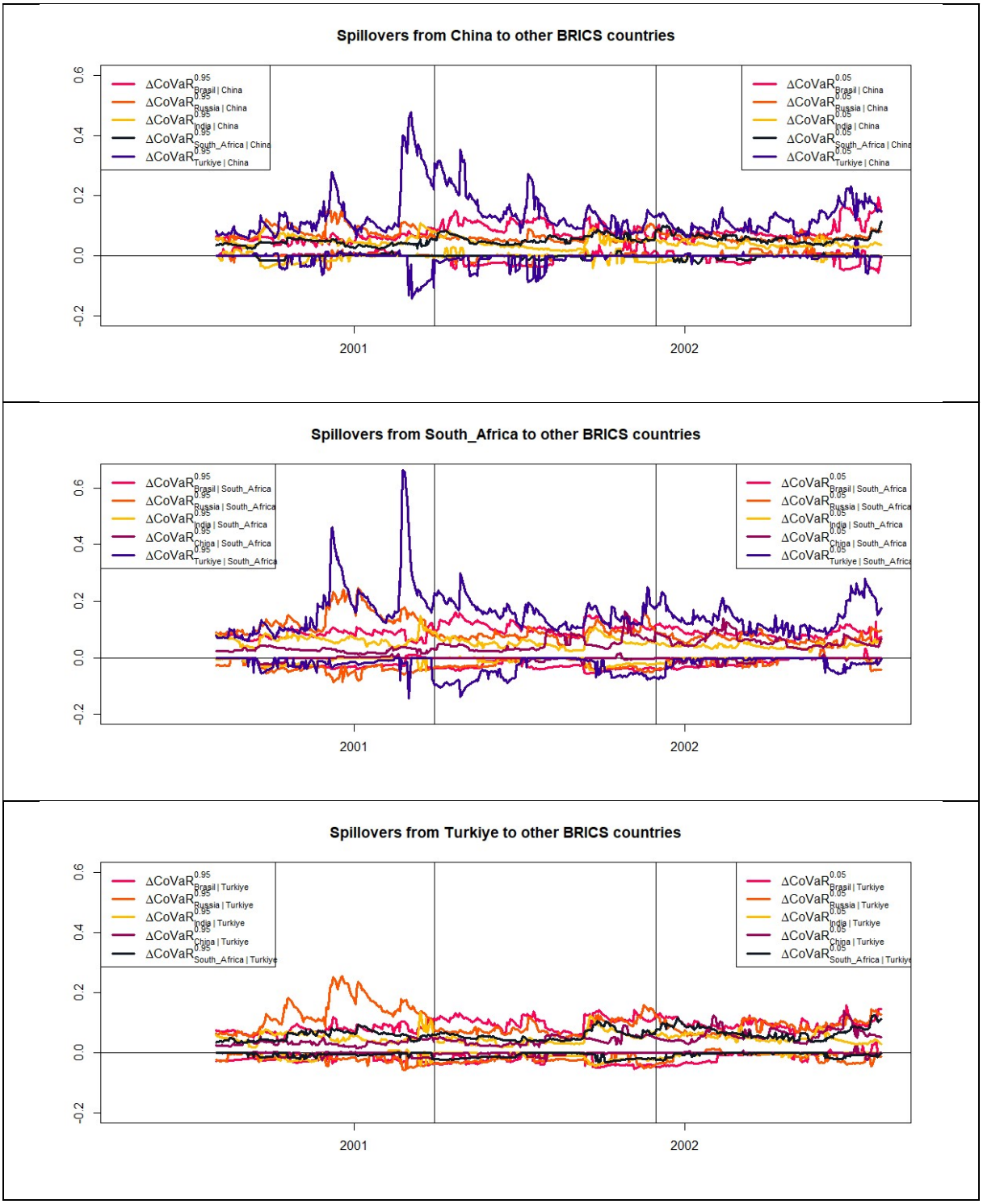


Figure 3.2 Graphical representations of the downside and upside ΔCoVaR estimates of BRICS countries (2001 crisis) (continued)

3.3.3 Results of 2008 Crisis

3.3.3.1 Time-Varying Copula Results of 2008 Crisis

According to the TVFC analysis conducted on the 2008 crisis, the number of copula families obtained before crisis (BC), during crisis (DC), and after crisis (AC) periods is presented in Table 3.11. One of the most striking results of 2008 crisis period compared to the 2001 crisis is the absence of independence copula families in both BC, DC, and AC periods for some pairs. For instance, no “independence copula” family was found for pairs such as Brazil-South Africa, Brazil-Türkiye, Russia-South Africa, and South Africa-Türkiye for the periods of the 2008 crisis. Similarly to the 2001 crisis, while the number of independence copula families in pairs excluding China was low, pairs involving China still exhibited a considerable number of independence copula families. For instance, for the Brazil-China pair, the number of independence copula families decreased from 139 in the BC period and 119 in the DC period to 75 in the AC period. Likewise, for the Russia-China pair, the number of Independence copula family decreased from 129 in the BC period and 134 in the DC period to 11 in the AC period. The number of independence copula families between India and China decreased from 127 in the BC period to 23 in the AC period. The number of independence copula families obtained between India and China decreased from 127 in the BC period to 11 in the DC period, and then increased to 23 in the AC period. For the China-South Africa pair, this value decreased from 130 in the BC period to 132 in the DC period and then dropped to 13 in the AC period. Finally, for the China-Türkiye pair, the values decreased from 157 in the BC period to 119 in the DC period and further declined to 26 in the AC period. The most common feature in all pairs involving China is the extreme decrease in the number of independence copula families in the AC period. Therefore, it is quite normal to expect an increase in the dependency structures of China's stock market with other BRICS-T country stock markets after the 2008 crisis.

In some periods, stock indices may exhibit negative relationships with each other. The greatest advantage of using the TVFC approach can be observed again in Table 3.11. If a time-varying single copula approach had been used, negative relationships would not have been detected. For example, when examining the values related to pairs such as Brazil-India, Brazil-China, Russia-China, India-China, China-South Africa, and China-Türkiye, which yield copula families rotated by 90 or 270 degrees, it is observed that these pairs' stock markets had negative dependency structures periodically.

Table 3.11 Selected copula families with their frequencies (2008 crisis)

		Br-Ru			Br-In			Br-Ch			Br-So			Br-Tu		
Name	**TD STR**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**
Independence	No		5		46	47		139	119	75						
Gaussian	No	92	38	4	27	17	43	1	3	11	43	109	51	3	6	38
Student t	Symm.		16	59	39	77	87	28	11	3	48	17	53	3	78	38
Clayton	Only Lw	55	9	33	6	2	17		1	79	53	20	22	12		
Gumbel	Only Up	10	30	36	41	4	71	3	4			9	16	2	67	27
Frank	No	30	6	17	35	11	6	4	5	6	89	73		69	9	
Joe	Only Up	6	14		17	21	27	12	69	9			9		13	1
BB1	Asym										6		2			
BB6	Only Up															
BB7	Asym	3	76	28	1	14	16			3	20	9	109	22	59	25
BB8	Only Up	5				1								20	7	
180 d.r. Clayton	Only Up	11	4		5	12		4	45	6				9	12	1
180 d.r. Gumbel	Only Lw	128	26	73	53	24	47	29		46	81	78	29	136	81	114
180 d.r. Joe	Only Lw	5	31	48	54	63	13	30	7	112	4		4	62		25
180 d.r. BB1	Asym										2	1				
180 d.r. BB6	Only Lw															
180 d.r. BB7	Asym	24	14	21		18	9		2	1		53	82		3	93
180 d.r. BB8	Only Lw			15		1				4	44	6		2	8	
90 d.r. Clayton	No															
90 d.r. Gumbel	No															
90 d.r. Joe	No															
90 d.r. BB1	No															
90 d.r. BB6	No															
90 d.r. BB7	No															
90 d.r. BB8	No															
270 d.r. Clayton	No															
270 d.r. Gumbel	No								1							
270 d.r. Joe	No					1			4							
270 d.r. BB1	No															
270 d.r. BB6	No															
270 d.r. BB7	No															
270 d.r. BB8	No															
Tawn type 1	Only Up		38	7	8	2	19	51	12					6	48	
180 d.r. Tawn type 1	Only Lw	7	56			5		2	14	15	3	19	4			12
90 d.r. Tawn type 1	No				1											
270 d.r. Tawn type 1	No							11	4							
Tawn type 2	Only Up		18	9		74	1	40	60	1			13			10
180 d.r. Tawn type 2	Only Lw	18	13	44	61		38	39	33	23	1			48	3	10
90 d.r. Tawn type 2	No															
270 d.r. Tawn type 2	No							1								

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye; BC: Before 2008 crisis; DC: During 2008 crisis; AC: After 2008 crisis; TD STR: Tail Dependency Structure; BB1: Clayton-Gumbel; BB6: Joe-Gumbel; BB7: Joe-Clayton; BB8: Joe-Frank; d.r.: degrees rotated; Symm.: Symmmetric; Only Lw: Only Lower; Only Up: Only Upper; Asym: Asymmetric

Table 3.11 Selected copula families with their frequencies (2008 crisis) (continued)

		Ru-In			Ru-Ch			Ru-So			Ru-Tu			In-Ch		
Name	**TD STR**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**
Independence	No	7	9		129	134	11					5		127	11	23
Gaussian	No	29	26	44	4	7	60	51	73	66	74	55	58	2	94	34
Student t	Symm.	37	56	3	34	6	5	2	28	15	2	31	45	20	21	3
Clayton	Only Lw	36	67	10		32	63	42	32	33	23	3	36	6	49	59
Gumbel	Only Up	30	25	1	10	7	1	12	78		15		7	1	50	10
Frank	No	11	58	11	23	2		44	7	61	28	14	11	28	32	6
Joe	Only Up				18	11	27								8	16
BB1	Asym	3		4					3			15	16			
BB6	Only Up															
BB7	Asym	47	2	18	1	5		10	76	34	40	68	16		7	6
BB8	Only Up	6			3	5		14			10		1			
180 d.r. Clayton	Only Up	1						13			1				17	11
180 d.r. Gumbel	Only Lw	34	64	83		67	26	148	31	105	110	96	71	38	42	14
180 d.r. Joe	Only Lw	60	77	36	73	6	84		9	28	4	17	42	31		73
180 d.r. BB1	Asym								2		1		2			
180 d.r. BB6	Only Lw															
180 d.r. BB7	Asym	5		23		9		11	40	25	38	17	47		3	1
180 d.r. BB8	Only Lw	5		19				6		27	23	3	31			4
90 d.r. Clayton	No															
90 d.r. Gumbel	No					1										
90 d.r. Joe	No													13		
90 d.r. BB1	No															
90 d.r. BB6	No															
90 d.r. BB7	No															
90 d.r. BB8	No															
270 d.r. Clayton	No													2		
270 d.r. Gumbel	No													19		
270 d.r. Joe	No															
270 d.r. BB1	No															
270 d.r. BB6	No															
270 d.r. BB7	No															
270 d.r. BB8	No															
Tawn type 1	Only Up	3	7		3	2		1	3			1		7	21	23
180 d.r. Tawn type 1	Only Lw	58	1		18	27	57	8			6	9	2	57	3	90
90 d.r. Tawn type 1	No				4	3								1		
270 d.r. Tawn type 1	No				22											
Tawn type 2	Only Up	11		41	3	1	35	32	12		19				22	3
180 d.r. Tawn type 2	Only Lw	11	2	101	45	69	21					60	9	37	14	17
90 d.r. Tawn type 2	No				4									5		1
270 d.r. Tawn type 2	No						4									

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye; BC: Before 2008 crisis; DC: During 2008 crisis; AC: After 2008 crisis; TD STR: Tail Dependency Structure; BB1: Clayton-Gumbel; BB6: Joe-Gumbel; BB7: Joe-Clayton; BB8: Joe-Frank; d.r.: degrees rotated; Symm.: Symmmetric; Only Lw: Only Lower; Only Up: Only Upper; Asym: Asymmetric

Table 3.11 Selected copula families with their frequencies (2008 crisis) (continued)

		In-So			In-Tu			Ch-So			Ch-Tu			So-Tu		
Name	**TD STR**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**
Independence	No	8	26		13			130	132	13	157	119	26			
Gaussian	No	45	53	38	136	66	85	8	25	84	3		37	29	110	68
Student t	Symm.	9	45	19	76	37	5	21	4	8	4	94	12	6	4	20
Clayton	Only Lw	37	23	1	6	45	26	22		18	14	13	75	26	47	2
Gumbel	Only Up	50	31	122	24	28	96	2	17	4	10	6	2	1	30	36
Frank	No	9	69	43	9	52	24	1	25	6	17	7	17	116	62	13
Joe	Only Up		12		9			2	24	3	6	14	7			
BB1	Asym			1												2
BB6	Only Up															
BB7	Asym	36	28	30	9	11	16		1			10			12	77
BB8	Only Up		4							3		10				11
180 d.r. Clayton	Only Up		9	5	17	2	29		43	9		7	40		22	19
180 d.r. Gumbel	Only Lw	55	30	79	12	68	57		5	16	10	19	23	155	21	71
180 d.r. Joe	Only Lw	57	23	5	35	19	5	70	41	150	60	18	21	5		5
180 d.r. BB1	Asym	2		3												
180 d.r. BB6	Only Lw															
180 d.r. BB7	Asym	32	10	17		14	2		2	2			1		33	41
180 d.r. BB8	Only Lw		11			11	13						9	54	1	
90 d.r. Clayton	No															
90 d.r. Gumbel	No							1								
90 d.r. Joe	No							4								
90 d.r. BB1	No															
90 d.r. BB6	No															
90 d.r. BB7	No															
90 d.r. BB8	No															
270 d.r. Clayton	No															
270 d.r. Gumbel	No															
270 d.r. Joe	No										2	11				
270 d.r. BB1	No															
270 d.r. BB6	No															
270 d.r. BB7	No															
270 d.r. BB8	No															
Tawn type 1	Only Up		1		2		2			10	20		7		30	
180 d.r. Tawn type 1	Only Lw	4	2	26		1	4	36	23	8	20	32	19		7	8
90 d.r. Tawn type 1	No								4		1					
270 d.r. Tawn type 1	No										13					
Tawn type 2	Only Up	42	12	5	18	10	7	72	42		18	32	26		2	2
180 d.r. Tawn type 2	Only Lw	8	5		28	30	23	13	4	60	23	2	71	2	13	19
90 d.r. Tawn type 2	No							10	2		16					
270 d.r. Tawn type 2	No							2					1			

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye; BC: Before 2008 crisis; DC: During 2008 crisis; AC: After 2008 crisis; TD STR: Tail Dependency Structure; BB1: Clayton-Gumbel; BB6: Joe-Gumbel; BB7: Joe-Clayton; BB8: Joe-Frank; d.r.: degrees rotated; Symm.: Symmmetric; Only Lw: Only Lower; Only Up: Only Upper; Asym: Asymmetric

The values showing the percentages of copula families obtained for the tail dependence types in the periods related to the 2008 crisis are provided in Table 3.12. As previously mentioned while interpreting the 2001 crisis table, it can be said that Table 3.12 is essentially a summary of Table 3.11. In Table 3.12, the values for the same tail dependence structures as in Table 3.11 are aggregated and presented as percentages. The comments made regarding China based on the Independence copula numbers in Table 3.11 can be further examined in detail through

Table 3.12. The "no tail dependency" percentages for all pairs involving China experienced a significant decrease in the AC period compared to other periods.

Additionally, the "no tail dependency" percentages, ranging from 55% to 90% in the 2001 crisis for pairs involving China, vary from 16% to 55% in the 2008 crisis. This indicates a clear increase in China's dependence on other BRICS-T country markets over the past approximately 4-5 years. Generally, decreases in "no tail dependency" percentages were observed in the AC period compared to the BC period. The pairs where no decrease was observed are Russia-India, Russia-South Africa, and India-South Africa. When examining the "no tail dependency" percentages for pairs formed by Türkiye and Brazil with other BRICS-T countries, similar to the example of China, significant decreases were observed in the AC period compared to the BC period. When examining the "only lower tail dependency" percentages, notable results include the increase between Brazil and China and the decrease between South Africa and Türkiye. When examining the "only upper tail dependency" percentages, there are generally increases in the DC period compared to the BC period. However, these increases were not a common result for all pairs.

Table 3.12 The percentages of the tail dependence types for each pair (2008 crisis)

	Br-Ru			**Br-In**			**Br-Ch**			**Br-So**			**Br-Tu**		
	BC	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**
No	31%	12%	5%	28%	19%	12%	40%	35%	23%	34%	46%	13%	18%	4%	10%
Symm.		4%	15%	10%	20%	22%	7%	3%	1%	12%	4%	13%	1%	20%	10%
Only Lw	54%	34%	54%	44%	24%	29%	25%	14%	71%	47%	31%	15%	66%	23%	41%
Only Up	8%	26%	13%	18%	29%	30%	28%	48%	4%		2%	10%	9%	37%	10%
Asym	7%	23%	12%		8%	6%		1%	1%	7%	16%	49%	6%	16%	30%
	Ru-In			**Ru-Ch**			**Ru-So**			**Ru-Tu**			**In-Ch**		
	BC	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**
No	12%	24%	14%	47%	37%	19%	24%	20%	32%	26%	19%	18%	50%	35%	16%
Symm.	9%	14%	1%	9%	2%	1%	1%	7%	4%	1%	8%	11%	5%	5%	1%
Only Lw	52%	54%	63%	35%	51%	64%	52%	18%	49%	42%	48%	48%	43%	27%	65%
Only Up	13%	8%	11%	9%	7%	16%	18%	24%		11%		2%	2%	30%	16%
Asym	14%	1%	11%		4%		5%	31%	15%	20%	25%	21%		3%	2%
	In-So			**In-Tu**			**Ch-So**			**Ch-Tu**			**So-Tu**		
	BC	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**
No	16%	38%	21%	40%	30%	28%	40%	48%	26%	53%	35%	21%	37%	44%	21%
Symm.	2%	11%	5%	19%	9%	1%	5%	1%	2%	1%	24%	3%	2%	1%	5%
Only Lw	41%	24%	28%	21%	44%	32%	36%	19%	64%	32%	21%	55%	61%	23%	27%
Only Up	23%	18%	34%	18%	10%	34%	19%	32%	7%	14%	18%	21%		21%	17%
Asym	18%	10%	13%	2%	6%	5%		1%	1%		3%			11%	30%

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye; BC: Before 2008 crisis;
DC: During 2008 crisis; AC: After 2008 crisis; Symm.: Symmmetric; Only Lw: Only Lower;
Only Up: Only Upper; Asym: Asymmetric

The lower tail dependence values, upper tail dependence values, and Kendall's Tau values for country stock markets during the 2008 crisis periods are presented in Table 3.13. Accordingly, similar to the 2001 crisis, it has been determined that China had the lowest dependence coefficients for country stock markets during the 2008 crisis periods. However, the dependence coefficients showed a significant increase compared to the 2001 crisis periods. When examining the lower tail dependence coefficients, Türkiye's lower tail dependence coefficients with Brazil, Russia, and South Africa are quite high. The lower tail dependence coefficient for the Brazil-Türkiye pair decreased from 0.32 in the BC period to 0.23 in the DC period but increased to 0.37 in the AC period. These values were calculated as 0.16, 0.20, and 0.09, respectively, during the 2001 crisis. Additionally, it was found that the lower tail dependence coefficient for the Russia-Türkiye pair was 0.33 in the BC period, 0.36 in the DC period, and 0.38 in the AC period. These values were determined as 0.07, 0.20, and 0.09 during the 2001 crisis, respectively. When examining the lower tail dependence values of the South Africa-Türkiye pair, it was observed that this coefficient decreased from 0.30 in the BC period to 0.17 in the DC period and increased to 0.33 in the AC period. The lower tail dependence coefficient values for this pair during the 2001 crisis were found to be 0.04, 0.23, and 0.03, respectively. The most striking feature regarding the lower tail dependence values between the 2001 and 2008 crises is the changes in the DC periods. While there was generally an increase in lower tail dependence coefficients for pairs during the 2001 crisis, this increase gave way to decreases after the 2001 crisis. However, during the 2008 crisis, it has been generally observed that the lower tail dependence values calculated for pairs, except for a few pairs, decreased compared to the BC period. Another result for all pairs is that the lower tail dependence coefficients calculated after the 2008 crisis are higher compared to the BC and AC periods. These findings have indicated that the dependence among BRICS-T countries during negative financial shocks was higher in the period after the 2008 crisis compared to the period before the 2008 crisis and during the 2008 crisis itself.

When examining the upper tail dependence coefficients for the 2008 crisis periods, it can be said that there were no high values, similar to the lower tail dependence values. Especially, the upper tail dependence coefficients for pairs involving China are considerably lower compared to other pairs. The pair with the highest upper tail dependence after the 2008 crisis is the Brazil-South Africa pair. The upper tail dependence for this pair was found to be 0.36 in the AC period, 0.08 in the BC period, and 0.11 in the DC period. Therefore, it has been determined that the dependence on positive financial shocks for this pair increased

significantly after the crisis. When examining the second-highest upper tail dependence coefficient, it is observed that South Africa is again involved. The upper tail dependence coefficient for the South Africa-Türkiye pair in the AC period was found to be 0.29. While this pair had a coefficient of 0.01 before the crisis, it was 0.16 during the crisis. Therefore, it has been concluded that the dependence on positive shocks for the South Africa-Türkiye pair increased significantly in the AC period compared to the BC and DC periods.

When examining Kendall's Tau values indicating the overall dependence degree, different results were obtained compared to the 2001 crisis. It was found that the negative dependencies present among some pairs during the 2001 crisis were not present in the BC, DC, and AC periods of the 2008 crisis. It can be seen from Table 3.13 that South Africa's dependence coefficients with other pairs are higher compared to other pairs. It was determined that South Africa's dependence coefficients with Brazil, Russia, and Türkiye were all above 0.40 in all three periods. Similar to the 2001 crisis, it was also found during the 2008 crisis that China's dependence coefficients with other BRICS-T countries remained at the lowest level compared to other pairs.

Table 3.13 Lower tail dependence, upper tail dependence, and Kendall's Tau values (2008 Crisis)

	Brazil			**Russia**			**India**			**China**			**South Africa**			**Türkiye**		
	BC	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**
	Lower tail dependence values																	
Brazil	1	1	1															
Russia	.22	.19	.30	1	1	1												
India	.12	.18	.17	.28	.29	.33	1	1	1									
China	.05	.02	.19	.11	.12	.19	.09	.10	.19	1	1	1						
South A.	.27	.26	.41	.32	.26	.34	.20	.14	.19	.09	.05	.19	1	1	1			
Türkiye	.32	.23	.37	.33	.36	.38	.14	.23	.13	.07	.12	.13	.30	.17	.33	1	1	1
	Upper tail dependence values																	
Brazil	1	1	1	.04	.17	.11	.08	.16	.18	.05	.13	.01	.08	.11	.36	.05	.31	.20
Russia				1	1	1	.12	.07	.08	.03	.03	.05	.07	.31	.08	.15	.16	.15
India							1	1	1	.01	.08	.04	.14	.10	.23	.13	.09	.16
China										1	1	1	.03	.06	.01	.01	.10	.04
South A.													1	1	1	.01	.16	.29
Türkiye																1	1	1
	Kendall's Tau values																	
Brazil	1	1	1	.26	.26	.27	.15	.19	.24	.06	.10	.14	.43	.44	.47	.34	.37	.38
Russia				1	1	1	.28	.29	.38	.08	.12	.20	.41	.41	.48	.44	.39	.43
India							1	1	1	.06	.22	.18	.25	.26	.40	.27	.33	.33
China										1	1	1	.07	.10	.21	.05	.10	.16
South A.													1	1	1	.47	.43	.49
Türkiye																1	1	1

South A.: South Africa; BC: Before 2008 Crisis; DC: During 2008 Crisis; AC: After 2008 Crisis

3.3.3.2 Risk Spillover Results of 2008 Crisis

- **Kolmogorov–Smirnov Bootstrapping Test Results (2008 Crisis)**

Average VaR and CoVaR values for the 2008 crisis are provided in Table 3.14. Additionally, the results of Kolmogorov-Smirnov tests conducted to investigate the presence of risk spillover are also presented in Table 3.14. According to the Kolmogorov-Smirnov test results, the null hypotheses for both downside risk spillovers and upside risk spillovers were rejected for all three periods. This indicates that statistically significant upside and downside risk spillovers were present for all BRICS-T countries during the 2008 crisis periods.

Table 3.14 Averages of VaR and CoVaR values of the indices and KS bootstrap test results (2008 crisis)

Spillover		Downside Spillovers								
from	to	BC			DC			AC		
		VaR	CoVaR	p-value	VaR	CoVaR	p-value	VaR	CoVaR	p-value
Br	Ru	-0.023	-0.046	*	-0.051	-0.098	*	-0.029	-0.063	*
Br	In	-0.025	-0.041	*	-0.044	-0.076	*	-0.024	-0.044	*
Br	Ch	-0.028	-0.041	*	-0.037	-0.048	*	-0.024	-0.048	*
Br	So	-0.028	-0.052	*	-0.049	-0.094	*	-0.027	-0.055	*
Br	Tu	-0.036	-0.078	*	-0.049	-0.100	*	-0.031	-0.071	*
Ru	Br	-0.035	-0.063	*	-0.057	-0.102	*	-0.033	-0.065	*
Ru	In	-0.025	-0.050	*	-0.044	-0.089	*	-0.024	-0.051	*
Ru	Ch	-0.028	-0.047	*	-0.037	-0.065	*	-0.024	-0.049	*
Ru	So	-0.028	-0.052	*	-0.049	-0.093	*	-0.027	-0.053	*
Ru	Tu	-0.036	-0.079	*	-0.049	-0.111	*	-0.031	-0.071	*
In	Br	-0.035	-0.055	*	-0.057	-0.095	*	-0.033	-0.059	*
In	Ru	-0.023	-0.048	*	-0.051	-0.105	*	-0.029	-0.065	*
In	Ch	-0.028	-0.044	*	-0.037	-0.068	*	-0.024	-0.050	*
In	So	-0.028	-0.049	*	-0.049	-0.083	*	-0.027	-0.049	*
In	Tu	-0.036	-0.070	*	-0.049	-0.103	*	-0.031	-0.060	*
Ch	Br	-0.035	-0.046	*	-0.057	-0.070	*	-0.033	-0.055	*
Ch	Ru	-0.023	-0.034	*	-0.051	-0.087	*	-0.029	-0.053	*
Ch	In	-0.025	-0.036	*	-0.044	-0.073	*	-0.024	-0.042	*
Ch	So	-0.028	-0.037	*	-0.049	-0.061	*	-0.027	-0.048	*
Ch	Tu	-0.036	-0.048	*	-0.049	-0.078	*	-0.031	-0.055	*
So	Br	-0.035	-0.067	*	-0.057	-0.114	*	-0.033	-0.069	*
So	Ru	-0.023	-0.049	*	-0.051	-0.108	*	-0.029	-0.065	*
So	In	-0.025	-0.047	*	-0.044	-0.081	*	-0.024	-0.046	*
So	Ch	-0.028	-0.043	*	-0.037	-0.049	*	-0.024	-0.054	*
So	Tu	-0.036	-0.077	*	-0.049	-0.102	*	-0.031	-0.070	*
Tu	Br	-0.035	-0.068	*	-0.057	-0.107	*	-0.033	-0.068	*
Tu	Ru	-0.023	-0.051	*	-0.051	-0.114	*	-0.029	-0.067	*
Tu	In	-0.025	-0.047	*	-0.044	-0.088	*	-0.024	-0.044	*
Tu	Ch	-0.028	-0.042	*	-0.037	-0.061	*	-0.024	-0.047	*
Tu	So	-0.028	-0.052	*	-0.049	-0.090	*	-0.027	-0.053	*

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye; BC: Before 2008 Crisis;
DC: During 2008 Crisis; AC: After 2008 Crisis; CoVaR: Conditional Value-at-Risk; VaR: Value-at-Risk;
*: $p<0.05$

Table 3.14 Averages of VaR and CoVaR values of the indices and KS bootstrap test results (2008 crisis) (continued)

Spillover		Upside Spillovers								
from	to	BC			DC			AC		
		VaR	CoVaR	p-value	VaR	CoVaR	p-value	VaR	CoVaR	p-value
Br	Ru	0.023	0.035	*	0.049	0.085	*	0.029	0.046	*
Br	In	0.024	0.034	*	0.042	0.070	*	0.023	0.041	*
Br	Ch	0.028	0.036	*	0.036	0.063	*	0.024	0.028	*
Br	So	0.027	0.042	*	0.047	0.079	*	0.026	0.048	*
Br	Tu	0.036	0.057	*	0.048	0.100	*	0.031	0.060	*
Ru	Br	0.034	0.049	*	0.055	0.090	*	0.032	0.049	*
Ru	In	0.024	0.039	*	0.042	0.062	*	0.023	0.039	*
Ru	Ch	0.028	0.035	*	0.036	0.046	*	0.024	0.038	*
Ru	So	0.027	0.044	*	0.047	0.084	*	0.026	0.042	*
Ru	Tu	0.036	0.069	*	0.048	0.090	*	0.031	0.056	*
In	Br	0.034	0.047	*	0.055	0.089	*	0.032	0.054	*
In	Ru	0.023	0.038	*	0.049	0.072	*	0.029	0.052	*
In	Ch	0.028	0.031	*	0.036	0.065	*	0.024	0.034	*
In	So	0.027	0.042	*	0.047	0.071	*	0.026	0.046	*
In	Tu	0.036	0.064	*	0.048	0.084	*	0.031	0.057	*
Ch	Br	0.034	0.041	*	0.055	0.087	*	0.032	0.038	*
Ch	Ru	0.023	0.027	*	0.049	0.063	*	0.029	0.044	*
Ch	In	0.024	0.027	*	0.042	0.066	*	0.023	0.032	*
Ch	So	0.027	0.034	*	0.047	0.065	*	0.026	0.034	*
Ch	Tu	0.036	0.040	*	0.048	0.073	*	0.031	0.044	*
So	Br	0.034	0.055	*	0.055	0.098	*	0.032	0.063	*
So	Ru	0.023	0.043	*	0.049	0.101	*	0.029	0.052	*
So	In	0.024	0.042	*	0.042	0.066	*	0.023	0.044	*
So	Ch	0.028	0.039	*	0.036	0.054	*	0.024	0.035	*
So	Tu	0.036	0.063	*	0.048	0.094	*	0.031	0.064	*
Tu	Br	0.034	0.051	*	0.055	0.103	*	0.032	0.057	*
Tu	Ru	0.023	0.044	*	0.049	0.090	*	0.029	0.053	*
Tu	In	0.024	0.041	*	0.042	0.069	*	0.023	0.041	*
Tu	Ch	0.028	0.032	*	0.036	0.057	*	0.024	0.036	*
Tu	So	0.027	0.042	*	0.047	0.079	*	0.026	0.047	*

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye; BC: Before 2008 Crisis; DC: During 2008 Crisis; AC: After 2008 Crisis; CoVaR: Conditional Value-at-Risk; VaR: Value-at-Risk;
*: $p<0.05$

- **CoVaR Results (2008 Crisis)**

The average VaR and CoVaR values calculated from Table 3.14 are displayed in Figure 3.3. When examining downside spillover values, it was found that during the BC period, the CoVaR values from other BRICS-T countries to Türkiye were the lowest. In the DC and AC periods, the downside risk spillover values from other BRICS-T countries to Türkiye and Russia were the lowest. Generally, China was the least affected by other BRICS-T countries during the BC and DC periods, while India was the least affected during the AC period.

Regarding upside risk spillover values, Türkiye was the most affected by other BRICS-T countries during the BC period. In the AC and DC periods, both Türkiye and Brazil were the most affected. China was found to be the least affected by other BRICS-T countries during these periods.

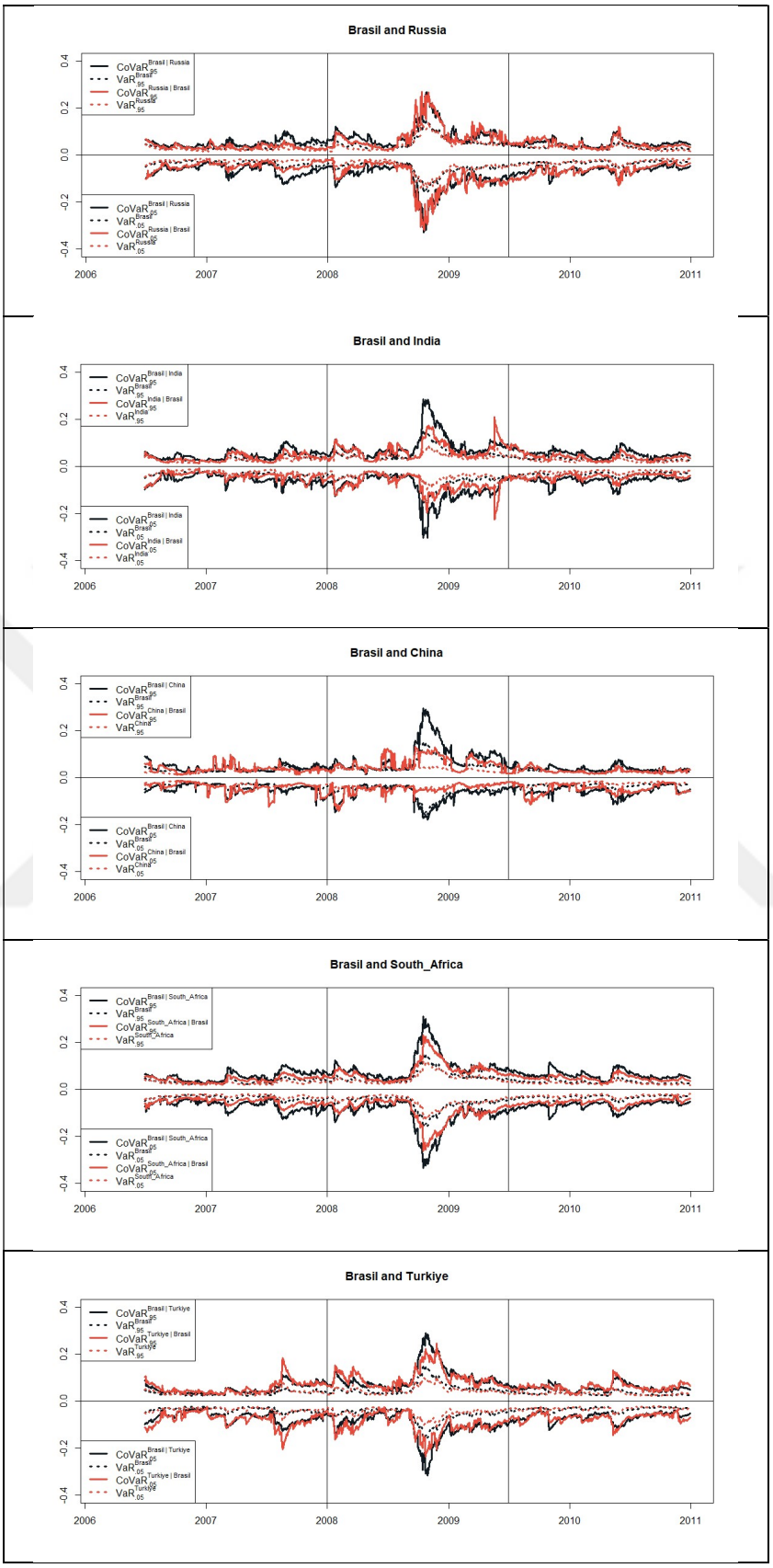


Figure 3.3 Graphic representation of downside and upside VaR and CoVaR estimates of BRICS-T countries (2008 Crisis)

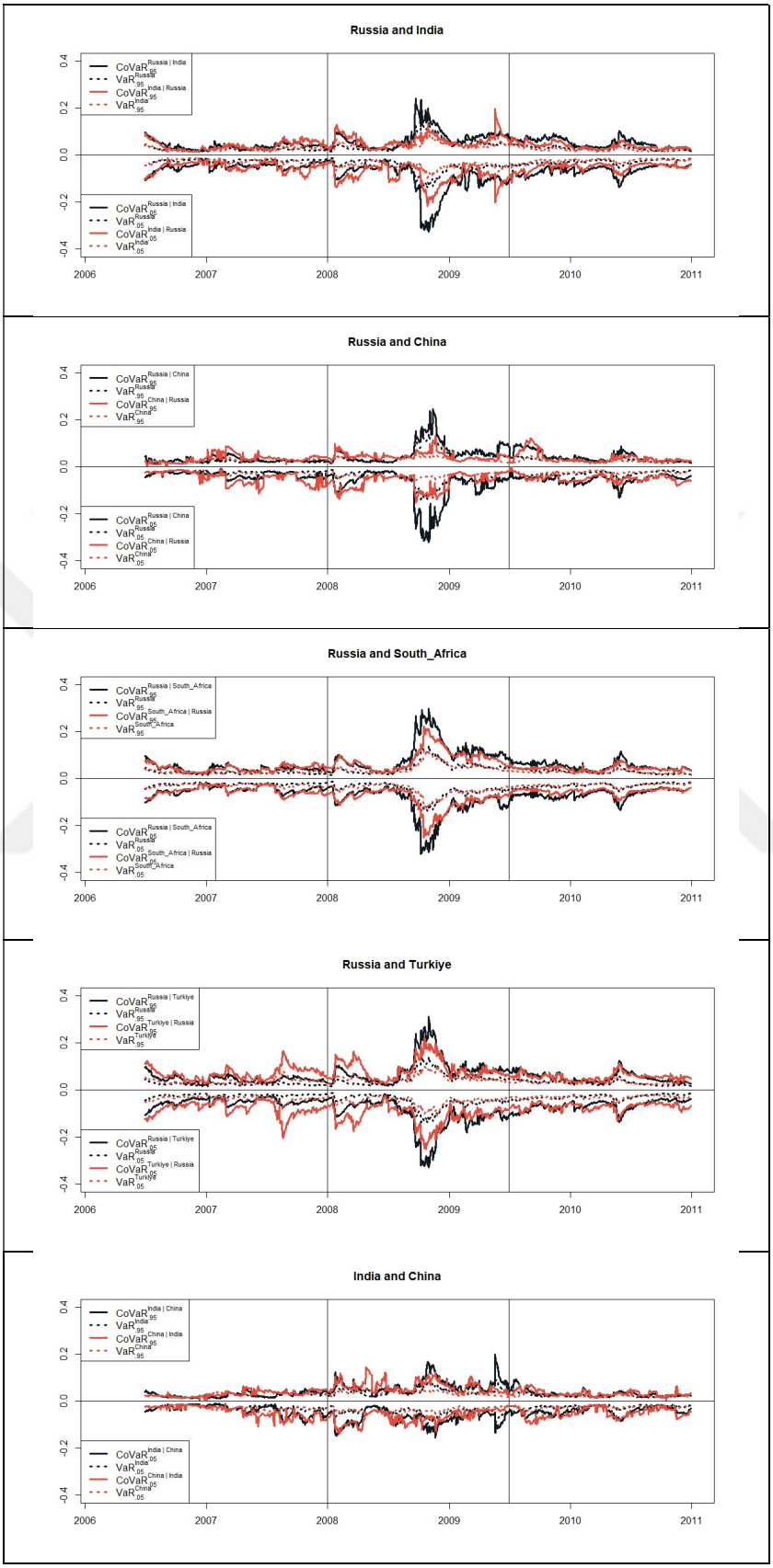


Figure 3.3 Graphic representation of downside and upside VaR and CoVaR estimates of BRICS-T countries (2008 Crisis) (continued)

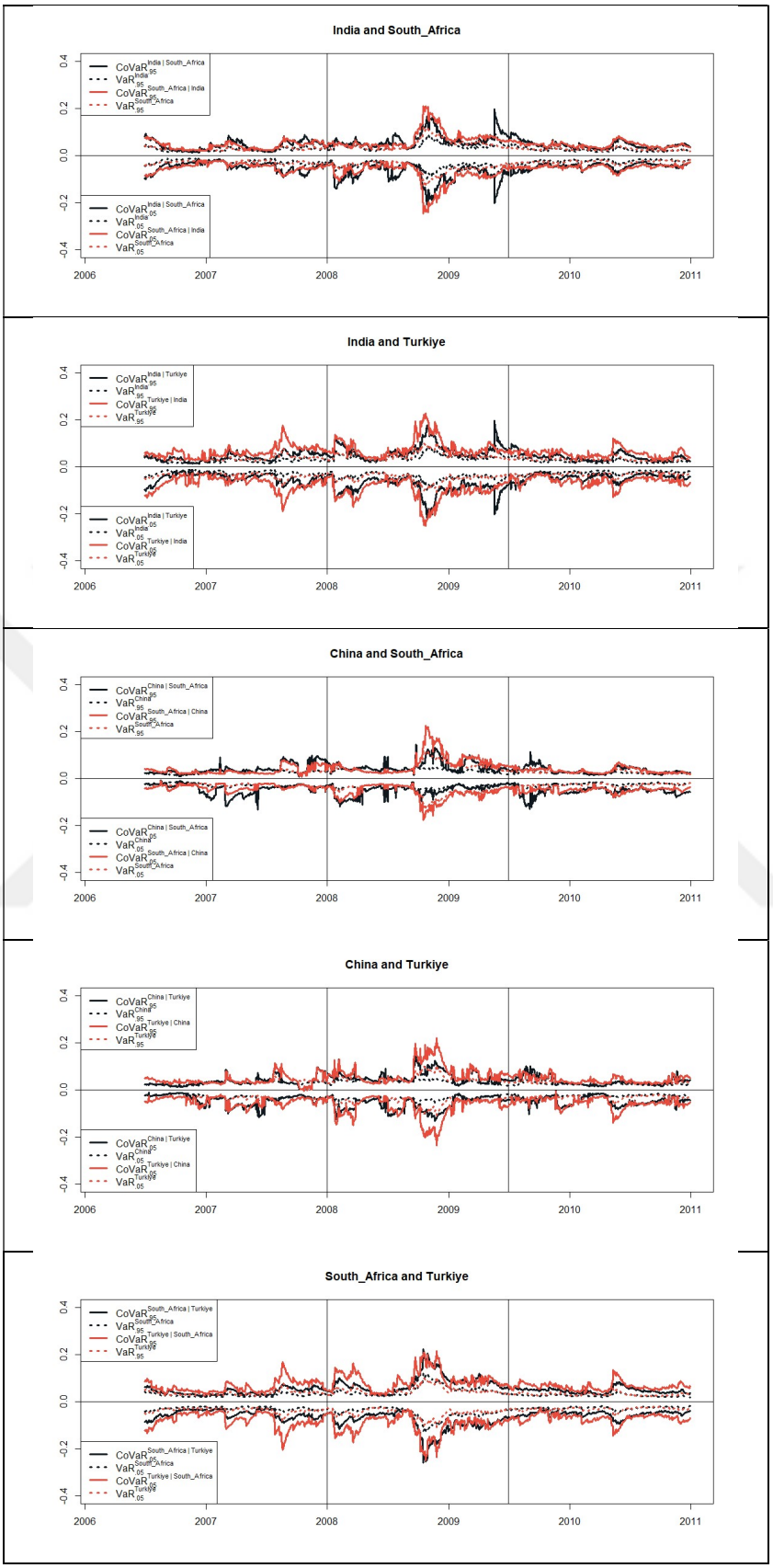


Figure 3.3 Graphic representation of downside and upside VaR and CoVaR estimates of BRICS-T countries (2008 Crisis) (continued)

- **ΔCoVaR Results (2008 Crisis)**

Table 3.15 presents the average downside and upside ΔCoVaR values for BRICS-T countries during the 2008 crisis. Graphical representations of these values are shown in Figure 3.4.

According to the results, the downside risk contribution values from Brazil to China and from South Africa to China are higher in the DC period compared to the BC period. Additionally, the downside risk contribution values from Brazil to Türkiye, Russia to Türkiye, India to Türkiye, South Africa to Türkiye, and Türkiye to India are higher in the AC period compared to the BC period.

When examining upside risk contributions, it was found that the ΔCoVaR values for all pairs are higher in the DC period compared to the BC period. Conversely, the ΔCoVaR values for all pairs in the AC period are lower compared to the DC period. Therefore, considering the upside risk contributions, it was concluded that the risk contributions among BRICS-T countries were more variable during the 2008 crisis periods compared to the 2001 crisis. Additionally, similar to the 2001 crisis, Türkiye was the most affected by other BRICS-T countries during the 2008 crisis, while China was the least affected.

Table 3.15 Averages of ΔCoVaR values (2008 Crisis)

Spillovers		ΔCoVaR downside			ΔCoVaR upside		
from	**to**	**BC**	**DC**	**AC**	**BC**	**DC**	**AC**
Russia	Brazil	-0.021	-0.034	-0.025	0.091	0.157	0.089
Brazil	Russia	-0.018	-0.037	-0.027	0.063	0.145	0.082
India	Brazil	-0.015	-0.030	-0.020	0.087	0.154	0.093
Brazil	India	-0.012	-0.026	-0.015	0.063	0.121	0.069
China	Brazil	-0.008	-0.008	-0.018	0.079	0.148	0.075
Brazil	China	-0.011	-0.009	-0.020	0.067	0.102	0.057
South Africa	Brazil	-0.024	-0.043	-0.028	0.099	0.169	0.104
Brazil	South Africa	-0.018	-0.034	-0.021	0.076	0.140	0.082
Türkiye	Brazil	-0.025	-0.038	-0.027	0.094	0.172	0.098
Brazil	Türkiye	-0.033	-0.040	-0.032	0.102	0.159	0.099
India	Russia	-0.020	-0.043	-0.028	0.066	0.135	0.088
Russia	India	-0.020	-0.036	-0.021	0.069	0.115	0.068
China	Russia	-0.009	-0.029	-0.019	0.052	0.121	0.077
Russia	China	-0.016	-0.023	-0.020	0.066	0.087	0.066
South Africa	Russia	-0.020	-0.045	-0.028	0.072	0.165	0.089
Russia	South Africa	-0.018	-0.033	-0.019	0.078	0.144	0.076
Türkiye	Russia	-0.021	-0.050	-0.030	0.074	0.154	0.090
Russia	Türkiye	-0.034	-0.049	-0.032	0.114	0.152	0.095
China	India	-0.009	-0.022	-0.015	0.054	0.118	0.059
India	China	-0.014	-0.024	-0.021	0.062	0.108	0.062
South Africa	India	-0.017	-0.028	-0.017	0.072	0.119	0.073
India	South Africa	-0.016	-0.025	-0.016	0.075	0.129	0.078
Türkiye	India	-0.017	-0.034	-0.015	0.071	0.123	0.070
India	Türkiye	-0.027	-0.042	-0.022	0.107	0.144	0.095
South Africa	China	-0.013	-0.010	-0.024	0.069	0.093	0.064
China	South Africa	-0.007	-0.009	-0.016	0.063	0.118	0.066
Türkiye	China	-0.012	-0.021	-0.018	0.062	0.096	0.064
China	Türkiye	-0.010	-0.025	-0.019	0.077	0.126	0.079
Türkiye	South Africa	-0.018	-0.030	-0.019	0.076	0.140	0.080
South Africa	Türkiye	-0.032	-0.041	-0.031	0.108	0.155	0.104

BC: Before 2008 Crisis; DC: During 2008 Crisis; AC: After 2008 Crisis; CoVaR: Conditional Value-at-Risk

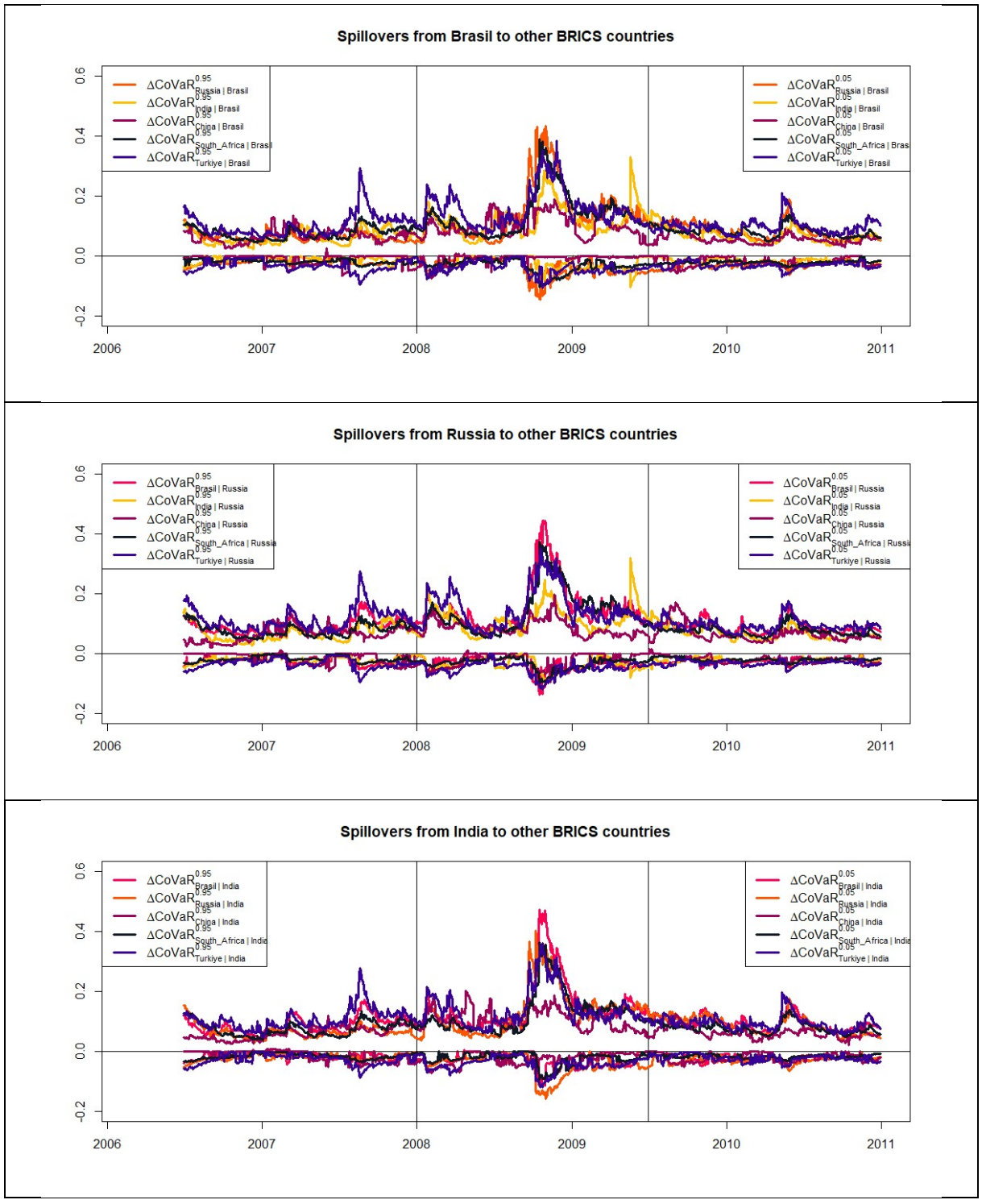


Figure 3.4 Graphical representations of the downside and upside ΔCoVaR estimates of BRICS countries (2008 crisis)

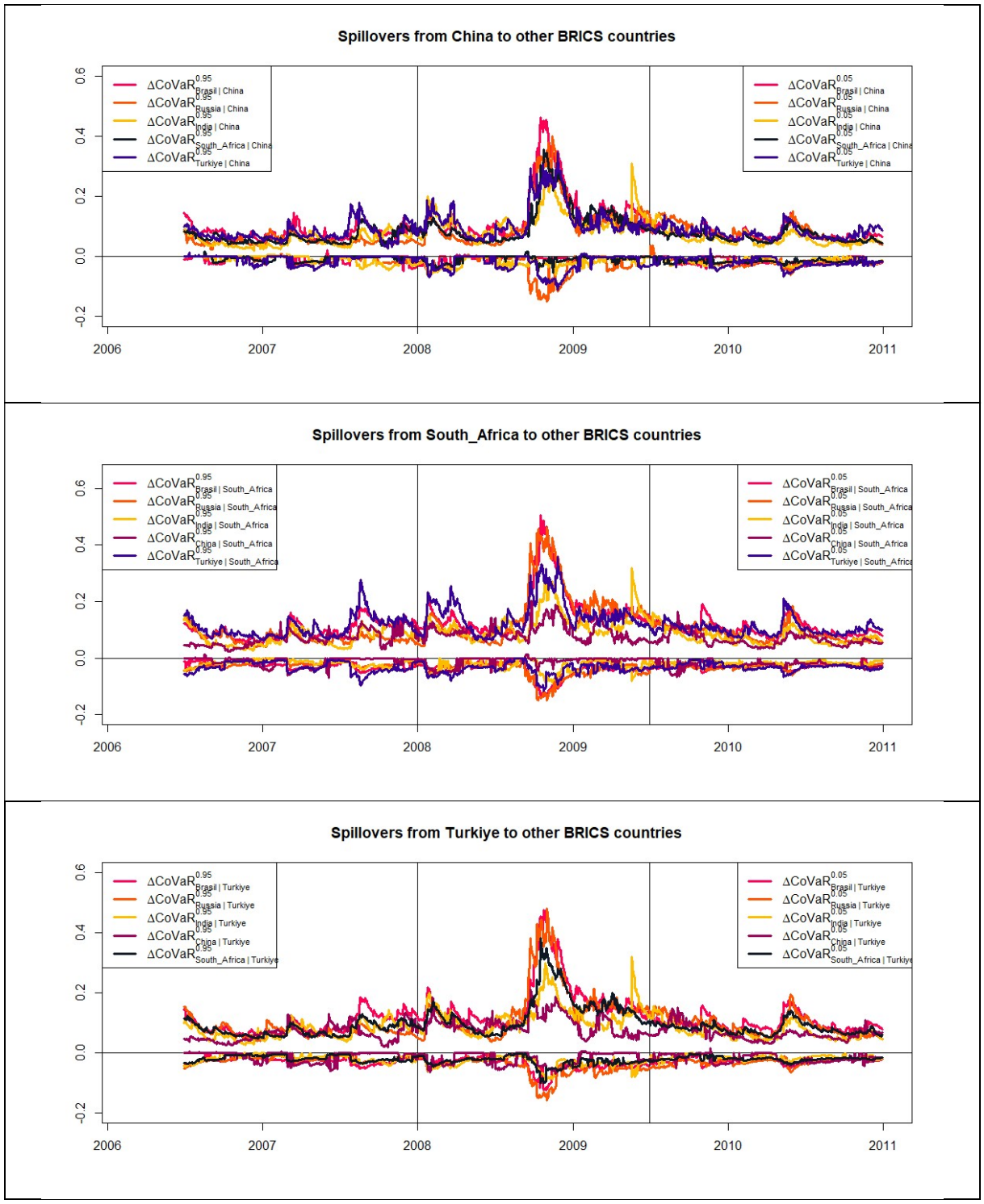


Figure 3.4 Graphical representations of the downside and upside ΔCoVaR estimates of BRICS countries (2008 crisis) (continued)

3.3.4 Results of 2020 COVID-19 Pandemic

3.3.4.1 Time-Varying Copula Results of 2020 COVID-19 Pandemic

The results of the TVFC analysis conducted for the 2020 COVID-19 pandemic period are presented in Table 3.16, showing the number of copula families obtained before the pandemic (BC) and after the pandemic (AC). When investigating the independence copula family numbers in Table 3.16, the pairs of Brazil-South Africa, Russia-South Africa, and China-South Africa are notable. The Independence copula family numbers for these three pairs were found to be 0 in both the BC and AC periods. This indicates that the dependency levels of these three pairs are quite high, as inferred solely from this value.

In previous analyses related to the 2001 and 2008 crises, the dependency values formed by China with other pairs were found to be relatively low, and the number of independence copula families was significantly higher compared to other pairs. However, the result that the number of independence copula families between China and any other country's stock market is 0 appeared for the first time in this period. The number of copula families representing negative relationships, represented by 90-degree and 270-degree rotated copula families, is almost negligible.

For the Brazil-China pair, one 90-degree rotated Tawn Type-1 copula and four 90-degree rotated Tawn Type-2 copula were obtained before the pandemic. Additionally, for the China-Türkiye pair, copula families containing various negative relationships were obtained for both BC and AC periods. No negative dependency was found in the remaining pairs. When examining the number of independence copula families for the China-Türkiye pair in the BC period, it was inferred that the dependency levels of these two countries were among the lowest values.

Table 3.16 Selected copula families with their frequencies (2020 COVID-19 Pandemic)

		Br-Ru		Br-In		Br-Ch		Br-So		Br-Tu	
Name	**TD STR**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**
Independence	No		7	102	32	134	43			30	56
Gaussian	No	1	20		5		6	43	31	10	23
Student t	Symm.	26	71	57	36	32	3	1	48	2	
Clayton	Only Lw			6	28	19	1	19	8		22
Gumbel	Only Up	4	3		7			5	22	11	1
Frank	No	40	7		4			19		6	2
Joe	Only Up	22	27	1	9	24	62		5		
BB1	Asym										
BB6	Only Up										
BB7	Asym		1		2			2	24		11
BB8	Only Up	3									
180 d.r. Clayton	Only Up	9	11		1		3	5	6	19	
180 d.r. Gumbel	Only Lw	50	28	8	44		2	58	32	9	20
180 d.r. Joe	Only Lw	39		57	29	6	11	7	20	51	72
180 d.r. BB1	Asym		4								
180 d.r. BB6	Only Lw										
180 d.r. BB7	Asym	18	39		8			50	33		
180 d.r. BB8	Only Lw			2				2			
90 d.r. Clayton	No										
90 d.r. Gumbel	No										
90 d.r. Joe	No										
90 d.r. BB1	No										
90 d.r. BB6	No										
90 d.r. BB7	No										
90 d.r. BB8	No										
270 d.r. Clayton	No										
270 d.r. Gumbel	No										
270 d.r. Joe	No										
270 d.r. BB1	No										
270 d.r. BB6	No										
270 d.r. BB7	No										
270 d.r. BB8	No										
Tawn type 1	Only Up	2	8	5		14		31	29	29	
180 d.r. Tawn type 1	Only Lw		6	3	2	8	37			2	14
90 d.r. Tawn type 1	No					1					
270 d.r. Tawn type 1	No									1	
Tawn type 2	Only Up	42	13	5	45		29			22	8
180 d.r. Tawn type 2	Only Lw	6	17	16	10	20	65	20	4	70	33
90 d.r. Tawn type 2	No					4					
270 d.r. Tawn type 2	No										

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye; BC: Before 2020 COVID-19 Pandemic;
AC: After 2020 COVID-19 Pandemic; TD STR: Tail Dependency Structure; BB1: Clayton-Gumbel; BB6: Joe-Gumbel;
BB7: Joe-Clayton; BB8: Joe-Frank; d.r.: degrees rotated; Symm.: Symmmetric; Only Lw: Only Lower; Only Up: Only Upper;
Asym: Asymmetric

Table 3.16 Selected copula families with their frequencies (2020 COVID-19 Pandemic) (continued)

		Ru-In		Ru-Ch		Ru-So		Ru-Tu		In-Ch	
Name	**TD STR**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**
Independence	No	47		38	25			63		37	
Gaussian	No	4	5	17	26	52	46	5	56	16	29
Student t	Symm.	29	79	31		10	65	19		2	1
Clayton	Only Lw	1	22	4	16	9	1	1	21	24	14
Gumbel	Only Up	67	24	34	1	24	29	22	40		3
Frank	No	18	14	22	31	64		12		11	25
Joe	Only Up	27	5	29	44			36	1		25
BB1	Asym								1		
BB6	Only Up										
BB7	Asym	5	1	10		2	28		42	7	4
BB8	Only Up					8					3
180 d.r. Clayton	Only Up	5	1	8	12	2	2	11	10	18	32
180 d.r. Gumbel	Only Lw		30	4	53	73	41	23	21	30	28
180 d.r. Joe	Only Lw				12	9	3	33	20	102	27
180 d.r. BB1	Asym		2			1					
180 d.r. BB6	Only Lw										
180 d.r. BB7	Asym		17				40	1			7
180 d.r. BB8	Only Lw		9			8				1	24
90 d.r. Clayton	No										
90 d.r. Gumbel	No										
90 d.r. Joe	No										
90 d.r. BB1	No										
90 d.r. BB6	No										
90 d.r. BB7	No										
90 d.r. BB8	No										
270 d.r. Clayton	No										
270 d.r. Gumbel	No										
270 d.r. Joe	No										
270 d.r. BB1	No										
270 d.r. BB6	No										
270 d.r. BB7	No										
270 d.r. BB8	No										
Tawn type 1	Only Up	2	23	2				18	23	2	1
180 d.r. Tawn type 1	Only Lw			38	2			3		1	
90 d.r. Tawn type 1	No										
270 d.r. Tawn type 1	No										
Tawn type 2	Only Up	10	17	21	22			5			4
180 d.r. Tawn type 2	Only Lw	47	13	4	18		7	10	27	11	35
90 d.r. Tawn type 2	No										
270 d.r. Tawn type 2	No										

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye; BC: Before 2020 COVID-19 Pandemic;
AC: After 2020 COVID-19 Pandemic; TD STR: Tail Dependency Structure; BB1: Clayton-Gumbel; BB6: Joe-Gumbel;
BB7: Joe-Clayton; BB8: Joe-Frank; d.r.: degrees rotated; Symm.: Symmmetric; Only Lw: Only Lower; Only Up: Only Upper;
Asym: Asymmetric

Table 3.16 Selected copula families with their frequencies (2020 COVID-19 Pandemic) (continued)

		In-So		In-Tu		Ch-So		Ch-Tu		So-Tu	
Name	**TD STR**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**
Independence	No	6		35	22			104	14	18	12
Gaussian	No	6	2	4	28	40	5	9	20	44	7
Student t	Symm.		83	16	10		14	20	2		
Clayton	Only Lw	104	13	87	22	26	55	2	8	21	5
Gumbel	Only Up		17	1	3	13	18	4	5	8	
Frank	No	7	4	17	19		33	6	4	30	
Joe	Only Up						39	5	23	18	
BB1	Asym										
BB6	Only Up										
BB7	Asym		14	1	20		26			2	68
BB8	Only Up					5	1	1			
180 d.r. Clayton	Only Up			2	2	24	22	7	18	35	9
180 d.r. Gumbel	Only Lw	39	73	1	29	16	36	7	65	2	10
180 d.r. Joe	Only Lw	82	24	60	59	57		5	4	39	41
180 d.r. BB1	Asym										
180 d.r. BB6	Only Lw										
180 d.r. BB7	Asym		4		2	13			14		13
180 d.r. BB8	Only Lw						5				
90 d.r. Clayton	No										
90 d.r. Gumbel	No										
90 d.r. Joe	No								11		
90 d.r. BB1	No										
90 d.r. BB6	No										
90 d.r. BB7	No								1		
90 d.r. BB8	No								1		
270 d.r. Clayton	No								8		
270 d.r. Gumbel	No										
270 d.r. Joe	No							1			
270 d.r. BB1	No										
270 d.r. BB6	No										
270 d.r. BB7	No								4		
270 d.r. BB8	No										
Tawn type 1	Only Up	2	10	15	8	49	4	1	1	2	
180 d.r. Tawn type 1	Only Lw		16				4		37	35	12
90 d.r. Tawn type 1	No								17		
270 d.r. Tawn type 1	No			2							
Tawn type 2	Only Up			2				16	1	5	5
180 d.r. Tawn type 2	Only Lw	16	2	19	38	19		63	4	3	80
90 d.r. Tawn type 2	No							11			
270 d.r. Tawn type 2	No										

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye; BC: Before 2020 COVID-19 Pandemic; AC: After 2020 COVID-19 Pandemic; TD STR: Tail Dependency Structure; BB1: Clayton-Gumbel; BB6: Joe-Gumbel; BB7: Joe-Clayton; BB8: Joe-Frank; d.r.: degrees rotated; Symm.: Symmmetric; Only Lw: Only Lower; Only Up: Only Upper; Asym: Asymmetric

The values showing the percentages of copula families according to tail dependency types are provided in Table 3.17 for the 2020 COVID-19 pandemic period. The "no tail dependency" percentages for the India-South Africa pair remained considerably low both in the BC and AC periods compared to other pairs. The percentage of "only lower tail dependency" for this pair

was found to be 92% in the BC period and 49% in the AC period. This indicates that while this pair was highly dependent on each other during periods of negative shocks in the BC period, this dependency structure decreased in the AC period.

Table 3.17 The percentages of the tail dependence types for each pair (2020 COVID-19 Pandemic)

	Br-Ru		**Br-In**		**Br-Ch**		**Br-So**		**Br-Tu**	
	BC	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**
No	16%	13%	39%	16%	53%	19%	24%	12%	18%	31%
Symm.	10%	27%	22%	14%	12%	1%		18%	1%	
Only Lw	36%	19%	35%	43%	20%	44%	40%	24%	50%	61%
Only Up	31%	24%	4%	24%	15%	36%	16%	24%	31%	3%
Asym	7%	17%	0%	4%	0%	0%	20%	22%		4%
	Ru-In		**Ru-Ch**		**Ru-So**		**Ru-Tu**		**In-Ch**	
	BC	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**
No	26%	7%	29%	31%	44%	18%	31%	21%	24%	21%
Symm.	11%	30%	12%		4%	25%	7%		1%	
Only Lw	18%	28%	19%	39%	38%	20%	27%	34%	65%	49%
Only Up	42%	27%	36%	30%	13%	12%	35%	28%	8%	26%
Asym	2%	8%	4%		1%	26%		16%	3%	4%
	In-So		**In-Tu**		**Ch-So**		**Ch-Tu**		**So-Tu**	
	BC	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**
No	7%	2%	22%	26%	15%	15%	50%	31%	35%	7%
Symm.		32%	6%	4%		5%	8%	1%		
Only Lw	92%	49%	64%	56%	45%	38%	29%	45%	38%	56%
Only Up	1%	10%	8%	5%	35%	32%	13%	18%	26%	5%
Asym		7%		8%	5%	10%		5%	1%	31%

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye;
BC: Before 2020 COVID-19 Pandemic; AC: After 2020 COVID-19 Pandemic;
Symm.: Symmmetric; Only Lw: Only Lower; Only Up: Only Upper; Asym: Asymmetric

The lower tail dependency values, upper tail dependency values, and Kendall's Tau values for BRICS-T countries' stock markets during the 2020 COVID-19 pandemic periods are provided in Table 3.18. It was found that, except for the India-China pair, the lower tail dependency values for all other pairs were higher in the AC period compared to the BC period. This suggests that during the COVID-19 pandemic, countries (excluding the India-China pair) were more affected by negative financial shocks compared to the BC period. The most significant change in lower tail dependency coefficients occurred for the South Africa-Türkiye pair, increasing from 0.10 in the BC period to 0.39 in the AC period.

Examining the values for upper tail dependency structures, increases were observed in the AC period compared to the BC period. Except for the Russia-China and Brazil-Türkiye pairs, it was found that the upper tail dependency values for all other pairs were higher in the AC period than in the BC period. In fact, the upper tail dependency coefficient for the India-South

Africa pair increased from 0 in the BC period to 0.20 in the AC period. During the BC period, the Russia-South Africa pair had one of the lowest upper tail dependency coefficients, registering 0, whereas in the AC period, it emerged as the pair with the highest upper tail dependency coefficient, reaching a value of 0.29. This clearly indicates that the Russia-South Africa pair's dependencies in the presence of positive financial shocks increased significantly after the pandemic compared to before the pandemic period.

Examining Kendall's Tau values representing the overall dependency level, it was observed that the COVID-19 pandemic made all BRICS-T country stock markets more interdependent. Specifically, all Kendall's Tau dependency coefficients for the AC period were higher than those for the BC period. These results clearly demonstrate the impact of the COVID-19 pandemic on the dependency structures of country stock markets.

Table 3.18 Lower tail dependence, upper tail dependence, and Kendall's Tau values (2020 COVID-19 Pandemic)

	Brazil		**Russia**		**India**		**China**		**South Africa**		**Türkiye**	
	BC	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**
	Lower tail dependence values											
Brazil	1	1										
Russia	0.18	0.22	1	1								
India	0.11	0.19	0.07	0.24	1	1						
China	0.04	0.12	0.07	0.11	0.23	0.18	1	1				
South A.	0.20	0.32	0.17	0.38	0.24	0.40	0.20	0.21	1	1		
Türkiye	0.15	0.24	0.12	0.22	0.22	0.28	0.10	0.17	0.10	0.39	1	1
	Upper tail dependence values											
Brazil	1	1	0.15	0.24	0.04	0.11	0.05	0.09	0.14	0.29	0.05	0.01
Russia			1	1	0.14	0.24	0.13	0.08	0.06	0.29	0.10	0.14
India					1	1	0.02	0.07	0.00	0.20	0.02	0.06
China							1	1	0.11	0.17	0.05	0.06
South A.									1	1	0.09	0.14
Türkiye											1	1
	Kendall's Tau values											
Brazil	1	1	0.24	0.28	0.05	0.19	0.03	0.15	0.30	0.42	0.15	0.19
Russia			1	1	0.15	0.32	0.15	0.18	0.37	0.46	0.15	0.32
India					1	1	0.18	0.28	0.17	0.37	0.17	0.28
China							1	1	0.27	0.28	0.10	0.17
South A.									1	1	0.20	0.32
Türkiye											1	1

South A.: South Africa; BC: Before 2020 COVID-19 Pandemic; AC: After 2020 COVID-19 Pandemic

3.3.4.2 Risk Spillover Results of the 2020 COVID-19 Pandemic

- **Kolmogorov–Smirnov Bootstrapping Test Results (2020 COVID-19 Pandemic)**

The average VaR and CoVaR values for the 2020 COVID-19 pandemic period are provided in Table 3.19. Additionally, the results of the Kolmogorov-Smirnov tests conducted to investigate the presence of risk spillovers are presented in Table 3.19. According to the Kolmogorov-Smirnov test results, the null hypotheses for both downside and upside risk spillovers were rejected for both periods. Therefore, it is statistically significant that both upside and downside risk spillovers exist for all BRICS-T countries during the 2020 COVID-19 pandemic periods.

Table 3.19 Averages of VaR and CoVaR values of the indices and KS bootstrap test results (2020 COVID-19 Pandemic)

Spillover		Downside Spillovers					
from	to	BC			AC		
		VaR	CoVaR	p-value	VaR	CoVaR	p-value
Br	Ru	-0.017	-0.032	*	-0.035	-0.070	*
Br	In	-0.017	-0.026	*	-0.028	-0.054	*
Br	Ch	-0.019	-0.025	*	-0.021	-0.035	*
Br	So	-0.021	-0.039	*	-0.035	-0.068	*
Br	Tu	-0.029	-0.053	*	-0.033	-0.064	*
Ru	Br	-0.029	-0.049	*	-0.048	-0.087	*
Ru	In	-0.017	-0.024	*	-0.028	-0.057	*
Ru	Ch	-0.019	-0.028	*	-0.021	-0.037	*
Ru	So	-0.021	-0.038	*	-0.035	-0.070	*
Ru	Tu	-0.029	-0.047	*	-0.033	-0.068	*
In	Br	-0.029	-0.043	*	-0.048	-0.086	*
In	Ru	-0.017	-0.027	*	-0.035	-0.072	*
In	Ch	-0.019	-0.041	*	-0.021	-0.042	*
In	So	-0.021	-0.040	*	-0.035	-0.069	*
In	Tu	-0.029	-0.058	*	-0.033	-0.070	*
Ch	Br	-0.029	-0.036	*	-0.048	-0.078	*
Ch	Ru	-0.017	-0.025	*	-0.035	-0.062	*
Ch	In	-0.017	-0.032	*	-0.028	-0.056	*
Ch	So	-0.021	-0.038	*	-0.035	-0.061	*
Ch	Tu	-0.029	-0.044	*	-0.033	-0.055	*
So	Br	-0.029	-0.054	*	-0.048	-0.096	*
So	Ru	-0.017	-0.035	*	-0.035	-0.081	*
So	In	-0.017	-0.035	*	-0.028	-0.062	*
So	Ch	-0.019	-0.041	*	-0.021	-0.043	*
So	Tu	-0.029	-0.048	*	-0.033	-0.073	*
Tu	Br	-0.029	-0.048	*	-0.048	-0.088	*
Tu	Ru	-0.017	-0.027	*	-0.035	-0.074	*
Tu	In	-0.017	-0.031	*	-0.028	-0.059	*
Tu	Ch	-0.019	-0.031	*	-0.021	-0.036	*
Tu	So	-0.021	-0.031	*	-0.035	-0.068	*

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye;
BC: Before 2020 COVID-19 Pandemic; AC: 2020 COVID-19 Pandemic;
CoVaR: Conditional Value-at-Risk; VaR: Value-at-Risk; *: $p<0.05$

Table 3.19 Averages of VaR and CoVaR values of the indices and KS bootstrap test results (2020 COVID-19 Pandemic) (continued)

Spillover		Upside Spillovers					
from	to	BC			AC		
		VaR	CoVaR	p-value	VaR	CoVaR	p-value
Br	Ru	0.018	0.030	*	0.034	0.066	*
Br	In	0.017	0.020	*	0.027	0.041	*
Br	Ch	0.018	0.022	*	0.020	0.032	*
Br	So	0.021	0.032	*	0.033	0.059	*
Br	Tu	0.029	0.042	*	0.033	0.042	*
Ru	Br	0.028	0.045	*	0.047	0.083	*
Ru	In	0.017	0.026	*	0.027	0.049	*
Ru	Ch	0.018	0.032	*	0.020	0.033	*
Ru	So	0.021	0.032	*	0.033	0.061	*
Ru	Tu	0.029	0.044	*	0.033	0.059	*
In	Br	0.028	0.034	*	0.047	0.068	*
In	Ru	0.018	0.029	*	0.034	0.064	*
In	Ch	0.018	0.024	*	0.020	0.036	*
In	So	0.021	0.024	*	0.033	0.056	*
In	Tu	0.029	0.036	*	0.033	0.051	*
Ch	Br	0.028	0.033	*	0.047	0.067	*
Ch	Ru	0.018	0.029	*	0.034	0.051	*
Ch	In	0.017	0.020	*	0.027	0.042	*
Ch	So	0.021	0.030	*	0.033	0.053	*
Ch	Tu	0.029	0.038	*	0.033	0.049	*
So	Br	0.028	0.045	*	0.047	0.086	*
So	Ru	0.018	0.030	*	0.034	0.072	*
So	In	0.017	0.019	*	0.027	0.049	*
So	Ch	0.018	0.033	*	0.020	0.039	*
So	Tu	0.029	0.045	*	0.033	0.054	*
Tu	Br	0.028	0.038	*	0.047	0.057	*
Tu	Ru	0.018	0.027	*	0.034	0.062	*
Tu	In	0.017	0.020	*	0.027	0.044	*
Tu	Ch	0.018	0.026	*	0.020	0.034	*
Tu	So	0.021	0.029	*	0.033	0.052	*

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye;
BC: Before 2020 COVID-19 Pandemic; AC: After 2020 COVID-19 Pandemic;
CoVaR: Conditional Value-at-Risk; VaR: Value-at-Risk; *: $p<0.05$

- **CoVaR Results (2020 COVID-19 Pandemic)**

The average VaR and CoVaR values calculated from Table 3.19 are displayed in Figure 3.5. When examining downside spillover values, it was observed that during the BC period, Türkiye and Brazil were the most affected by risk spillovers from other BRICS-T countries. Unlike the 2001 and 2008 crises, China was not the least affected by other BRICS-T countries before the 2020 COVID-19 pandemic period. However, in the AC period, China was once

again the least affected by other BRICS-T countries. During the AC period, Brazil, rather than Türkiye, was the most affected by other BRICS-T countries.

Regarding upside risk spillover values, similar to downside risk spillovers, Türkiye and Brazil were the most affected by risk spillovers from other BRICS-T countries during the BC period. Before the 2020 COVID-19 pandemic, India was the least affected by other BRICS-T countries, which is surprising given that China is usually the least affected. However, during the AC period, China was once again the least affected by other BRICS-T countries. In the AC period, Brazil and Russia were the most affected by other BRICS-T countries. Considering that Türkiye is usually the most affected, this result is noteworthy.

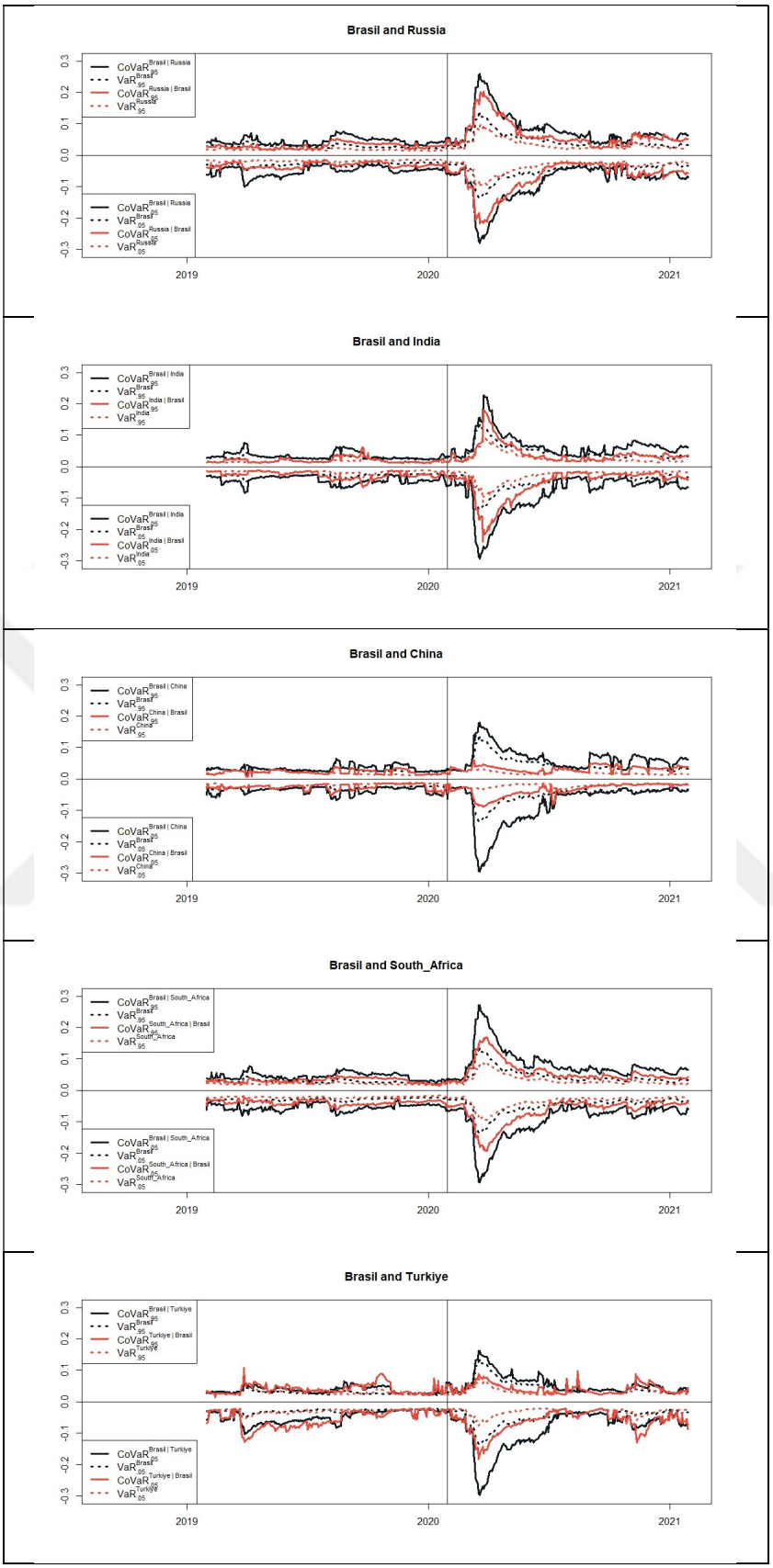


Figure 3.5 Graphic representations of downside and upside VaR and CoVaR estimates of BRICS-T countries (2020 COVID-19 Pandemic)

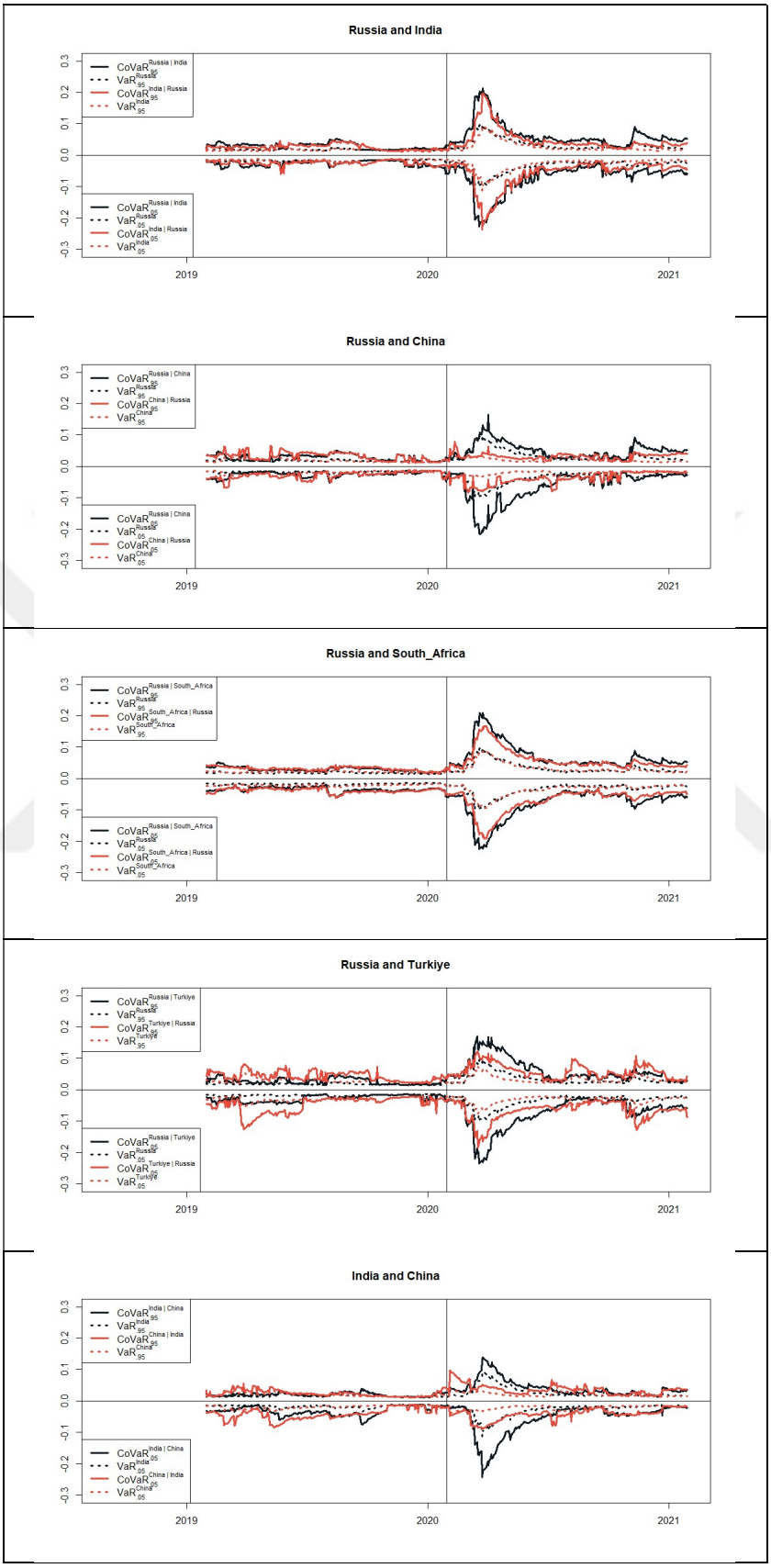


Figure 3.5 Graphic representations of downside and upside VaR and CoVaR estimates of BRICS-T countries (2020 COVID-19 Pandemic) (continued)

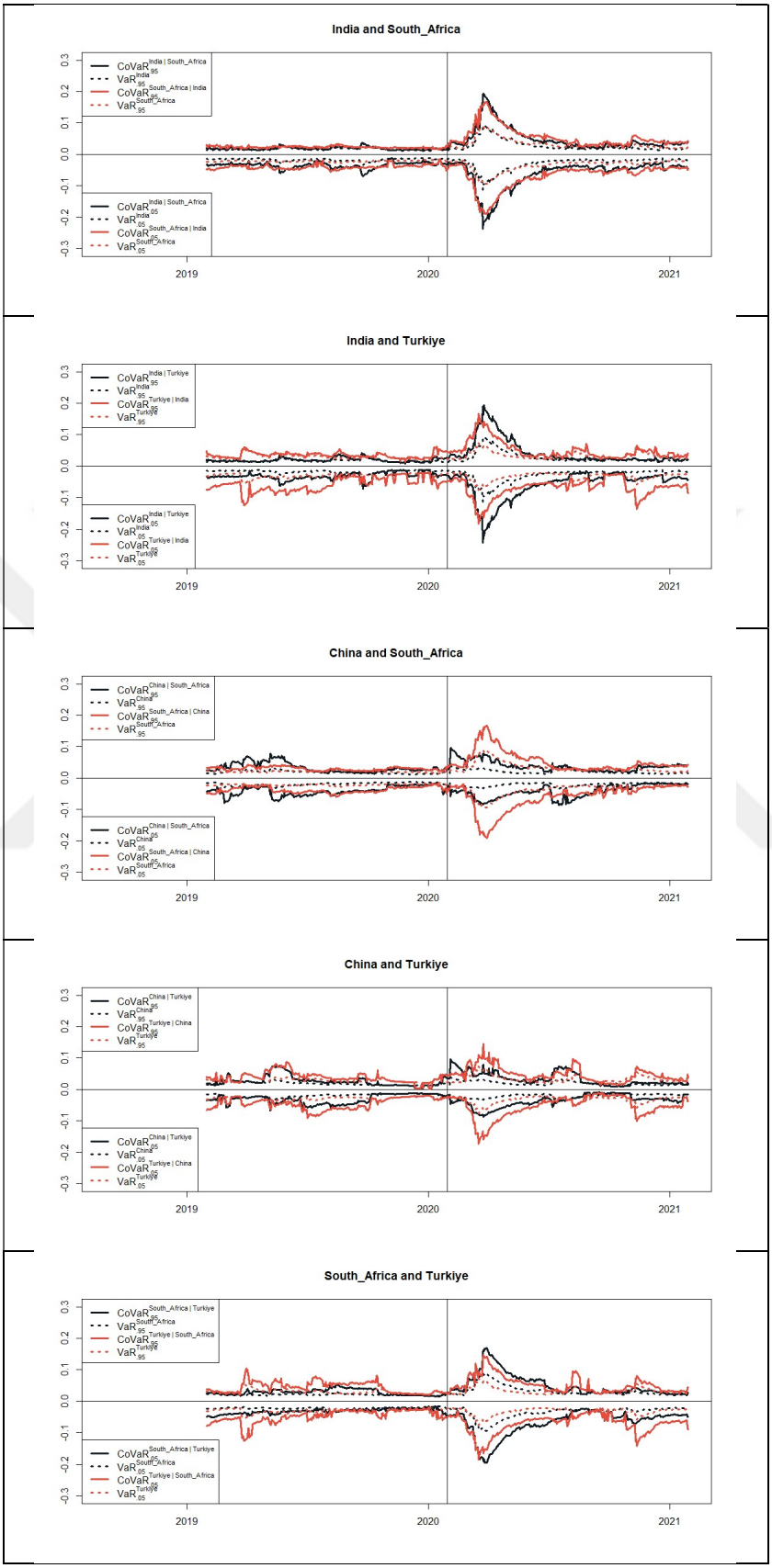


Figure 3.5 Graphic representations of downside and upside VaR and CoVaR estimates of BRICS-T countries (2020 COVID-19 Pandemic) (continued)

- **ΔCoVaR Results (2020 COVID-19 Pandemic)**

Table 3.20 presents the average downside and upside ΔCoVaR values for BRICS-T countries during the 2020 COVID-19 pandemic. Graphical representations of these values are shown in Figure 3.6. According to these results, only the downside risk contribution value from India to China increased in the AC period compared to the BC period. The downside risk contribution values for all other pairs decreased. When examining upside risk contribution values, it was found that the upside risk contribution values for all pairs increased in the AC period compared to the BC period.

Table 3.20 Averages of ΔCoVaR values (2020 COVID-19 Pandemic)

Spillovers		ΔCoVaR downside		ΔCoVaR upside	
from	**to**	**BC**	**AC**	**BC**	**AC**
Russia	Brazil	-0.016	-0.030	0.078	0.139
Brazil	Russia	-0.011	-0.028	0.050	0.108
India	Brazil	-0.012	-0.030	0.065	0.124
Brazil	India	-0.008	-0.021	0.038	0.075
China	Brazil	-0.006	-0.023	0.063	0.122
Brazil	China	-0.005	-0.011	0.042	0.056
South Africa	Brazil	-0.019	-0.036	0.080	0.146
Brazil	South Africa	-0.013	-0.025	0.057	0.102
Türkiye	Brazil	-0.014	-0.031	0.071	0.114
Brazil	Türkiye	-0.019	-0.024	0.076	0.081
India	Russia	-0.007	-0.029	0.048	0.107
Russia	India	-0.006	-0.022	0.044	0.084
China	Russia	-0.006	-0.021	0.048	0.092
Russia	China	-0.007	-0.013	0.053	0.057
South Africa	Russia	-0.013	-0.037	0.052	0.116
Russia	South Africa	-0.012	-0.027	0.058	0.104
Türkiye	Russia	-0.007	-0.030	0.046	0.105
Russia	Türkiye	-0.014	-0.027	0.077	0.100
China	India	-0.013	-0.021	0.040	0.076
India	China	-0.018	-0.017	0.047	0.062
South Africa	India	-0.015	-0.027	0.039	0.084
India	South Africa	-0.015	-0.027	0.049	0.099
Türkiye	India	-0.011	-0.024	0.040	0.079
India	Türkiye	-0.023	-0.030	0.070	0.092
South Africa	China	-0.017	-0.017	0.057	0.065
China	South Africa	-0.012	-0.019	0.056	0.095
Türkiye	China	-0.010	-0.012	0.047	0.057
China	Türkiye	-0.012	-0.019	0.071	0.085
Türkiye	South Africa	-0.007	-0.025	0.053	0.094
South Africa	Türkiye	-0.014	-0.032	0.079	0.095

BC: Before 2020 COVID-19 Pandemic; AC: 2020 COVID-19 Pandemic; CoVaR: Conditional Value-at-Risk

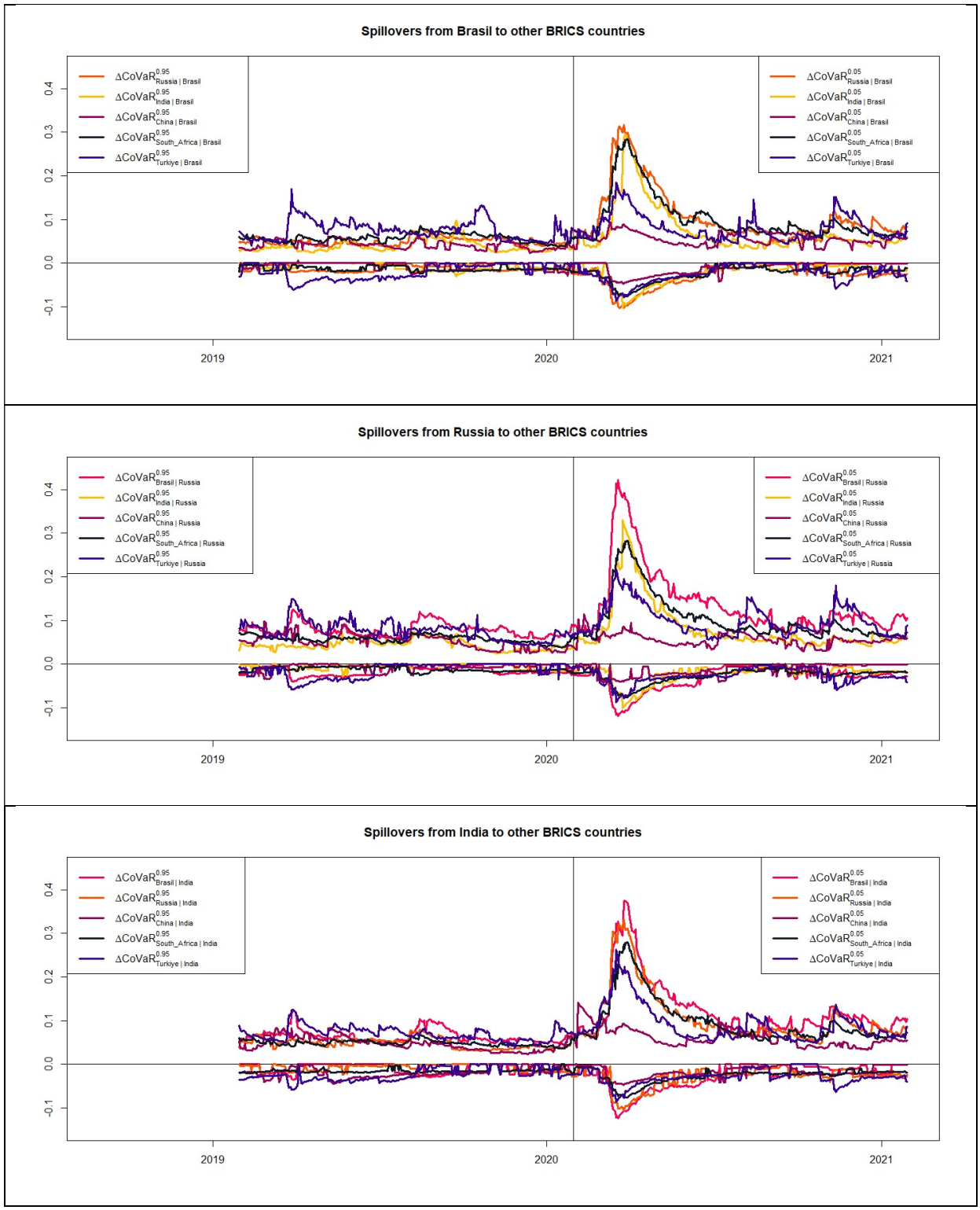


Figure 3.6 Graphical representations of the downside and upside ΔCoVaR estimates of BRICS countries (2020 COVID-19 Pandemic)



Figure 3.6 Graphical representations of the downside and upside ΔCoVaR estimates of BRICS countries (2020 COVID-19 Pandemic) (continued)

3.3.5 Results of Russia-Ukraine War Period

3.3.5.1 Time-Varying Copula Results of Russia-Ukraine War Period

According to the results of the TVFC analysis conducted for the period of the Russia-Ukraine war, the number of copula families obtained before the onset of war (BC) and after the onset of war (AC) is provided in Table 3.21. Upon examining the independence copula family numbers in Table 3.21, it is observed that the values for all pairs involving Russia have increased in the AC period. For the Brazil-Russia pair, the number of no tail dependency in the BC period was 0, while it increased to 50 in the AC period. Similarly, for the Russia-India pair, the number of no tail dependency in the BC period was also found to be 0, but this value increased to 65 in the AC period. A similar result was also found for the Russia-South Africa pair. For this pair, the number of no tail dependency, which was 0 in the BC period, increased to 31 in the AC period. While the number of no tail dependency for the Russia-China pair was 37 in the BC period, it increased to 113 in the AC period, and for the Russia-Türkiye pair, these values were 16 in the BC period and 30 in the AC period. Thus, it can be inferred solely from these values that there has been some decrease in the Russian stock index's dependency structures with other BRICS-T countries' stock market indices.

Table 3.21 Selected copula families with their frequencies (Russia-Ukraine War Period)

		Br-Ru		Br-In		Br-Ch		Br-So		Br-Tu	
Name	**TD STR**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**
Independence	No		50		14	82	95		30	42	5
Gaussian	No	62	22	7	11		17	41	56		1
Student t	Symm.	6			4	25	2		2	20	40
Clayton	Only Lw	5	17	80	21	6	27	12	37	58	30
Gumbel	Only Up	40			9		21	17			11
Frank	No	9	13		12	8	20	127	2	1	29
Joe	Only Up				8						14
BB1	Asym							1	13		
BB6	Only Up										
BB7	Asym	10					1	1	8	4	
BB8	Only Up				1			15			
180 d.r. Clayton	Only Up		3		13			4			
180 d.r. Gumbel	Only Lw	38	12	85	84		1	41	52	3	14
180 d.r. Joe	Only Lw	34		56	30	58	20	2		79	55
180 d.r. BB1	Asym								AC1		
180 d.r. BB6	Only Lw										
180 d.r. BB7	Asym	7			2			1	1		
180 d.r. BB8	Only Lw	34	1						4		3
90 d.r. Clayton	No										
90 d.r. Gumbel	No		6								
90 d.r. Joe	No		1								
90 d.r. BB1	No										
90 d.r. BB6	No										
90 d.r. BB7	No										
90 d.r. BB8	No										
270 d.r. Clayton	No		4								2
270 d.r. Gumbel	No										
270 d.r. Joe	No										
270 d.r. BB1	No										
270 d.r. BB6	No										
270 d.r. BB7	No										
270 d.r. BB8	No										
Tawn type 1	Only Up	13		4	15	18	12				2
180 d.r. Tawn type 1	Only Lw	2	46	5	26	13	7		44	31	23
90 d.r. Tawn type 1	No		15		12						28
270 d.r. Tawn type 1	No										4
Tawn type 2	Only Up	2	40	1		40	16		12		
180 d.r. Tawn type 2	Only Lw			24		12	23			24	
90 d.r. Tawn type 2	No		19								
270 d.r. Tawn type 2	No		13								1

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye; BC: Before the onset of Russia-Ukraine War;
AC: After the onset of Russia-Ukraine War; TD STR: Tail Dependency Structure; BB1: Clayton-Gumbel; BB6: Joe-Gumbel;
BB7: Joe-Clayton; BB8: Joe-Frank; d.r.: degrees rotated; Symm.: Symmmetric; Only Lw: Only Lower; Only Up: Only Upper;
Asym: Asymmetric

Table 3.21 Selected copula families with their frequencies (Russia-Ukraine War Period) (continued)

		Ru-In		Ru-Ch		Ru-So		Ru-Tu		In-Ch	
Name	**TD STR**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**
Independence	No		65	37	113		31	16	30	42	27
Gaussian	No	10	17	26		36	19	42	3	33	19
Student t	Symm.		5			63		3	43	17	23
Clayton	Only Lw	47	1	17	18			47	6	36	2
Gumbel	Only Up		4	11	9	34	11	42	10	1	27
Frank	No	2	12	40	7	37	56	44	6	28	16
Joe	Only Up		8	7	28	18	13		32		19
BB1	Asym					2	14				
BB6	Only Up										
BB7	Asym	23	20			4			6		
BB8	Only Up			3							
180 d.r. Clayton	Only Up		6	47	3	4	13		23		28
180 d.r. Gumbel	Only Lw	37	8	10	5	55	37	9	17	2	8
180 d.r. Joe	Only Lw	84	63	19	6		17	5	19	13	5
180 d.r. BB1	Asym										
180 d.r. BB6	Only Lw										
180 d.r. BB7	Asym		6	1		5	1		17	4	
180 d.r. BB8	Only Lw	11						1			
90 d.r. Clayton	No										
90 d.r. Gumbel	No										
90 d.r. Joe	No										
90 d.r. BB1	No										
90 d.r. BB6	No										
90 d.r. BB7	No										
90 d.r. BB8	No										
270 d.r. Clayton	No										
270 d.r. Gumbel	No										
270 d.r. Joe	No								10		
270 d.r. BB1	No										
270 d.r. BB6	No										
270 d.r. BB7	No										
270 d.r. BB8	No										
Tawn type 1	Only Up	2	33	11	14		15		22	14	21
180 d.r. Tawn type 1	Only Lw	19	1	24		4	8		4	14	
90 d.r. Tawn type 1	No								3		
270 d.r. Tawn type 1	No										
Tawn type 2	Only Up	27	13	2	18		8		5	7	
180 d.r. Tawn type 2	Only Lw			7	40		19	53	2	51	67
90 d.r. Tawn type 2	No				1						
270 d.r. Tawn type 2	No								4		

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye; BC: Before the onset of Russia-Ukraine War; AC: After the onset of Russia-Ukraine War; TD STR: Tail Dependency Structure; BB1: Clayton-Gumbel; BB6: Joe-Gumbel; BB7: Joe-Clayton; BB8: Joe-Frank; d.r.: degrees rotated; Symm.: Symmmetric; Only Lw: Only Lower; Only Up: Only Upper; Asym: Asymmetric

Table 3.21 Selected copula families with their frequencies (Russia-Ukraine War Period) (continued)

		In-So		In-Tu		Ch-So		Ch-Tu		So-Tu	
Name	**TD STR**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**
Independence	No			3	25	11		33	63	13	17
Gaussian	No	27	18	14	13	27	38	1	11	17	36
Student t	Symm.	1	18	28	62		2	40		27	1
Clayton	Only Lw	33	14	21	1	42	2	6	1		
Gumbel	Only Up	14	7	32	15	32	29		1	19	22
Frank	No	49	57	31	66	12	44	4	32	12	21
Joe	Only Up		8	3	3	48	7	61			24
BB1	Asym	4									4
BB6	Only Up										
BB7	Asym	13	13				27			7	7
BB8	Only Up		1							1	
180 d.r. Clayton	Only Up	5	37	3	16	13	14	2	12	1	59
180 d.r. Gumbel	Only Lw	23	69	38	8	15	39	2	47	2	21
180 d.r. Joe	Only Lw	20		3	1	11		64	2	26	3
180 d.r. BB1	Asym	2									
180 d.r. BB6	Only Lw										
180 d.r. BB7	Asym	6	4		9						6
180 d.r. BB8	Only Lw	2	6		1		1		1		
90 d.r. Clayton	No										
90 d.r. Gumbel	No										
90 d.r. Joe	No								2		
90 d.r. BB1	No										
90 d.r. BB6	No										
90 d.r. BB7	No										
90 d.r. BB8	No										
270 d.r. Clayton	No										
270 d.r. Gumbel	No										
270 d.r. Joe	No							1			
270 d.r. BB1	No										
270 d.r. BB6	No										
270 d.r. BB7	No										
270 d.r. BB8	No										
Tawn type 1	Only Up	12	5	26	34	22	7	12	34	58	10
180 d.r. Tawn type 1	Only Lw	3			8			7	21	2	
90 d.r. Tawn type 1	No								7		13
270 d.r. Tawn type 1	No										
Tawn type 2	Only Up			6		7		12	9	62	13
180 d.r. Tawn type 2	Only Lw	48	5	54		22	52	17	18	15	5
90 d.r. Tawn type 2	No										
270 d.r. Tawn type 2	No								1		

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye; BC: Before the onset of Russia-Ukraine War; AC: After the onset of Russia-Ukraine War; TD STR: Tail Dependency Structure; BB1: Clayton-Gumbel; BB6: Joe-Gumbel; BB7: Joe-Clayton; BB8: Joe-Frank; d.r.: degrees rotated; Symm.: Symmmetric; Only Lw: Only Lower; Only Up: Only Upper; Asym: Asymmetric

The values showing the percentages of copula families according to tail dependency types for the Russia-Ukraine war period are provided in Table 3.22. When examining the "no tail dependency" percentage, an increase in the AC period compared to the BC period is observed for all pairs involving Russia except for the Russia-Türkiye pair. For the Russia-Türkiye pair, the "no tail dependency" percentage decreased from 39% in the BC period to 21% in the AC

period. The percentage of "only lower tail dependency" for this pair also experienced a decline. This percentage, which was 44% in the BC period, dropped to 18% in the AC period. This decline has been replaced by an increase in the percentages of "symmetric tail dependency," "only upper tail dependency," and "asymmetric tail dependency."

The "symmetric tail dependency" percentage for the Russia-Türkiye pair increased from 1% in the BC period to 16% in the AC period. Additionally, the percentage of "only upper tail dependency," which was 16% in the BC period, rose to 25% in the AC period. Finally, the percentage of "asymmetric tail dependency," which was 0% in the BC period, increased to 9% in the AC period. Similarly, for all pairs involving Türkiye except for the Russia-Türkiye pair, an increase in the "no tail dependency" percentages in the AC period compared to the BC period was observed. Thus, it is observed that during the Russia-Ukraine war period, the only pair in which there was a clear increase in lower tail dependency for the BRICS-T countries' stock markets was the Russia-Türkiye pair.

Table 3.22 The percentages of the tail dependence types for each pair (Russia-Ukraine War Period)

	Br-Ru		**Br-In**		**Br-Ch**		**Br-So**		**Br-Tu**	
	BC	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**
No	27%	55%	3%	19%	34%	50%	64%	34%	16%	27%
Symm.	2%			2%	10%	1%		1%	8%	15%
Only Lw	43%	29%	95%	61%	34%	30%	21%	52%	74%	48%
Only Up	21%	16%	2%	18%	22%	19%	14%	5%		10%
Asym	6%			1%			1%	9%	2%	
	Ru-In		**Ru-Ch**		**Ru-So**		**Ru-Tu**		**In-Ch**	
	BC	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**
No	5%	36%	39%	46%	28%	40%	39%	21%	39%	24%
Symm.		2%			24%		1%	16%	6%	9%
Only Lw	76%	28%	29%	26%	23%	31%	44%	18%	44%	31%
Only Up	11%	24%	31%	27%	21%	23%	16%	35%	8%	36%
Asym	9%	10%			4%	6%		9%	2%	
	In-So		**In-Tu**		**Ch-So**		**Ch-Tu**		**So-Tu**	
	BC	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**	**BC**	**AC**
No	29%	29%	18%	40%	19%	31%	15%	44%	16%	33%
Symm.		7%	11%	24%		1%	15%	0%	10%	
Only Lw	49%	36%	44%	7%	34%	36%	37%	34%	17%	11%
Only Up	12%	22%	27%	26%	47%	22%	33%	21%	54%	49%
Asym	10%	6%		3%		10%			3%	6%

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye;
BC: Before the onset of the Russia-Ukraine War; AC: After the onset of the Russia-Ukraine War;
Symm.: Symmmetric; Only Lw: Only Lower; Only Up: Only Upper; Asym: Asymmetric

During the periods of the Russia-Ukraine war, the lower tail dependency values, upper tail dependency values, and Kendall's Tau values for country stock markets are presented in Table 3.23. Accordingly, parallel results to the interpretations made for the Russia-Türkiye pair in Table 3.22 can be observed in Table 3.23. When lower tail dependency coefficients are examined, a decrease in Russia's lower tail dependency coefficients with other BRICS-T countries except for Türkiye is observed in the AC period compared to the BC period. The same applies to Türkiye. It was found that Türkiye's lower tail dependency coefficients with other BRICS-T countries, except for Russia, decreased in the AC period compared to the BC period.

When upper tail dependency coefficients are examined, it was found that Russia's upper tail dependency coefficient with Brazil, China, and South Africa decreased in the AC period compared to the BC period. It was also observed that the upper tail dependency coefficient of Russia with India and Türkiye increased in the AC period compared to the BC period.

When investigating Kendall's Tau values, it is determined that the period of the Russia-Ukraine war made Russia and other BRICS-T country stock markets less dependent. It is concluded that Kendall's Tau dependency coefficients for all pairs involving Russia decreased in the AC period compared to the BC period.

Table 3.23 Lower tail dependence, upper tail dependence, and Kendall's Tau values (Russia-Ukraine War Period)

	Brazil		Russia		India		China		South Africa		Türkiye	
	BC	AC	BC	AC	BC	AC	BC	AC	BC	AC	BC	AC
	Lower tail dependence values											
Brazil	1	1										
Russia	0.12	0.05	1	1								
India	0.26	0.19	0.37	0.12	1	1						
China	0.09	0.05	0.08	0.07	0.10	0.09	1	1				
South A.	0.07	0.29	0.20	0.08	0.22	0.17	0.08	0.17	1	1		
Türkiye	0.23	0.18	0.10	0.11	0.16	0.11	0.12	0.08	0.11	0.06	1	1
	Upper tail dependence values											
Brazil	1	1	0.06	0.02	0.00	0.04	0.04	0.04	0.04	0.02	0.02	0.07
Russia			1	1	0.04	0.06	0.05	0.04	0.20	0.07	0.05	0.16
India					1	1	0.03	0.11	0.04	0.13	0.10	0.15
China							1	1	0.14	0.13	0.13	0.02
South A.									1	1	0.22	0.19
Türkiye											1	1
	Kendall's Tau values											
Brazil	1	1	0.20	0.07	0.19	0.18	0.06	0.09	0.33	0.34	0.15	0.15
Russia			1	1	0.29	0.13	0.16	0.08	0.34	0.18	0.21	0.13
India					1	1	0.13	0.16	0.28	0.31	0.23	0.20
China							1	1	0.18	0.30	0.12	0.12
South A.									1	1	0.26	0.24
Türkiye											1	1

South A.: South Africa; BC: Before the onset of the Russia-Ukraine War; AC: After the onset of the Russia-Ukraine War

3.3.5.2 Risk Spillover Results of the Russia-Ukraine War Period

- **Kolmogorov–Smirnov Bootstrapping Test Results (Russia-Ukraine War Period)**

Average VaR and CoVaR values for the Russia-Ukraine war period are provided in Table 3.24. Additionally, Kolmogorov-Smirnov test results questioning the presence of risk spillover are also presented in Table 3.24. According to the Kolmogorov-Smirnov test results, the null hypotheses for both downside and upside risk spillovers were rejected for both periods. Thus, it is statistically determined that there are upside and downside risk spillovers for all BRICS-T countries during the Russia-Ukraine war period.

Table 3.24 Averages of VaR and CoVaR values of the indices and KS bootstrap test results (Russia-Ukraine War Period)

Spillover		Downside Spillovers					
from	to	BC			AC		
		VaR	CoVaR	p-value	VaR	CoVaR	p-value
Br	Ru	-0.025	-0.044	*	-0.072	-0.050	*
Br	In	-0.017	-0.037	*	-0.033	-0.039	*
Br	Ch	-0.015	-0.025	*	-0.030	-0.033	*
Br	So	-0.025	-0.040	*	-0.055	-0.055	*
Br	Tu	-0.039	-0.072	*	-0.055	-0.062	*
Ru	Br	-0.033	-0.055	*	-0.043	-0.070	*
Ru	In	-0.017	-0.037	*	-0.029	-0.038	*
Ru	Ch	-0.015	-0.024	*	-0.027	-0.038	*
Ru	So	-0.025	-0.044	*	-0.044	-0.055	*
Ru	Tu	-0.039	-0.067	*	-0.051	-0.064	*
In	Br	-0.033	-0.066	*	-0.061	-0.061	*
In	Ru	-0.025	-0.057	*	-0.089	-0.044	*
In	Ch	-0.015	-0.028	*	-0.036	-0.042	*
In	So	-0.025	-0.045	*	-0.051	-0.054	*
In	Tu	-0.039	-0.071	*	-0.053	-0.067	*
Ch	Br	-0.033	-0.046	*	-0.050	-0.059	*
Ch	Ru	-0.025	-0.036	*	-0.069	-0.046	*
Ch	In	-0.017	-0.029	*	-0.031	-0.043	*
Ch	So	-0.025	-0.037	*	-0.052	-0.053	*
Ch	Tu	-0.039	-0.065	*	-0.048	-0.052	*
So	Br	-0.033	-0.054	*	-0.068	-0.074	*
So	Ru	-0.025	-0.050	*	-0.090	-0.054	*
So	In	-0.017	-0.034	*	-0.034	-0.046	*
So	Ch	-0.015	-0.026	*	-0.042	-0.045	*
So	Tu	-0.039	-0.067	*	-0.050	-0.066	*
Tu	Br	-0.033	-0.060	*	-0.058	-0.067	*
Tu	Ru	-0.025	-0.046	*	-0.088	-0.050	*
Tu	In	-0.017	-0.031	*	-0.031	-0.046	*
Tu	Ch	-0.015	-0.027	*	-0.029	-0.034	*
Tu	So	-0.025	-0.039	*	-0.043	-0.053	*

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye; BC: Before the onset of Russia-Ukraine War; AC: After the onset of Russia-Ukraine War; CoVaR: Conditional Value-at-Risk; VaR: Value-at-Risk; *: $p<0.05$

Table 3.24 Averages of VaR and CoVaR values of the indices and KS bootstrap test results (Russia-Ukraine War Period) (continued)

Spillover		Upside Spillovers					
from	to	BC			AC		
		VaR	CoVaR	p-value	VaR	CoVaR	p-value
Br	Ru	0.025	0.036	*	0.050	0.062	*
Br	In	0.014	0.021	*	0.018	0.024	*
Br	Ch	0.015	0.021	*	0.019	0.026	*
Br	So	0.024	0.035	*	0.029	0.044	*
Br	Tu	0.038	0.046	*	0.034	0.046	*
Ru	Br	0.032	0.045	*	0.036	0.043	*
Ru	In	0.014	0.025	*	0.018	0.025	*
Ru	Ch	0.015	0.024	*	0.019	0.027	*
Ru	So	0.024	0.040	*	0.029	0.040	*
Ru	Tu	0.038	0.055	*	0.034	0.054	*
In	Br	0.032	0.039	*	0.036	0.048	*
In	Ru	0.025	0.036	*	0.050	0.078	*
In	Ch	0.015	0.021	*	0.019	0.032	*
In	So	0.024	0.033	*	0.029	0.045	*
In	Tu	0.038	0.063	*	0.034	0.055	*
Ch	Br	0.032	0.041	*	0.036	0.043	*
Ch	Ru	0.025	0.035	*	0.050	0.066	*
Ch	In	0.014	0.022	*	0.018	0.027	*
Ch	So	0.024	0.035	*	0.029	0.045	*
Ch	Tu	0.038	0.053	*	0.034	0.043	*
So	Br	0.032	0.048	*	0.036	0.055	*
So	Ru	0.025	0.046	*	0.050	0.079	*
So	In	0.014	0.025	*	0.018	0.029	*
So	Ch	0.015	0.027	*	0.019	0.037	*
So	Tu	0.038	0.067	*	0.034	0.062	*
Tu	Br	0.032	0.038	*	0.036	0.048	*
Tu	Ru	0.025	0.036	*	0.050	0.082	*
Tu	In	0.014	0.027	*	0.018	0.029	*
Tu	Ch	0.015	0.025	*	0.019	0.026	*
Tu	So	0.024	0.039	*	0.029	0.047	*

Br: Brazil; Ru: Russia; In: India; Ch: China; So: South Africa; Tu: Türkiye; BC: Before the onset of Russia-Ukraine War; AC: After the onset of Russia-Ukraine War; CoVaR: Conditional Value-at-Risk; VaR: Value-at-Risk; *: $p<0.05$

- **CoVaR Results (Russia-Ukraine War Period)**

The average VaR and CoVaR values calculated from Table 3.24 are displayed in Figure 3.7. According to the downside spillover values, Türkiye was the most affected by risk spillovers from other BRICS-T countries during the BC period. Similar to the 2001 and 2008 crises, China was the least affected by other BRICS-T countries in the BC period. In the AC period,

Brazil and Türkiye were the most affected by other BRICS-T countries. India and China were the least affected by other BRICS-T countries in the AC period.

Regarding the upside risk spillover values, similar to the downside risk spillovers, Türkiye was again the most affected by risk spillovers from other BRICS-T countries during the BC period. Before the Russia-Ukraine war, India and China were the least affected by other BRICS-T countries. Similarly, India and China remained the least affected by other BRICS-T countries in the AC period. In the AC period, Russia was the most affected by other BRICS-T countries.

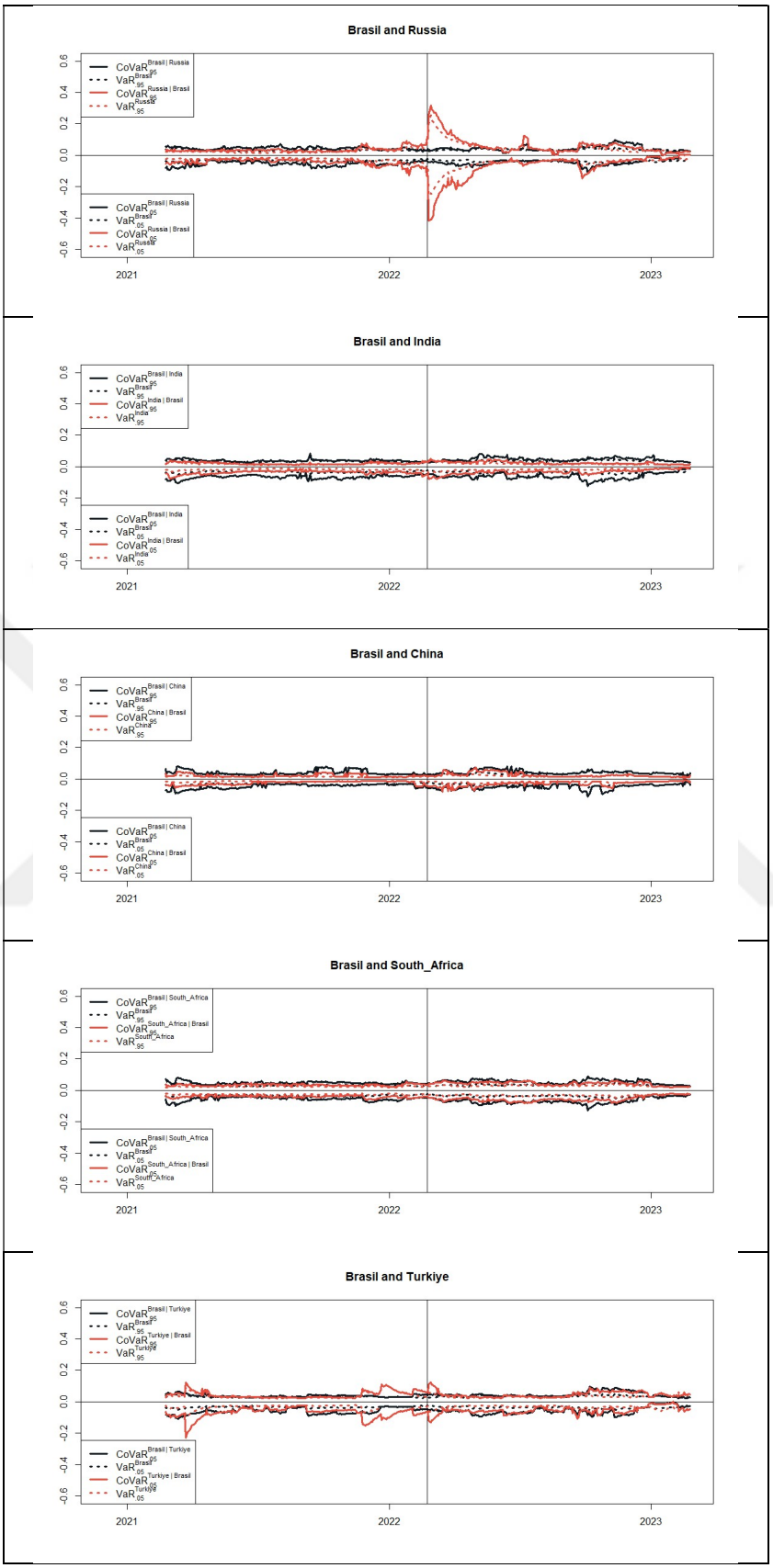


Figure 3.7 Graphic representations of downside and upside VaR and CoVaR estimates of BRICS-T countries (Russia-Ukraine War Period)

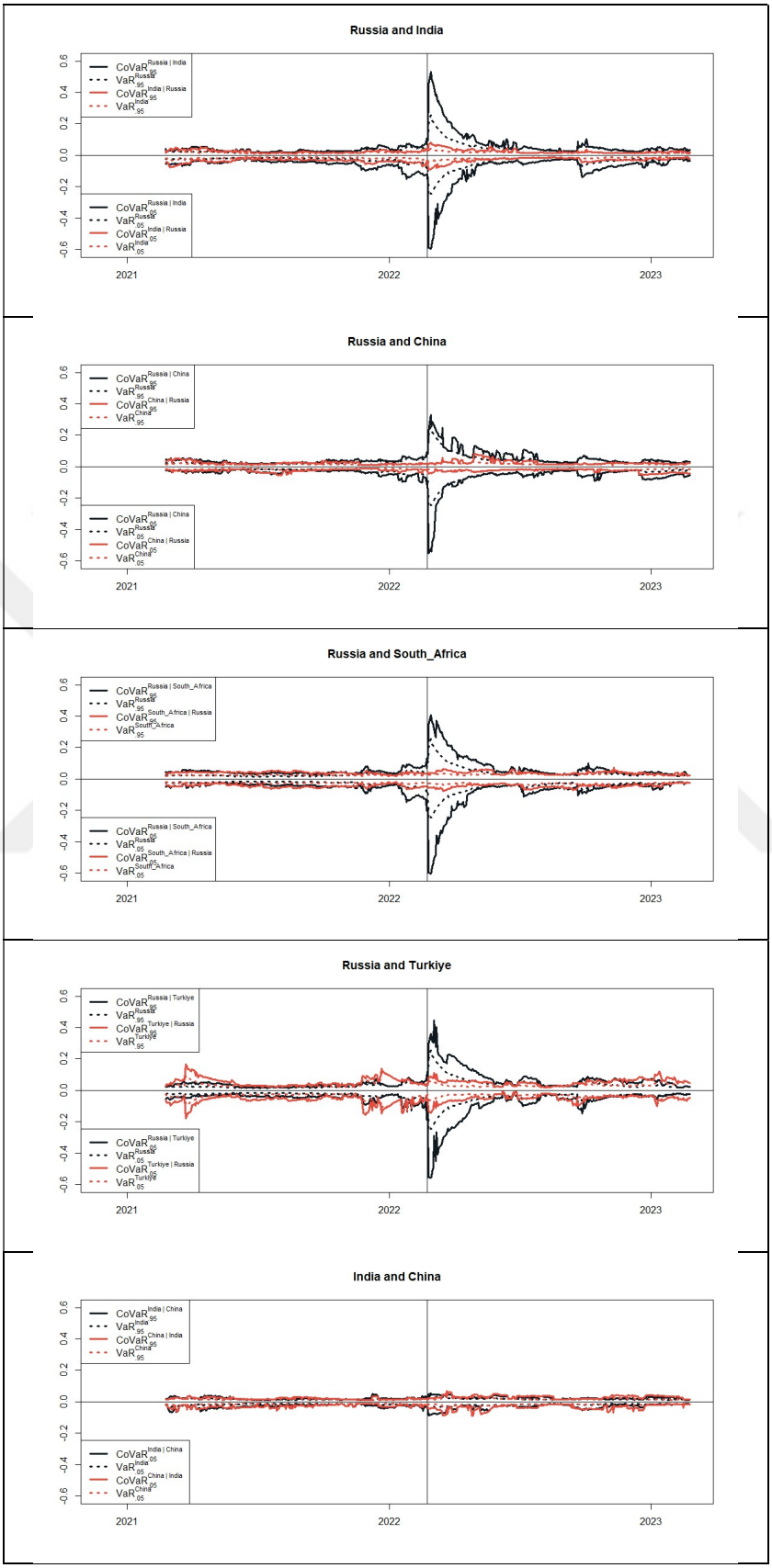


Figure 3.7 Graphic representations of downside and upside VaR and CoVaR estimates of BRICS-T countries (Russia-Ukraine War Period) (continued)

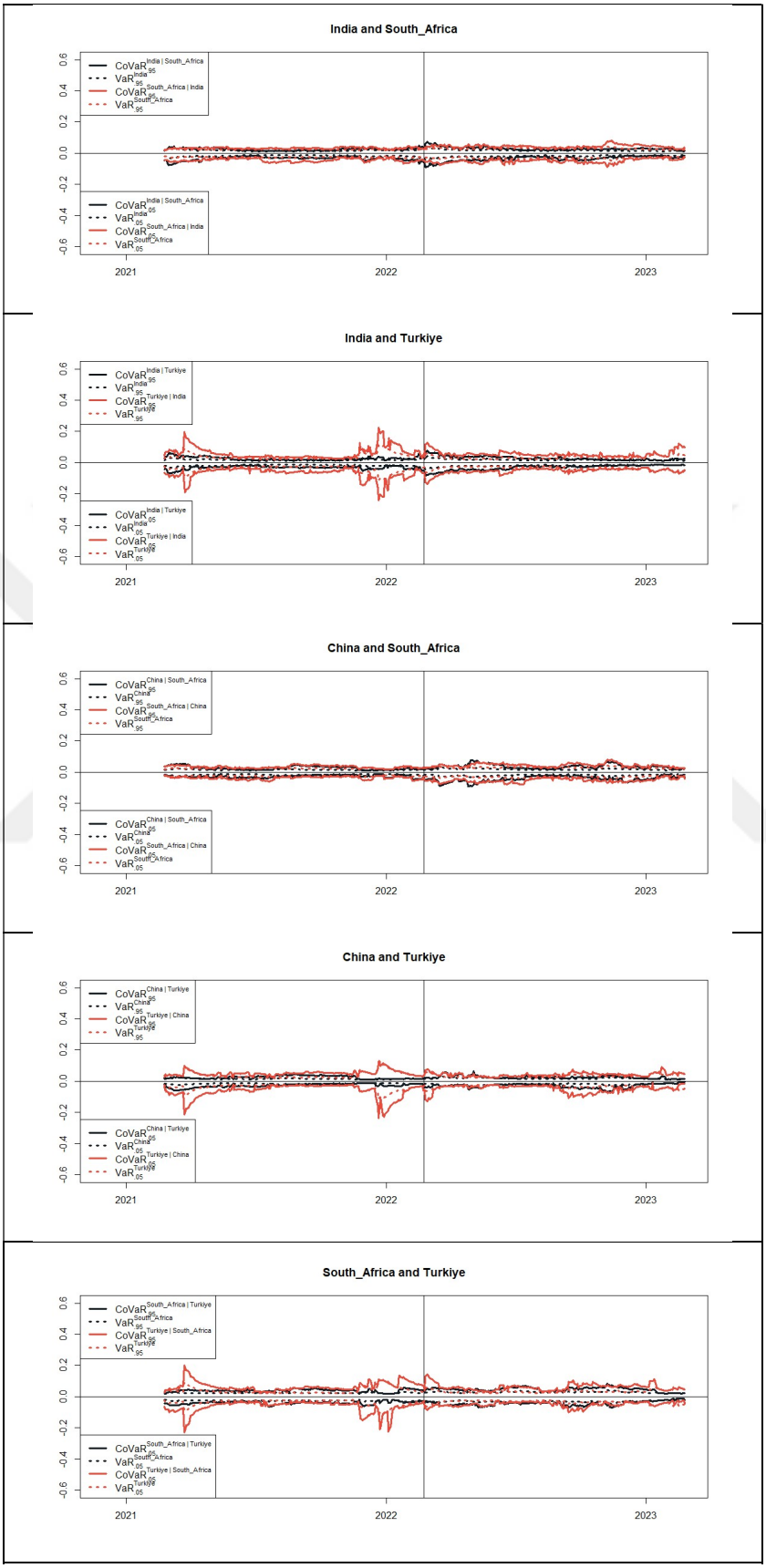


Figure 3.7 Graphic representations of downside and upside VaR and CoVaR estimates of BRICS-T countries (Russia-Ukraine War Period) (continued)

- **ΔCoVaR Results (Russia-Ukraine War Period)**

Table 3.25 presents the average downside and upside ΔCoVaR values for BRICS-T countries during the Russia-Ukraine war period. Graphical representations of these values are shown in Figure 3.8.

According to these results, the downside risk contribution values from all other BRICS-T countries to Russia decreased in the AC period compared to the period before the war. Conversely, for Türkiye, the downside risk contribution values from all other BRICS-T countries increased in the AC period compared to the period before the war.

When examining the upside risk contribution values, it was observed that the values from all other BRICS-T countries to Türkiye, as well as from Russia to Brazil and India, decreased in the AC period compared to the BC period. The upside risk contribution values from all other BRICS-T countries to Russia, which were in the range of 0.06-0.07 in the BC period, increased to 0.11-0.14 in the AC period.

Table 3.25 Averages of ΔCoVaR values (Russia-Ukraine War Period)

Spillovers		ΔCoVaR downside		ΔCoVaR upside	
from	**to**	**BC**	**AC**	**BC**	**AC**
Russia	Brazil	-0.016	-0.006	0.083	0.080
Brazil	Russia	-0.014	-0.017	0.066	0.118
India	Brazil	-0.026	-0.019	0.079	0.090
Brazil	India	-0.016	-0.011	0.042	0.046
China	Brazil	-0.011	-0.010	0.077	0.083
Brazil	China	-0.008	-0.009	0.038	0.047
South Africa	Brazil	-0.014	-0.024	0.088	0.099
Brazil	South Africa	-0.010	-0.019	0.064	0.080
Türkiye	Brazil	-0.022	-0.017	0.076	0.088
Brazil	Türkiye	-0.028	-0.018	0.090	0.083
India	Russia	-0.025	-0.029	0.068	0.138
Russia	India	-0.015	-0.008	0.046	0.046
China	Russia	-0.008	-0.013	0.063	0.122
Russia	China	-0.006	-0.006	0.041	0.048
South Africa	Russia	-0.019	-0.029	0.077	0.140
Russia	South Africa	-0.014	-0.010	0.070	0.074
Türkiye	Russia	-0.015	-0.030	0.066	0.140
Russia	Türkiye	-0.021	-0.014	0.101	0.091
China	India	-0.009	-0.010	0.042	0.048
India	China	-0.010	-0.013	0.039	0.055
South Africa	India	-0.013	-0.012	0.046	0.052
India	South Africa	-0.015	-0.015	0.063	0.081
Türkiye	India	-0.011	-0.009	0.047	0.050
India	Türkiye	-0.025	-0.015	0.108	0.094
South Africa	China	-0.008	-0.018	0.046	0.061
China	South Africa	-0.008	-0.016	0.063	0.082
Türkiye	China	-0.010	-0.008	0.043	0.047
China	Türkiye	-0.022	-0.011	0.096	0.080
Türkiye	South Africa	-0.011	-0.009	0.067	0.082
South Africa	Türkiye	-0.021	-0.011	0.112	0.100

BC: Before Russia-Ukraine War; AC: After Russia-Ukraine War; CoVaR: Conditional Value-at-Risk

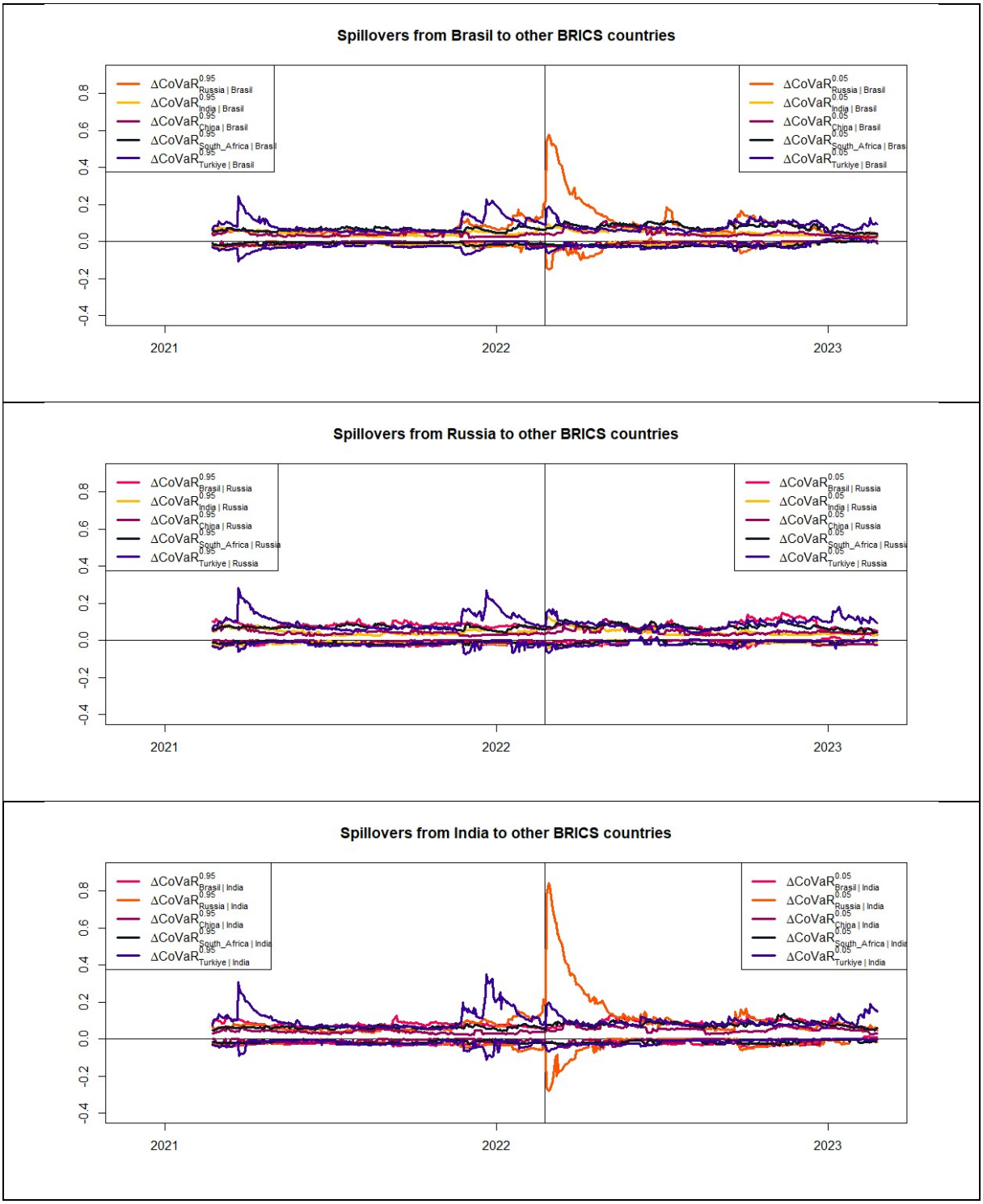


Figure 3.8 Graphical representations of the downside and upside ΔCoVaR estimates of BRICS countries (Russia-Ukraine War Period)

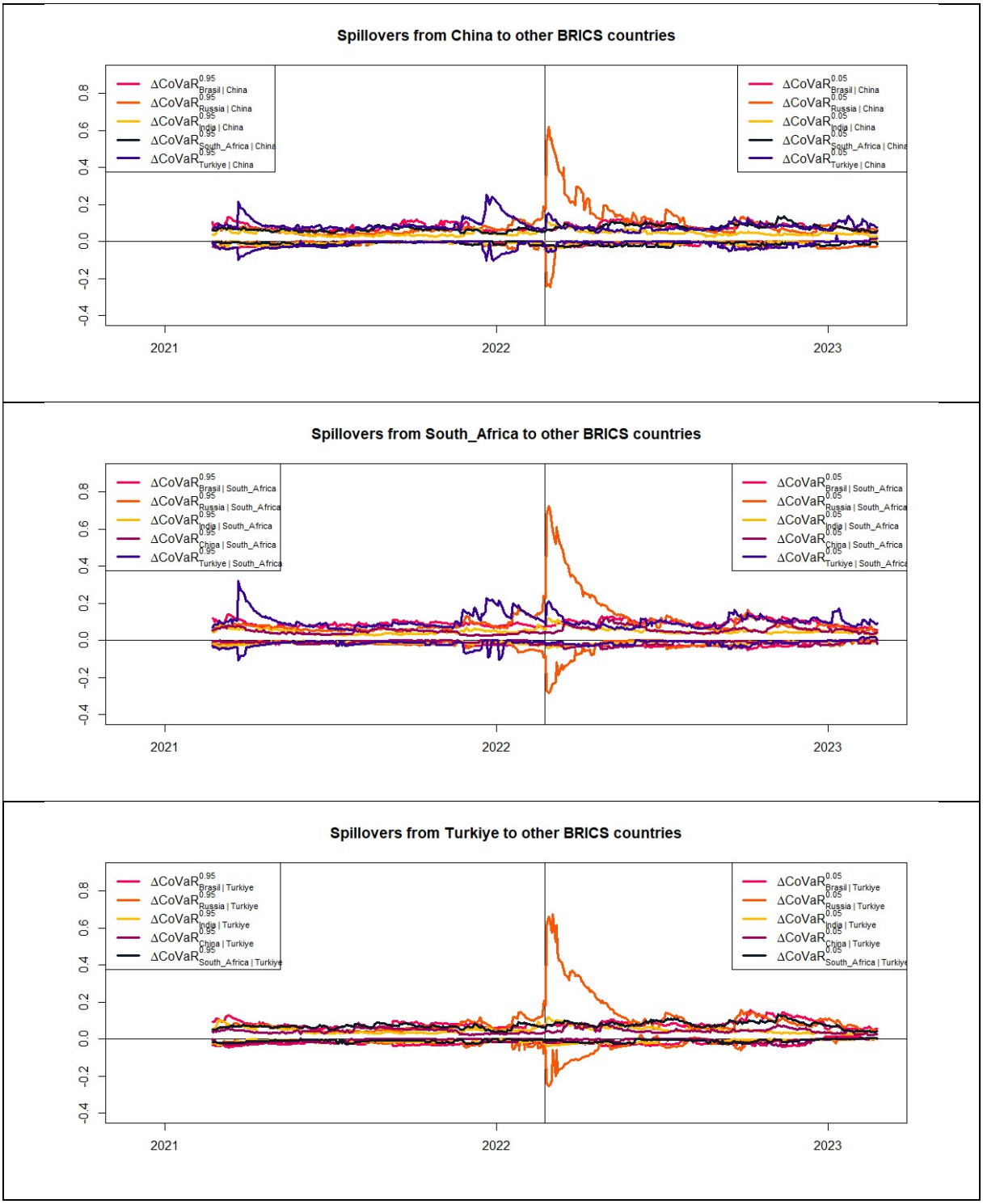


Figure 3.8 Graphical representations of the downside and upside ΔCoVaR estimates of BRICS countries (Russia-Ukraine War Period) (continued)

4

CONCLUSION

In recent years, many methods have been used to determine the dependency structures of two financial assets. One of the most commonly used methods is the copula method, which not only shows the degree of dependence between two assets but also presents the dependency structures in the presence of negative and positive financial shocks as lower and upper tail dependencies. Additionally, with the presence of dozens of copula families, the copula family that best matches the returns of the two financial assets is identified, adding richness to the comments on their dependency structures.

The dependencies between two assets are examined in two structures: time-varying and time-invariant. In time-invariant copulas, a single dependency value and copula family are determined for the entire period selected to identify the dependency structure between the two assets. However, the effect of time-varying asset pricing cannot be clearly seen in this analysis. In time-varying copulas, a window length is determined, and copula analysis is conducted for the relevant period. Then, the window is shifted by a time interval, and the analysis continues in this way. This approach reflects the time-varying nature of asset prices in the analysis. However, it is not only time that changes. As asset prices can change over time, the copula families representing the dependency structure between the two assets can also change over time. Most time-varying copula analyses allow the asset return values to change over time while keeping the copula family constant. However, more effective results can be obtained by allowing the copula families to be flexible. Therefore, in this study, a time-varying flexible copula (TVFC) approach, which allows for changes in both time and dependency structures, is proposed.

To examine whether the TVFC approach provides promising results compared to other copula methods, the major stock indices of the BRICS countries, representing emerging market economies, were included in the analysis. Türkiye, which came into the spotlight by joining the BRICS formation, has also been included in many studies in the literature under the name BRICS-T. Therefore, the performance of the TVFC approach compared to traditional copula approaches was evaluated based on the major stock indices of the BRICS-T countries. For this purpose, four different crisis periods were selected, including the crises of 2001, 2008,

and COVID-19, as well as the Ukraine-Russia war period. To examine the risk spillovers between the country stock markets, CoVaR copula and delta-CoVaR copula analyses were applied, and the risk spillovers and risk contributions of the country stock markets were analyzed.

Based on the TVFC results, significant dependency patterns and risk dynamics among BRICS-T countries' stock markets emerged during the 2001 crisis. China displayed the lowest dependency coefficients across the indices of these countries. Lower tail dependence for the Brazil-Russia pair decreased sharply from 0.20 before the crisis to 0.06 during the crisis and further to 0.03 afterward. In contrast, the Brazil-China pair saw an increase in lower tail dependence during the crisis compared to pre-crisis levels. South Africa and Türkiye experienced notable increases in lower tail dependence, specifically during the crisis period. Upper tail dependence coefficients for India showed variability, decreasing with South Africa while increasing with Türkiye during crisis periods. Regarding risk spillovers, Türkiye was notably the most exposed country to downside spillovers from other BRICS-T nations, a pattern consistent across various crisis periods. The Russia-China pair's VaR and CoVaR values highlighted a lack of significant downside risk spillovers between these two countries, contrasting with statistically identified spillovers for other BRICS-T countries. Upside risk contributions indicated Türkiye consistently faced the highest impact from other BRICS-T countries, while China consistently exhibited the lowest impact throughout the crisis periods.

During the 2008 crisis, distinct patterns of dependency and risk transmission among BRICS-T countries' stock markets emerged. China once again exhibited the lowest dependence coefficients, like the 2001 crisis, but with notable increases compared to the earlier period. This result matches the findings of Sportel and Verbus (2012). Türkiye showed significantly high lower tail dependence coefficients with Brazil, Russia, and South Africa during the crisis. Lower tail dependence coefficients generally decreased for most pairs compared to the pre-crisis period but rebounded post-crisis. Upper tail dependence coefficients were generally lower than lower tail dependence values, with marked increases observed for pairs like Brazil-South Africa and South Africa-Türkiye after the crisis. Kendall's Tau values indicated consistently high overall dependence for South Africa with other BRICS-T countries, exceeding 0.40 across all periods. In terms of risk spillovers, Türkiye was identified as the country most exposed to downside risk spillovers from other BRICS-T countries, particularly evident in the aftermath of the crisis. Conversely, China consistently experienced the least impact from risk spillovers throughout the crisis periods, with India least affected during the

post-crisis period. Brazil and Türkiye were identified as most affected by upside risk spillovers from other BRICS-T countries, especially noticeable during the recovery phase after the crisis. Overall, the 2008 crisis demonstrated heightened variability in risk contributions compared to the 2001 crisis, underscoring Türkiye's consistent vulnerability to external risk factors among the BRICS-T countries.

During the 2020 COVID-19 pandemic, BRICS-T countries' stock markets exhibited distinctive patterns of dependency and risk transmission. Except for the India-China pair, lower tail dependency values were notably higher in the AC period compared to the BC period, highlighting increased susceptibility to negative financial shocks across most pairs. This outcome is consistent with the conclusions drawn by Cheng et al. (2021). The South Africa-Türkiye pair particularly stood out with a significant rise in lower tail dependency from 0.10 before the pandemic to 0.39 during the crisis. Upper tail dependency values also showed a general increase in the AC period, particularly notable for pairs like India-South Africa and Russia-South Africa. Kendall's Tau values underscored heightened interdependence among BRICS-T country stock markets during the pandemic, with all coefficients in the AC period surpassing those in the BC period. In terms of risk spillovers, China reasserted its position as the least affected by risk transmissions from other BRICS-T countries. This result is parallel with the study by Cheng et al. (2021). Brazil and Russia, on the other hand, emerged as the most affected by risk spillovers during the AC period, marking a shift from Türkiye's usual vulnerability observed in earlier crises. Both downside and upside risk spillover values generally increased in the AC period compared to the BC period, indicating increased variability in risk interactions and highlighting the dynamic nature of risk contributions during the COVID-19 pandemic.

During the Russia-Ukraine war period, the dependency and risk dynamics among BRICS-T countries' stock markets exhibited notable shifts and patterns. Lower tail dependency coefficients for Russia decreased with most BRICS-T countries in the AC period compared to the BC period, except for Türkiye, which showed a similar decrease in its dependencies. Russia's upper tail dependency coefficients decreased with Brazil, China, and South Africa during the war period, while increasing with India and Türkiye compared to the pre-war period. Kendall's Tau values indicated decreased overall dependency between Russia and other BRICS-T countries in the AC period. In terms of risk spillovers, Türkiye was identified as the most affected by downside risk spillovers from other BRICS-T countries during the war, especially evident in the AC period. China consistently showed the least impact from

downside risk spillovers across both periods. Upside risk spillover values highlighted Türkiye as consistently the most affected by risk spillovers from other BRICS-T countries, while Russia experienced increased upside risk spillovers in the AC period compared to the BC period. ΔCoVaR results revealed a decrease in downside risk contributions from other BRICS-T countries to Russia in the AC period, contrasting with an increase for Türkiye. Upside risk contributions from other BRICS-T countries to Türkiye and from Russia to Brazil and India decreased in the AC period, whereas contributions to Russia increased, reflecting the changing risk dynamics during the Russia-Ukraine war period.

The implications of the study suggest that, unlike traditional copula methods, TVFC allows for the adaptation of copula families over time, providing a convenient depiction of evolving interdependencies among assets. Evaluating the TVFC approach across major stock indices of the BRICS-T countries during four crisis periods—2001, 2008, COVID-19, and the Russia-Ukraine war—revealed significant findings. Notably, China consistently exhibited the lowest dependency coefficients, while Türkiye often showed the highest vulnerability to downside risk spillovers. The TVFC method gave satisfactory outputs compared to the other copula approaches in model fit, highlighting its effectiveness in capturing complex market dynamics. Future research could extend the TVFC approach to broader sets of assets, explore its performance under diverse economic conditions, and refine methodologies for assessing systemic risks in global financial markets. These efforts promise to advance our understanding of risk interdependencies and contribute to more resilient financial systems globally.

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PUBLICATIONS FROM THE THESIS

Conference Papers

1. Karadag, T, Gölbaşı Şimşek, G. (2023, November 2-5). *Investigation of the dependence structures of BRICS countries' stock markets before and after COVID-19 pandemic*. 7th International Researchers, Statisticians, and Young Statisticians Congress, Istanbul, Türkiye, p. 69. https://dps.tuik.gov.tr/index.php/s/WFS1Lrh5hUTyuV8#pdfviewer

Papers

1. Karadag, T., & Golbasi Simsek, G. (2023). A time-varying copula approach to investigate the dependence structures of BRICS stock markets before and after COVID-19. *Emerging Markets Finance and Trade*, *59*(5), 1475-1486. Doi: 10.1080/1540496X.2022.2136942

Awards

1. TÜBİTAK 2211-A Domestic PhD Scholarship