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Article

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THE STABILITY OF ISLAMIC CRYPTOCURRENCIES AND COPULA-BASED DEPENDENCE WITH ALTERNATIVE CRYPTO AND FIAT CURRENCIES

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ABSTRACT

Purpose — This study aims to examine Islamic cryptocurrencies and their dependency on foreign exchange markets in vine copula architecture (CD-Vine) and provide a framework for detecting complex dependence structures, risk management implications, and hedging effectiveness.

Design/Methodology/Approach — This study used gold-backed cryptocurrencies and three fiat currencies. The vine copula approach was preferred because it applies several distributions and estimates complex dependencies. Hedging effectiveness was measured by constructing simulation-based portfolios optimised with DCC-*t*-Copula. Benford's law and realized variance were used to determine the stability of Islamic cryptocurrencies.

Findings — According to C-Vine and D-Vine copula models, paper money has a weak tail dependence with gold-backed cryptocurrencies. Only OneGram coin, whose volatility matched the risk of Bitcoin, showed zero irregularities in volume trading. The findings were robust to different estimations based on Minimum Spanning Tree and Dendrogram.

Originality/Value — This is the first study to examine Islamic cryptocurrencies' stability and the significance of hedging effectiveness on gold-backed cryptocurrencies under a copula-based approach.

Research Limitations — The study did not apply time-varying vine copula.

Practical Implications — The risk management perspective shows insignificant hedge effectiveness in the portfolio of fiat and gold-backed cryptocurrencies.

Keywords — Benford's law, Copula, Fiat currency, Gold-backed cryptocurrency, Hedging effectiveness

Article Classification — Research paper

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INTRODUCTION

According to a previous study, cryptocurrencies (also known as cryptos) and fiat money have a low dependence (Chemkha *et al.*, 2020). Further, Mnif and Jarboui (2021) who applied the PSY method found that Islamic cryptocurrencies were exempt from monetary policy shocks during the pandemic. Additionally, Jalan *et al.* (2021) investigated the volatilities of stablecoins and the dependence between stablecoins and Bitcoin. Stablecoins were originally created to alleviate some issues associated with cryptocurrencies such as excessive volatility and market manipulation. Theoretically, stablecoins backed by commodities or fiat currencies should be less volatile since their pricing is not determined by the market, in contrast to Bitcoin and other well-regarded cryptocurrencies. Interestingly, Jalan *et al.* (2021) established that the risk of gold-backed stablecoins matched the risk of Bitcoin during the pandemic. However, stablecoins were not sensitive to downturns from Bitcoin.

Motivated by the intriguing results from the previous studies, this research aims to examine the nexus between Islamic cryptocurrencies and paper money to determine the evolution of the relationship over time. It hypothesises that gold-backed cryptocurrencies and fiat currencies have a low dependence on each other. This is due to the lack of substantial dependence between major virtual and fiat currencies (Chemkha *et al.*, 2020). Additionally, Islamic cryptocurrencies showed no bubbles or explosive stages during the early stage of the pandemic (Mnif & Jarboui, 2021). Thus, this study has three objectives. These include:

1. Analysing the degree of dependence between the two markets, namely gold-backed crypto and fiat currencies, in the tails using vine copula architecture (CD-Vine).
2. Measuring the significance of hedging effectiveness between the two markets under CD-Vine copulas.
3. Measuring the stability of Islamic cryptocurrencies using Benford's law and determining their volatility by applying realized variance estimation.

This study contributes to the literature because it is closely related to the concern raised by Hasan (2018) about excessive use of the parametric approach in a field where ethical standards are immeasurable, such as Islamic finance. According to previous studies, the distribution of returns from cryptocurrencies backed by gold and gold-backed stablecoins was not a normal distribution (Jalan *et al.*, 2021; Nugroho, 2021). Therefore, this study used the copula-based approach with Kendall's τ to examine asymmetric and symmetric tail dependence (BenSaïda *et al.*, 2018).

This paper finds that the best-fitting model is the C-Vine copula. The model suggested that fiat money has extremely weak tail dependence with gold-backed cryptocurrencies. Therefore, hedging by means of a bivariate portfolio of gold-based cryptocurrencies and fiat currency is not an effective hedging strategy. This condition is attributed to the stability of Islamic cryptocurrency. This is the main contribution of this study to the literature and forms the basis for future works on Islamic finance.

The sections that ensue comprise the literature review and discussions of the copula modeling of Islamic cryptocurrencies and fiat money, the hedging effectiveness of the bivariate portfolio, the risk management implications, the stability of Islamic cryptocurrency, the robustness check, and the conclusion, respectively.

RELATED LITERATURE

Bitcoin is a virtual currency developed in 2009 to facilitate the development of a modern peer-to-peer network on the Internet. Specifically, online payments are settled using Bitcoin without going through a financial institution (Nakamoto, 2008). Since its inception, there has been debate as to whether it reflects transient asset bubbles or represents a structural change to currency use. Despite many contentious factors and price fluctuations raising questions, this virtual currency continues to escalate (Chemkha *et al.*, 2020). Although cryptocurrencies, specifically Bitcoin, were created to resolve issues with fiat money, such as limitless supply, their success has been partial (Ajouz *et al.*, 2020). In general, cryptocurrencies are targets for speculators, deceivers, and illegal activity, leading to extreme market volatility (Higbee, 2018).

According to Abozaid (2020), Bitcoin is the most notable cryptocurrency. However, it is not asset-backed, leading to a high level of uncertainty. Ajouz *et al.* (2020) reported that most people are open to use precious metal-backed cryptocurrencies in real world business transactions.

Moreover, Bakar *et al.* (2017) disqualified cryptocurrency from being classified as money for different reasons, including: there is no intrinsic value; an anonymous holder is involved; and there is instability. Meera (2018) argued that cryptocurrency should be backed by a real asset to comply with Islamic standards. Furthermore, Siswantoro *et al.* (2020) argued that cryptocurrency is regarded as a medium of exchange of digital currency rather than money for the following reasons: high volatility (higher than S&P 500), and not all cryptocurrencies have enough supply to cover transactions (Bitcoin supply is only 21 million units). Siswantoro *et al.* (2020) further provide a more detailed discussion on cryptocurrency as money within an Islamic framework.

OneGram was created in May 2017 as a groundbreaking blockchain application to meet the religious needs of some investors (Maierbrugger, 2017). Each OneGram Coin (OGC) represents one gram of gold, providing a stable base value. Furthermore, the Dubai-based OGC is gold-backed and vaulted (Chowdhury & Razak, 2019). Its board includes Islamic finance scholars who ensure the coin complies with Islamic standards (Aitken, 2017). Since gold coins served as money historically, and gold coins are mentioned by name in the Qurʾān, there is no juristic dispute that gold could legitimately serve as backing for a cryptocurrency. Al Maali Consulting approved OneGram as the first cryptocurrency in compliance with Islamic principles. Similarly, the Bahrain-based Shariyah Review Bureau approved X8X, backed by eight fiat currencies and gold, as an Islamic cryptocurrency.

Any recently created Islamic cryptocurrency generates a new market, and any trading or financial framework creation should be Sharīʿah-compliant (Chowdhury & Razak, 2019). Islamic fintech facilitates the production of Sharīʿah-compliant products sold globally. The market share of Islamic banks is likely to increase with the introduction of a fintech global network system in which clients can buy and sell fiat currencies on the spot (Selim, 2021). According to Hassan *et al.* (2020), the COVID-19 pandemic disproportionately affected the global financial sector. However, Islamic fintech can reshape Islamic finance into a viable and crisis-proof global industry.

Geopolitical risk has less impact on Islamic cryptocurrencies (Aloui *et al.*, 2021). Multivariate GARCH showed that an increase in geopolitical risk reduces the conditional link between Islamic cryptocurrencies and gold. The Islamic trader's beliefs forbid intentional or accidental speculation based on geopolitical risk and gold price expectations. The COVID-19 pandemic has insignificantly affected the volatilities of gold-backed cryptocurrency (Wasiuzzaman & Rahman, 2021). This indicates that gold-backed cryptocurrency has the features of gold and conventional crypto. Also, gold-backed cryptocurrency had a greater—though insignificant—mean return during the pandemic.

A recent study examined the Islamic cryptocurrency markets' resilience to COVID-19 shocks and the Federal Reserve's policies (Mnif & Jarboui, 2021). Applying a novel approach (PSY tests), the study showed Islamic cryptocurrency did not react to the Federal Open Market Committee events. Moreover, there were no bubbles in Islamic cryptocurrencies. This means that the investors in Islamic cryptocurrency are rational. Nugroho (2021) examined the volatility connectedness between gold and gold-backed cryptocurrencies using the Diebold-Yilmaz approach. Applying corrected Dynamic Conditional Correlation (DCC), the connectedness was positive. During COVID-19, gold was the risk receiver from the gold-backed cryptocurrencies. This shows that gold-backed cryptocurrencies are riskier than their underlying assets during market downturns.

According to Jalan *et al.* (2021), stablecoins backed by gold have a higher average realized variance than gold. This means that stablecoins are not good diversifiers. Applying Benford's law, two gold-backed stablecoins showed irregularities in volume. Moreover, the spillover approach concluded that gold was the risk transmitter for stablecoins backed by gold. These findings question the role of Islamic cryptocurrencies and show the necessity of a design rethink in case the anticipated goals of reduced volatility need to be accomplished. The literature examining the dependency between Islamic cryptocurrencies and foreign exchange markets in the vine copula architecture is scarce. Therefore, this study determines the risk management implications and hedging effectiveness under 'CD-Vine' copulas.

COPULA MODELING OF ISLAMIC CRYPTOCURRENCIES AND FIAT MONEY

The first step in the copula estimation in determining marginal distribution uses GJR-GARCH (Glosten *et al.*, 1993). The model is enhanced to the standard GARCH to detect the asymmetry effect. The second step involves measuring tail dependence using vine copula. This is a suitable approach because it uses various distributions and estimates complicated dependencies. The types of multivariate copula are limited, while the list of bivariate copulas is diverse. To address this dependency issue, Bedford and Cooke (2002) proposed a pair of copula constructions (PCCs) where the PCC is based on a multivariate probability density and a set of bivariate copulas. Furthermore, the PCC eliminates spurious dependencies in a regular and uncertain environment.

Source of Data

There are two cryptocurrencies backed by gold: Islamic and conventional. This study used two Islamic cryptocurrencies, namely, OneGram Coin (OGC) and X8X Token (X8X). Additionally, it applied one of the traditional gold-backed cryptocurrencies, DGX Gold Token (DGX), as the comparison because it had the biggest market capitalisation. The study was conducted from 15

February 2019 to 30 March 2021 and was confined by the availability of the aligned data series. The OGC prices were collected from worldcoinindex.com, while the cryptocurrencies' data were from coinmarketcap.com.

Following a previous study (Chemkha *et al.*, 2020), this study applied three fiat currencies, notably the Euro (EUR), Japanese yen (YEN) and British pound (GBP). It is noted that YEN, CHF (Swiss Franc), EUR and GBP have acted as safe haven currencies during times of market uncertainty (Ranaldo & Söderlind, 2010). However, CHF was the most volatile currency compared to EUR, GBP and YEN (Urquhart & Zhang, 2019), so only the latter fiat currencies were considered in this study. Similarly, Fatum and Yamamoto (2016) found that YEN was the safest currency during an economic crisis.

The prices of fiat currencies were sourced from investing.com and they were quoted against the U.S dollar. Moreover, this study used logarithmic returns. The weekend returns of the gold-backed cryptocurrencies data were omitted to align with the fiat currencies.

Marginal Distribution Estimation

This study applied GJR-GARCH in constructing marginal distributions (Glosten *et al.*, 1993). This model takes the following form:

$$r_t = \mu + \sum_{i=1}^{m} ar_i r_{t-i} + \sum_{j=1}^{n} ma_j \varepsilon_{t-i} + \varepsilon_t \quad (1)$$

$$\varepsilon_t = z_t \bullet \sigma_t \quad (2)$$

$$\sigma_t^2 = \omega + \alpha \varepsilon_{t-1}^2 + \chi 1_{\{\varepsilon_{t-1}<0\}} \varepsilon_{t-1}^2 + \beta \sigma_{t-1}^2 \quad (3)$$

where the indicator of z is the standardised residuals and χ is the size effect. The GJR-GARCH can be estimated using the R package 'rmgarch' of Ghalanos (2019). The standardised residuals (Z_t) were transformed into uniform distributed residuals, U_t before using the vine copula estimation.

Vine Copula Methodology

The Sklar theorem constitutes copulas' essential function to explain statistics dependency (Sklar, 1959). For instance, S_1 and S_2 are random variables. The joint distribution is the marginal product. This study used Kendall's τ to measure the main dependency. The unique copula is:

$$C\left(F_1(s_1), F_2(s_2)\right) = F_1(s_1) F_2(s_2) \quad (4)$$

Vines graphically represent pair copula constructions (PCCs). To illustrate the PCCs, a visual model called a vine was created. Each pair of the first C-Vine tree's root node uses bivariate copulas, as follows:

$$f(s) = \prod_{k=1}^{d} f_k(s)_k \; x \; \prod_{i=1}^{d-1} \prod_{j=1}^{d-i} c_{a,a+b|1:(a-1)} (F(s_a|s_1, \dots, s_{a-1}), F(s_{a+b}|s_1, \dots, s_{a-1}) | \theta_{a,a+b|1:(a-1)}) \quad (5)$$

where $c_{a,a+b|1:(a-1)}$ is the bivariate copula, and k = 1,…,d, is the marginal densities. Choosing an order of variables yields the D-Vine. In the D-Vine, a d-dimensional density is:

$$ff(s) = \prod_{k=1}^{d} f_k(s)_k \ x \ \prod_{i=1}^{d-1} \prod_{j=1}^{d-i} c_{b,b+a|(b+1):(b+a-1)}(F(s_b|s_{b+1},\dots,s_{b+a-1}), F(s_{b+a}|s_{b+1},\dots,s_{b+a-1})|\theta_{b,b+a|(b+1):(b+a-1)}) \quad (6)$$

A detailed vine copula estimation process using 'CD-Vine' package in R programming language can be found at Brechmann and Schepsmeier (2013), which also looks at the joint distribution's tails or extreme values. The lower and upper tail dependence is defined as:

$$\lambda_{ab}^{lower} = \lim_{q\downarrow 0} P(X_a < F_a^{-1}(q)|X_b < F_b^{-1}(q)) \quad (7)$$

$$\lambda_{ab}^{upper} = \lim_{q\uparrow 1} P(X_a > F_a^{-1}(q)|X_b > F_b^{-1}(q)) \quad (8)$$

A copula has symmetric tail dependence if $\lambda_{ab}^{lower} = \lambda_{ab}^{upper}$ for all *a,b*. This analysis used the maximum likelihood (MLE) approach to get the CD-Vine copula parameters. The procedure (MLE) is determined in two steps, including translating the margins $\{s_1,\dots,s_d\}_{t=1}^{T}$ into uniform formats $\{u_1,\dots,u_d\}_{t=1}^{T}$, and measuring the parameters of copula dependence structure. Moreover, this study also used 'VineCopula' package (Nagler *et al.*, 2021).

Stylised Facts

Table 1 reveals the basic statistics from 15 February 2019 to 30 March 2021. The descriptive statistics show an intrinsic disparity between the two currency groups. The returns (mean) of the major foreign currencies were low compared to those of cryptocurrencies backed by gold. However, higher volatility was observed relative to the fiat currencies in Islamic cryptocurrency. The positive skewness on Islamic cryptocurrencies suggested a strong possibility for high returns. In contrast, the skewness values were negative for fiat currencies, indicating that the returns to the left of (less than) the mean are fewer. However, they are further away from it than the returns to the right of (higher than) the mean.

All return values incorporated a leptokurtic distribution with the Shapiro-Wilk (SW) test result. The Phillips-Perron (PP) unit root evaluation and the Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) stationary test showed that all returns were stationary. In comparison, the expected shortfall (ES) test results showed that gold-backed cryptocurrencies were risky compared to foreign currencies. The cryptocurrencies backed by gold had a notably superior risk-adjusted performance, whereas the fiat currencies had better minimum drawdown. **Figure 1** (**Panel A**) reveals that the correlation among the paper money was higher than the cryptocurrencies.

Vine Copula Results and Interpretation

The standardised residuals Z_t were transformed into uniform distributed residuals U_t, which was used as the input for copula estimations. **Figure 1** (**Panel B**) shows that the transformation did not change the correlation structure between each variable. Moreover, AR (1)-GJR-GARCH (1,1) was used to get the standardised residuals.

Table 2 indicates diagnostic tests of GARCH (1,1). According to **Table 2**, the GARCH parameters were fit. For instance, the autocorrelation (Ljung-Box Q) and heteroscedasticity issues (ARCH test) were addressed.

Table 1: Stylised Facts

	EUR	YEN	GBP	OGC	X8X	DGX
Expected Shortfall (ES)	-0.008	-0.010	-0.012	-0.486	-0.298	-0.075
Sharpe	0.034	0.011	0.022	0.031	0.064	-0.028
Sortino	0.049	0.015	0.031	0.049	0.111	0.043
Omega	1.100	1.040	1.060	1.190	1.250	1.100
Min Drawdown	-0.066	-0.083	-0.142	-1.155	-0.870	-0.403
Mean	0.010	0.010	0.010	0.760	0.970	0.110
Standard Deviation (STDEV)	0.004	0.005	0.006	0.240	0.149	0.037
Skewness	-0.248	-0.814	-0.269	0.801	1.704	0.975
Kurtosis	3.518	12.074	4.346	21.169	15.756	12.816
Shapiro-Wilk (SW)	0.970**	0.849**	0.953**	0.494**	0.802**	0.815**
Kwiatkowski-Phillips-Schmidt-Shin (KPSS) stationarity test	0.052	0.052	0.038	0.037	0.041	0.033
Phillips-Perron (PP) unit root test	-20.877**	-27.858**	-19.889**	-29.209**	-26.312**	-37.370**
Ljung-Box Q lag 10	37.965**	37.481**	42.130**	67.877**	16.218*	68.181**
Ljung-Box Q lag 15	38.958**	48.934**	45.069**	108.890**	24.493*	71.176**

Note: **, * show significance at 5 per cent and 10 per cent, respectively.
Source: Author's own

Table 2: Diagnostic Tests

	Estimate	t–value
Ω	0.003	2.704**
α	0.125	4.737***
β	0.882	38.018***
Skew	0.927	35.874***
Shape	4.205	10.165***
Information Criterion:		
AIC	1.004	
BIC	1.018	
Log – likelihood	-985	
Standardised Residuals:		
	Stat	**p–value**
Ljung-Box Q lag 10	9.979	0.458
Ljung-Box Q lag 15	15.507	0.415
Ljung-Box Q lag 10 – squared residuals	11.391	0.327
Ljung-Box Q lag 15 – squared residuals	17.706	0.275
ARCH test	13.413	0.338

Note: ***, ** indicate significance at 1 per cent and 5 per cent, respectively.
Source: Author's own

Further, the tree's variables are ranked first in estimating the vine copula. The C-Vine's main node maximises absolute pairwise Kendall's τ (Czado *et al.*, 2012). **Table 3** presents the pairwise Kendall's τ of uniform distributed residuals. The sum of Kendall's τ is sorted from highest to lowest in a C-Vine estimation to find the order. The order inferred in the D-Vine decomposition is to rank the pairwise from highest to lowest.

Table 3 shows that Euro was the first root variable to significantly impact other markets, while the gold-based cryptocurrencies had no dominant position in the markets. Consequently, the order for the C-Vine model was EUR, YEN, GBP, DGX, OGC, and X8X. The first tree of the D-Vine is created by arranging the pairwise τ from highest to lowest. Therefore, the order of the D-Vine estimation is GBP, EUR, YEN, DGX, OGC, and X8X.

Estimating the vine copula is meant to obtain the suitable bivariate copula family. The Gaussian and Frank copulas are appropriate when estimating the dependence in the center of the variables' joint distributions. The Clayton and Gumbel bivariate copulas can asymmetrically model the dependence in the tails while student-t copula is intended to symmetrically model the tail dependence. Detailed information on copula families can be found in Hernandez *et al.* (2019). The copulas selected in this study include Frank (F), Independent (I), and Gumbel (G). **Figures 2** and **3** show the architectures of the CD-Vine in the first and second trees. The results show that the degree of dependency was non-negative and relatively larger for pairs in the same group of currencies. Furthermore, the first tree of the D-Vine reveals that Frank copula and Clayton were the selected copulas among gold-based cryptocurrencies. This implies that YEN and DGX had a bigger dependence in the lower tail while the other pairs had no tail dependence.

In the first tree of C-Vine, Kendall's τ indicates a weak connectedness between EUR and OGC while EUR/X8X showed no dependence relationship (tail independence). There was also a tail symmetry between EUR and Yen. **Table 4** shows the full estimation of the copula models.

The Akaike Information Criterion (AIC) and Log-Likelihood in **Table 5** indicate that the C-Vine design was more viable in this study than D-Vine. The Clarke test was used to decide which vines fit the given data (Clarke, 2007). **Table 5** also shows that the estimation of C-Vine and D-Vine were not statistically similar. CD-Vine copula parameters indicate that the degree of dependency was non-negative and relatively higher for pairs in the same group of currencies. The best-fitting model in this study (C-Vine) shows that fiat money has a weak tail dependence with gold-based cryptocurrencies. These findings are in line with Ji *et al.* (2018), which applied an acyclic graph and found the characteristics of cryptocurrency were different from the rest of the markets. The C-Vine shows that Kendall's τ in the EUR-YEN and YEN-GBP were rather low. This is because the Bank of Japan's monetary policy coordination with the other G7 central banks is low (Dimitriou *et al.*, 2017). The Brexit vote presents a warning to the British pound's economic prospects (Dhingra *et al.*, 2016). Also, a previous study showed that X8X was immune to monetary policies during the COVID-19 outbreak (Mnif & Jarboui, 2021). Hence, the results of this study support the previous findings that Islamic assets are usury-free and immune to interest rate changes.

Table 3: Pairwise Kendall's τ

	EUR	YEN	GBP	OGC	X8X	DGX
EUR	1.000	0.255	0.362	0.026	0.004	0.116
YEN	0.255	1.000	0.205	0.069	0.048	0.133
GBP	0.362	0.205	1.000	0.009	0.022	0.066
OGC	0.026	0.069	0.009	1.000	0.125	0.132
X8X	0.004	0.048	0.022	0.125	1.000	0.095
DGX	0.116	0.133	0.066	0.132	0.095	1.000
SUM	1.764	1.710	1.664	1.362	1.294	1.541

Source: Author's own

Table 4: Full Estimation of CD-Vine

Trees	Pairs	Copulas	Parameters		Kendall's τ	Tail	
			1	2		Upper	Lower
Panel A: C-Vine							
1	EUR,YEN	t	0.390	10.696	0.260	0.043	0.043
	EUR,GBP	F	3.683	0.000	0.360	0.000	0.000
	EUR,DGX	F	1.075	0.000	0.120	0.000	0.000
	EUR,OGC	SC	0.057	0.000	0.030	0.001	0.000
	EUR,X8X	I	0.000	0.000	0.000	0.000	0.000
2	YEN|GBP,EUR	G	1.108	0.000	0.100	0.131	0.000
	YEN|DGX,EUR	N	0.167	0.000	0.110	0.000	0.000
	YEN|OGC,EUR	N	0.122	0.000	0.080	0.000	0.000
	YEN|X8X,EUR	F	0.570	0.000	0.060	0.000	0.000
3	GBP,DGX|EUR,YEN	C	0.000	0.000	0.000	0.000	0.000
	GBP,OGC|EUR,YEN	I	0.000	0.000	0.000	0.000	0.000
	GBP,X8X|EUR,YEN	SG	1.019	0.000	0.020	0.000	0.026
4	DGX,X8X|EUR,YEN,GBP	SG	1.120	0.000	0.110	0.000	0.143
	OGC,X8X|EUR,YEN,GBP	F	0.741	0.000	0.080	0.000	0.000
5	DGX,OGC|EUR,YEN,GBP,X8X	SG	1.094	0.000	0.090	0.000	0.116
Panel B: D-Vine							
1	GBP,EUR	F	3.643	0.000	0.360	0.000	0.000
	EUR,YEN	F	2.428	0.000	0.250	0.000	0.000
	YEN,DGX	C	0.256	0.000	0.110	0.000	0.066
	DGX,OGC	I	0.000	0.000	0.000	0.000	0.000
	OGC,X8X	F	1.121	0.000	0.120	0.000	0.000
2	GBP,YEN|EUR	SC	0.201	0.000	0.090	0.031	0.000
	EUR,DGX|YEN	F	0.651	0.000	0.070	0.000	0.000
	YEN,OGC|DGX	SC	0.069	0.000	0.030	0.001	0.000
	DGX,X8X|OGC	I	0.000	0.000	0.000	0.000	0.000
3	GBP,DGX|EUR,YEN	N	-0.002	0.000	0.000	0.000	0.000
	EUR,OGC|YEN,DGX	N	-0.022	0.000	-0.010	0.000	0.000
	YEN,X8X|DGX,OGC	F	0.250	0.000	0.030	0.000	0.000
4	GBP,OGC|EUR,YEN,DGX	F	-0.087	0.000	-0.010	0.000	0.000
	EUR, X8X|YEN,DGX,OGC	F	-0.292	0.000	-0.030	0.000	0.000
5	GBP,X8X|EUR,YEN,DGX,OGC	F	0.261	0.000	0.030	0.000	0.000

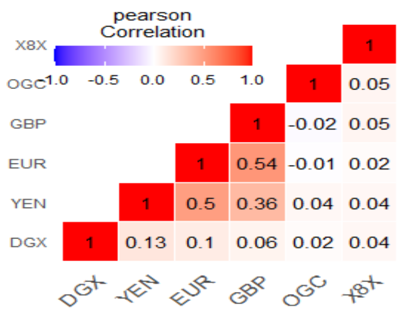
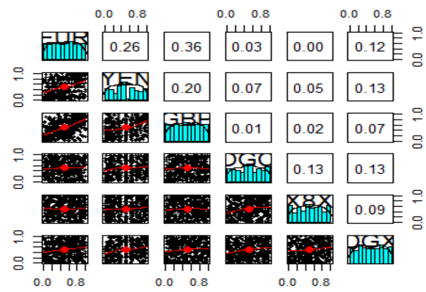
Note: The copulas employed are Frank (F), Student-t (t), Independence (I), Survival Gumbel (SG), Survival Clayton (SC), Clayton (C), and Gaussian (N).
Source: Author's own

Table 5: Information Criteria and Clarke Test

Information Criteria		C-Vine	D-Vine
Log likelihood		183.64	173.23
AIC		-335.28	-330.46
	Statistic	**Schwarz**	**Akaike**
Clarke Test	331	325	325
p–value	(0.000)	(0.000)	(0.000)

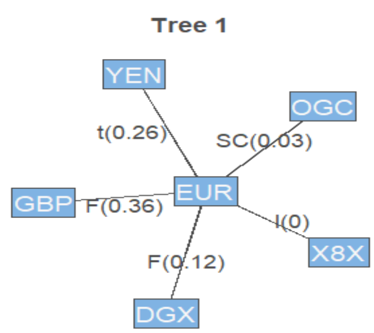
Source: Author's own

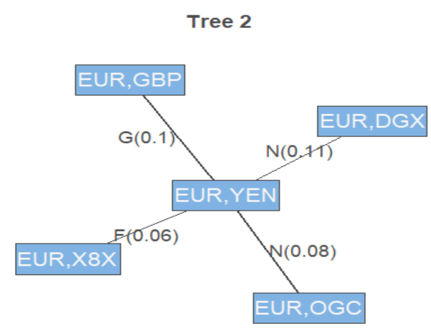
Figure 1: Correlation Matrix and Uniform Residuals

Panel A: Correlation Matrix	Panel B: Uniform Residuals Correlation Matrix
	

Note: Panel A shows correlation heatmap while panel B reveals the results of the transformation of the standardised residuals into uniform distributed residuals which are used as the input of copula estimations.
Source: Author's own

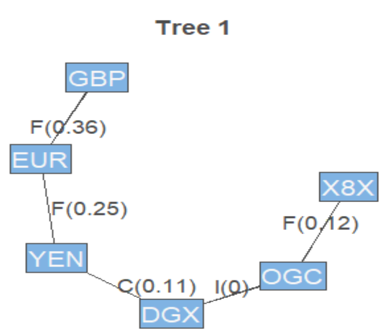
Figure 2: Tree 1 and 2 of C-Vine

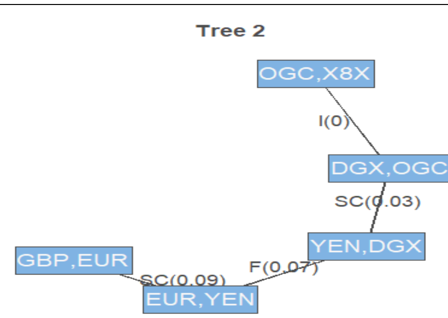




Note: The copulas employed are Frank (F), Student-t (t), Independence (I), Gumbel (G), Survival Clayton (SC), Clayton (C), and Gaussian (N). The numbers in parentheses are Kendall's τ.
Source: Author's own

Figure 3: Tree 1 and 2 of D-Vine





Note: The copulas employed are Frank (F), Survival Gumbel (SG), Gumbel (G), Independence (I), and Gaussian (N). The numbers in parentheses are Kendall's τ.
Source: Author's own

Hedging Effectiveness of Bivariate Portfolio

As an implication of the degree of dependence, this study measured the hedge effectiveness of Islamic cryptocurrencies and paper money using DCC-*t*-Copula, based on a research by Antonakakis *et al.* (2020). The covariances from the standard DCC are:

$$H_t = \sqrt{D_t} X_t \sqrt{D_t} \tag{9}$$

$$\rho_{ab,t} = \frac{q_{ab,t}}{\sqrt{q_{aa,t} q_{bb,t}}} \tag{10}$$

where $X_t = \left[\rho_{ab,t}\right]$ and $q_{ab,t}$ is obtained using GARCH (1,1) as follows:

$$Q_t = (1 - \phi_1 - \phi_2)\underline{Q} + \phi_1 z_{t-1} z'_{t-1} + \phi_2(Q_{t-1}) \tag{11}$$

Where $\underline{Q}$ is the covariance matrix of z_t and both ϕ_1 and ϕ_2 are non negative. The DCC-*t*-Copula is (Patton, 2006):

$$C_t\left(\mu_{1,t,\ldots,}\mu_{N,t}; X_t\right) = T_y(D_1^{-1}\left(z_{1,t}\right), \ldots, D_N^{-1}(z_{N,t})) \tag{12}$$

where T_y is a student-t with y degrees of freedom, under the optimal weights approach, the conditional variances–covariance were used to obtain the bivariate portfolio weights (Kroner & Ng, 1998).

Table 6 presents the bivariate portfolios optimised by the DCC-*t*-Copula. It shows the weights ($\omega_{ab,t}$) and hedge effectiveness under CD-Vine estimation. The median of EUR/YEN can be explained as a portfolio that cost USD1 where USD0.65 was invested in EUR and USD0.35 in YEN. None of the gold-backed cryptocurrencies could effectively hedge the risk of fiat currencies. The crypto technology can alter traditional structures of fiat currencies and may lead to a low dependence between the two assets. As a result, investors may benefit from diversification (Bouri *et al.*, 2017; Chemkha *et al.*, 2020). However, this study showed that the hedging effectiveness of Islamic cryptocurrencies against the risk of fiat currencies was insignificant.

Table 6: Bivariate Portfolios with Optimal Weight Approach

C-Vine			D-Vine		
$\omega_{ab,t}$	**Median**	**Hedge Effectiveness**	$\omega_{ab,t}$	**Median**	**Hedge Effectiveness**
EUR/YEN	0.650	0.180**	YEN/EUR	0.630	0.220**
EUR/GBP	0.870	0.030**	YEN/GBP	0.860	0.040**
EUR/DGX	1.000	0.000**	YEN/DGX	1.000	0.000**
EUR/OGC	1.000	0.000**	YEN/OGC	1.000	0.000**
EUR/X8X	1.000	0.000**	YEN/X8X	0.990	0.010**
YEN/GBP	0.670	0.190**	EUR/GBP	0.660	0.220**
YEN/DGX	1.000	0.000**	EUR/DGX	1.000	0.000**
YEN/OGC	1.000	0.000**	EUR/OGC	1.000	0.000**
YEN/X8X	1.000	0.000**	EUR/X8X	0.990	0.010**
GBP/DGX	1.000	0.000**	GBP/DGX	1.000	0.000**
GBP/OGC	1.000	0.000**	GBP/OGC	1.000	0.000**
GBP/X8X	0.990	0.000**	GBP/X8X	0.980	0.020**
DGX/OGC	0.230	0.680**	DGX/OGC	0.250	0.680**
DGX/X8X	0.000	0.980**	DGX/X8X	0.000	0.980**
OGC/X8X	0.030	0.940**	OGC/X8X	0.030	0.940**

Note: ** Statistically significant at 5 per cent. Source: Author's own

Risk Management

To measure the performance of vine copulas on Value at Risk (VaR) and expected shortfall (ES), the following steps were taken:

1. The Monte Carlo approach was used to generate 10,000 random numbers based on the uniform variates of CD-Vine copulas.
2. Simulation results were scaled back to log returns using the inverse distribution or $F_i^{-1}(u_i)$.
3. Equally weighted portfolios were generated.
4. The VaR and ES of the portfolios were calculated with 0.99 and 0.95 confidence levels.

Moreover, this study measured the implication of CD-Vine portfolios on risk management. **Table 7** presents the VaR and ES under CD-Vine simulations. Panel A is the equally weighted portfolio consisting of all currencies while Panel B is the equally weighted portfolio consisting of fiat currencies. Higher values indicate better performance. The inclusion of gold-backed cryptocurrencies could enhance portfolio performance while higher returns help make up for the virtual currencies' volatility.

The possible reasons for the non-existence of hedge effectiveness in the bivariate portfolios include:

1. Sharīʿah-compliant finance does not permit speculation.
2. Islamic cryptocurrencies have a smaller market capitalisation than conventional cryptocurrencies and are less able to repel volatilities.
3. Sharīʿah-compliant cryptocurrencies are insufficiently established in many countries. They are still underdeveloped than major conventional cryptocurrencies such as Bitcoin and Ethereum.
4. Gold-backed cryptocurrencies' volatilities are closer to Bitcoin than their underlying asset. The non-existence of hedge effectiveness in the bivariate portfolios consisting of Islamic cryptocurrencies and major foreign exchange markets complements the current literature.

Table 7: Risk Management Implications

	Confidence Level	C-Vine	D-Vine
Panel A: All currencies			
VaR	95%	-0.083	-0.081
	99%	-0.118	-0.116
ES	95%	-0.105	-0.102
	99%	-0.136	-0.133
Omega Ratio		1.148	1.180
Panel B: Fiat currencies			
VaR	95%	-0.006	-0.006
	99%	-0.009	-0.009
ES	95%	-0.008	-0.008
	99%	-0.010	-0.010
Omega Ratio		1.050	1.046

Source: Author's own

Stability of Islamic Cryptocurrency

Following Jalan *et al.* (2021), the stability of Islamic cryptocurrencies is measured using Benford's law (Benford, 1938) while realized variance is to estimate volatility. Realized variance (RVol) is measured by:

$$RVol_{t,M} = \sum_{j=1}^{m} return_{t,j}^{2} \quad (13)$$

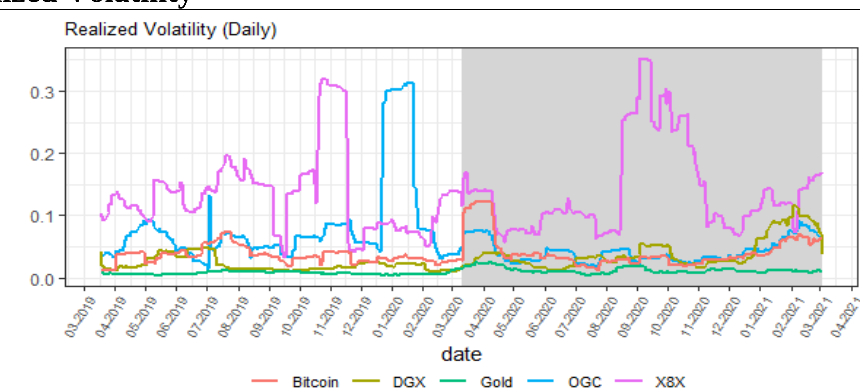
Figure 4 shows realized volatility using the rolling windows of 20 trading days. It shows the volatility of Islamic cryptocurrency, gold and Bitcoin; hence gold and Bitcoin are included in the graph as a comparison. Higher values in the graph indicate higher risk. The graph indicates that realized variance for Islamic cryptocurrencies was higher than that of Bitcoin and gold. However, the average volatility of OGC was lower during the pandemic, although relatively similar to Bitcoin. This finding is similar to the previous research of Jalan *et al.* (2021).

Benford's law was applied to search for probable trade volume abnormalities. The law states that numbers in a series follow a regular pattern, where low digits appear more frequently at initial places than larger digits. Moreover, the volatility over volume or VV formula (Fong *et al.*, 2018) was applied to Pearson's Chi-square and Mantissa Arc Tests:

$$VV_t = \frac{\ln\left(\frac{High_{prices}}{Low_{prices}}\right)}{\sqrt{Volume}} \quad (14)$$

Table 8 presents the Benford's law tests to detect irregularities in trading volume. The null hypothesis is that trading volume conforms to Benford's law. The null hypothesis for X8X and DGX is rejected, indicating deviations in Benford's law. However, OGC did not deviate from Benford's law. These findings show the importance of conducting more investigations in questionable trading volumes.

Figure 4: Realized Volatility



Source: Author's own

Table 8: Benford's Law Tests

Test	OGC	X8X	DGX
Pearson's Chi-squared	X-squared = 7.494 p-value = 0.484	X-squared = 71.415 p-value = 0.000	X-squared = 60.622 p-value = 0.000
Mantissa Arc	L = 0.000 p-value = 0.562	L = 0.076 p-value = 0.000	L = 0.035 p-value = 0.562

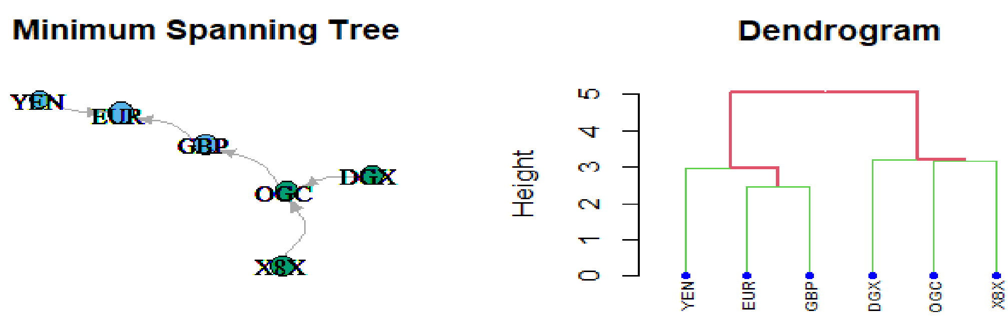
Source: Author's own

Robustness Check

This study used Minimum Spanning Tree (MST) and Dendrogram to verify the vine copula findings. MST is the product of minimising the total edges in the complex network of all spanning trees. As a result, it was created and used as the basis for Dendrogram (Donmez *et al.*, 2021). This study used the approach of Mantegna and Stanley (1999) to estimate the distance, where correlation matrices need to be converted to metric distance (Mantegna, 1999; Ulusoy *et al.*, 2012). **Figure 5** shows the results of the MST and Dendrogram.

Based on the MST, EUR was the center of the fiat currencies examined in this study. The Dendrogram shows that there were two types of clusters in the tree. Essentially, the robustness test results support the findings of the vine copula. **Figure 5** indicates that EUR and OGC are each the most influential currency in fiat and gold-backed cryptocurrency, respectively.

Figure 5: Minimum Spanning Tree and Dendrogram



Source: Author's own

CONCLUSION

This study used copula-based methods (CD-Vine and DCC-*t*-copula) to measure the dependency and hedging effectiveness between gold-backed cryptocurrencies and fiat currencies. The fiat currencies showed weak tail dependence with gold-backed cryptocurrencies. According to previous studies, a low dependence between conventional cryptocurrencies and fiat currencies might diversify the portfolio. However, this study showed that the hedging effectiveness of Islamic cryptocurrencies against the risk of fiat currencies was insignificant. This condition is attributed to the stability of Islamic cryptocurrencies. Furthermore, this study applied realized variance and Benford's law to investigate the stability of Islamic cryptocurrencies whose volatility matched the risk of Bitcoin. Only OneGram Coin showed no irregularities in volume trading. Islamic cryptocurrencies have a smaller market capitalisation than big cryptocurrencies and may be less able to repel shocks. Moreover, gold-backed cryptocurrency is still inadequately found in most countries. These factors may contribute to the significantly low hedging effectiveness between gold-backed cryptocurrencies and fiat currencies.

The result of the stability of Islamic cryptocurrencies is useful to policymakers because they show the potential drawbacks of this innovation. Specifically, the drawbacks include high volatility and irregularities in volume trading. In case the anticipated goals of reduced volatility are to be accomplished, the findings question the role of Islamic cryptocurrencies, necessitating a design rethink. Future studies may focus on trade volumes of gold-backed cryptocurrency and, for general dependency, change the model with the regular or R-vine copula.

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