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Price volatility and regulatory risk of selected cryptocurrencies as a challenge for financial markets

Abstract

The aim of this article is to estimate and compare the price volatility risk of cryptocurrencies (BTC and ETH) and traditional financial assets using GARCH models, as well as to identify regulatory risk stemming from existing and proposed normative frameworks. The research hypothesis assumes that cryptocurrencies – particularly BTC and ETH – exhibit a higher level of risk compared to traditional financial instruments, due to their significant price volatility and insufficient regulatory frameworks. As a result, their potential as portfolio diversification assets may be limited, and their presence in financial markets may contribute to increased investment risk. The empirical analysis applies GARCH(1,1) econometric models to examine the conditional volatility of cryptocurrency prices and compare them with traditional financial assets such as the EUR/USD and USD/PLN currency pairs, as well as the S&P500 and WIG20 stock indices. The results confirm that BTC and ETH demonstrate significantly higher price volatility than conventional financial instruments. Moreover, the Value at Risk (VaR) measures for the analysed cryptocurrencies are substantially higher than those for traditio-

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nal assets. The study also includes a regulatory dimension, providing a normative analysis of legal acts relating to the crypto-asset market and assessing the role of such regulations in mitigating risk in financial markets.

Keywords: cryptocurrencies, price volatility, bitcoin, ether, GARCH

JEL codes: C58, G12, G18, K22

Introduction

1. The growing role of cryptocurrencies in financial markets

Cryptocurrencies, led by BTC and ETH, have gained a prominent place in global financial markets over the past decade or so. The dynamic growth in the popularity of these assets is the result of a combination of innovative blockchain technologies, growing social acceptance and the search for alternative forms of investment in the face of low interest rates and macroeconomic uncertainty (Corbet et al. 2019). The growing market capitalisation of cryptocurrencies, which has reached trillions of dollars in recent years, means that a potential collapse of this market could have cascading effects on other segments of the financial system, particularly in the context of institutional links between investors and regulated markets and the cryptocurrency sector (European Central Bank 2019; International Monetary Fund 2021). Such risks became apparent, for example, during the spectacular price declines of cryptocurrencies in 2018 and 2022. After reaching historic peaks in December 2017 and January 2018, when BTC reached USD 19 345 (16 December 2017) and ETH around USD 1 385 (13 January 2018), prices fell sharply. During the first quarter of 2018. BTC lost about 64% of its value and ETH saw a decline of about 94% from its peak to its low of 15 December 2018. The year 2022 brought another significant wave of declines in the cryptocurrency market. Bitcoin started the year at US 47 450 and ended the year at US 16 513, down 65.2%. Ether lost approximately 68.2% of its value over the same period.

In light of the high price volatility and the potential transmission of risk across markets, this study aims to estimate and compare the volatility risk associated with cryptocurrencies (BTC and ETH) and traditional financial assets using GARCH models, as well as to identify regulatory risk stemming from existing and proposed legal frameworks. According to the research hypothesis, cryptocurrencies, in particular BTC and ETH, exhibit a higher level of risk compared to traditional financial instruments due to their significant price volatility and insufficient regulatory framework. As a result, their potential as an investment portfolio diversification asset may be limited and their presence in financial markets may contribute to an increase in risk.

2. Price volatility risk of cryptocurrencies and portfolio diversification

Research on the links between the cryptocurrency market and traditional financial markets does not allow for definitive conclusions regarding the potentially stabilising or destabilising impact of cryptocurrencies arising from their price volatility risk. Bouri et al. (2017) used the DCC-GARCH model to investigate whether BTC can act as a hedge or safe haven against traditional assets (global equities, bonds, oil, gold, commodity index, US dollar). The results showed that BTC's advantage could be at best its low correlation with these assets under normal conditions, and a significant role as a strong safe haven was only observed in the case of extreme weekly declines in Asian stock markets (Bouri et al. 2017). In other words, except in exceptional crisis situations, BTC did not hedge risks in traditional markets, although it could serve as a portfolio diversification component (Ji et al. 2019; Liu and Tsyvinski 2018). The potential of cryptocurrencies to diversify an investment portfolio – due to their low level of correlation to other financial assets – was considered one of the determinants of their growing popularity. Similarly, Dyhrberg (2016), using GARCH models, found that BTC exhibited intermediate characteristics between gold and FIAT currencies. Her model demonstrated bitcoin's hedging properties similar to gold – BTC reacted asymmetrically to shocks, making it useful for risk management

Other work, however, suggests the limitations of cryptocurrencies as 'safe havens'. This is primarily supported by the risk of sudden losses associated with extreme price fluctuations, which could lead to negative consequences for individual investors and thus potential macro-financial consequences (Financial Stability Board 2018; Gandal et al. 2018). Also Klein et al. (2018) argue that the highly speculative nature of cryptocurrencies undermines their credibility as a stable hedging instrument, especially during periods of extreme market volatility. In other words, in situations of severe financial turbulence, cryptocurrencies do not provide as reliable value protection as traditional safe assets (e.g. gold or government bonds). The relatively low correlation of cryptocurrencies with traditional assets during calm periods means that adding a small exposure to cryptocurrencies may have so far had a stabilising effect on the portfolio through a diversification effect. However, with the evolution of the cryptocurrency market there is a growing interdependence and potential risk transmission channels. Canh et al. (2019) examined seven types of cryptocurrencies (bitcoin, litecoin, ripple, stellar, monero, dash, bytecoin) for coincident changes and structural breakthroughs using parameter stability tests, Granger causality tests and the DCC-MGARCH model. They showed that all of these cryptocurrencies experienced significant structural price changes, with shocks initially occurring in the smaller cryptocurrencies then spilling over to the larger ones (testing on data up to 2018). Furthermore, strong positive dynamic correlations and linkage of volatility within the cryptocurrency market were found (Canh et al. 2019). This means that a collapse in one cryptocurrency can easily translate into declines in others, a potentially destabilising mechanism within this market segment. It is important to note, however, that the cited studies focus primarily on the price-related aspects of cryptocurrencies, without addressing legal

risks associated with BTC and ETH. The authors of this study extend the scope of analysis to include this dimension, which is explored in greater detail in the section devoted to the regulatory risk of these two cryptocurrencies. Numerous studies investigate the transmission of volatility and shocks between cryptocurrencies and, for instance, equity or commodity markets.

Many studies have analysed the transmission of volatility and shocks between cryptocurrencies and, for example, the stock or commodity markets. Symitsi and Chalvatzis (2018) investigated the relationship of BTC with energy and technology stocks using a VAR-BEKK-AGARCH model on daily data up to 2017. They showed that price changes and volatility of BTC affect the share prices of these companies (one-way spillover effects). In addition, they identified bidirectional responses to inter-market shocks and time-varying correlations that are relevant for investment portfolio management. Another study using BEKK and DCC-MGARCH models (period January 2017 – May 2021) examined the integration of BTC with several of the world's largest equity markets. It was found that the average dynamic correlation between BTC and stock indices was low, confirming the short-term hedging potential of BTC (Sajeev and Afjal 2022). However, on deeper analysis, it appeared that negative shocks to the BTC market (sharp declines) translated more strongly into stock market reactions than positive shocks. In particular, crisis years (such as 2018 or 2022) saw more pronounced stock market reactions to cryptocurrency collapses than to cryptocurrency appreciation. This suggests an asymmetry in transmission – falls in cryptocurrencies may carry a destabilising effect on other financial markets to a greater extent than rises have a stabilising effect.

Recent work examining the COVID-19 pandemic period indicates that the relationship between cryptocurrencies and traditional assets can intensify during periods of extreme uncertainty. For example, a study on daily data from 2011 to mid-2022 (distinguishing the pre-pandemic sub-period and during the pandemic) used a combination of a DCC-GARCH model and neural networks to analyse the price volatility link between BTC, gold and six major global stock market indices. The results indicated a long-run volatility transmission between BTC and gold, as well as between BTC and stock markets (Ibrahim et al. 2024). Interestingly, short-term strong linkages emerged mainly during periods of stress – for example, during the 2020 market panic, significant short-term contagion occurred between BTC and the Chinese and Japanese stock markets. The study also highlighted that the high volatility of BTC poses a difficult-to-control threat to local equity markets (Ibrahim et al. 2024).

In summary, the literature points to the dual impact of cryptocurrencies on risk for financial markets. Under normal market conditions, cryptocurrencies (mainly including the most studied BTC) are characterised by relative independence from traditional assets, which implies stabilisation benefits through diversification. However, in crisis conditions, correlations can increase rapidly and shocks to the cryptocurrency market can spill over to other market segments, having a destabilising effect. As the cryptocurrency market has evolved, it has also seen an increase internal correlations within the segment since 2018, highlighting

systemic risk within the cryptocurrency market itself and limiting the – previously mentioned – opportunities to hedge risk by investing in different cryptocurrencies (Koutmos 2018; Smales 2021; Xu, Zhang, and Zhang 2021; Yi, Xu, and Wang 2018).

1. Data and research method

1.1. Data

This study of cryptocurrency price volatility stands out in terms of the length of the period analysed – it covers over nine years of daily data (2016-Q1 2025). In comparison, many other studies have used much shorter periods. For example, Sajeev and Afial (2022) analysed four years and one quarter (i.e. from March 2017 – to May 2015), Bouri et al. (2017) examined the period from the beginning of July 2011 to December 2015, i.e. approximately four and a half years. and Dyhrberg (2016) just under five years (from 19 June 2010 to 22 May 2015). The longer time series in this study allows for a more accurate assessment of the price volatility and risks associated with cryptocurrencies over the long term. The choice of this time range is dictated by both the availability of data and significant developments in the cryptocurrency market. The initial date of the study was set at 1 January 2016 since ETH was created in the second half of 2015 (7 August 2015). Starting the analysis at the beginning of 2016 made it possible to simultaneously analyse the two most important cryptocurrencies – BTC and ETH – from the early stage of the latter's development. The end date, 31 March 2025, was chosen to include the most recent period of analysis, thus allowing the most recent conclusions on price volatility and risk in the cryptocurrency market.

Table 1. Characteristics of the logarithmic rates of return of the variables studied

Date	BTC	ETH	EURUSD	USDPLN	SP500	WIG20
Observations	3377	3377	2389	2388	2323	2310
Mean	0.00155	0.00225	~0	~0	0.00044	0.000173
SD	0.03563	0.05148	0.00457	0.006529	0.011394	0.013893
Skewness	-0.34618	0.009135	-0.02486	0.287525	-0.84085	-0.65524
Kurtosis	8.960696	9.51671	4.89045	6.693409	19.168257	11.39759
ADF_pval	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***

Significance levels:* p<0.05,** p<0.01,*** p<0.001.

Source: own elaboration.

Table 1 shows the statistical characteristics of the logarithmic returns for the six analysed variables. The data for BTC and ETH include 3377 daily observations, which is due to the fact that cryptocurrencies are traded 7 days a week, without weekend or holiday breaks. In contrast, traditional market assets – currency pairs (EUR/USD, USD/PLN) and stock indices (S&P500, WIG20) – have a lower number of observations (in the range from 2310 to 2389), as they are only traded on weekdays. The average daily returns for BTC (0.155%) and ETH (0.225%) are noticeably higher than for traditional assets, for which the values oscillate around zero. The standard deviations of the surveyed variables confirm the significantly higher volatility of cryptocurrencies – 3.56% for BTC and as much as 5.15% for ETH respectively – compared to the relatively low volatility for EUR/USD (0.46%), USD/PLN (0.65%) and the moderate volatility of stock indices (S&P500 – 1.14%, WIG20 – 1.39%). The skewness and kurtosis indices identify the asymmetry and leptokurticism of the distributions – all series show excess tails compared to a normal distribution, which justifies the use of GARCH models with Student's t-distribution. The highest kurtosis was observed for the S&P500 index (over 19), indicating an exceptionally strong concentration of large deviations from the mean. Importantly, the results of the ADF test for all the variables tested indicate the stationarity of the return series – for each of them, the p-value was less than 0.001, which allows us to reject the hypothesis of the presence of a unit root at the 0.1% significance level.

GARCH(1,1) models were estimated separately for each asset on the full available dataset, without artificially synchronising the quotation calendars. Only at the benchmarking stage were the series matched against a common portion of the dates, allowing the results to be correctly summarised without interfering with the structure of the original data. This approach allows both the full use of the information contained in the cryptocurrency data (including weekend data) and consistency in cross-sectional analyses and visualisations between asset classes.

1.2. Research method

Research dedicated to the volatility of cryptocurrencies has used various methods to capture the unique properties of volatility and to understand the interdependencies between these asset classes. By far the dominant approach has been GARCH models and their variations, attempting to assess the volatility of cryptocurrencies over time. This is because cryptocurrency prices are characterised by the occurrence of volatility clustering, i.e. periods of large price swings interspersed with periods of relative stability. GARCH models, are particularly effective in studying this type of volatility, as they consider the fact that current price volatility depends on the volatility observed in the past. In addition, as confirmed by Katsiampa's (2017) observations, cryptocurrency price series have distributions with a significant number of extreme observations (so-called fat tails). GARCH models deal well with such extremes as they assume conditional heteroscedasticity, allowing for a better representation of the dynamic features of the data (Bollerslev 1986). Price volatility

is, as defined by the Basel Committee, among the core components of market risk, understood as the risk of incurring losses as a result of adverse movements in the market price of financial instruments (Bank for International Settlements 2016) .

As noted by Fiszeder (2009, p. 88), one of the most widely used models from this family is GARCH(1,1), which is recommended in the literature as a starting point for modelling volatility in financial markets, including the cryptocurrency market, due to its simplicity and good predictive properties (Chu et al. 2017; Dyhrberg 2016; Katsiampa 2017). In general, already Bollerslev (1986) has shown that GARCH(1,1) effectively models conditional variance dynamics and provides stable and reliable short-term forecasts.

The full specification of the GARCH(1,1) model used includes two equations – the mean equation and the conditional variance equation:

1) Equation of the mean: $r_t = \mu + \varepsilon_t$
2) Variance equation: $\sigma_t^2 + \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2$

Where:

r_t – the asset's rate of return over time,
μ – a constant component in the average equation, reflecting the expected rate of return of the asset,
ε_t – prediction error (model residual), with $\varepsilon_t \mid \Omega_{t-1} \sim t(0, \sigma_t^2, \nu)$ having a Student's t-distribution with ν degrees of freedom,
σ_t^2 – conditional variance of returns,
$\omega > 0$ – constant variance component, representing the long-term level of variability,
$\alpha \geq 0$ – ARCH parameter measuring the immediate response of the variance to new information (recent price shocks),
$\beta \geq 0$ – GARCH parameter indicating the persistence of variation, i.e. the extent to which the current variance depends on previous values.

The choice of the GARCH(1,1) model is also justified by the fact that empirical studies of the cryptocurrency market have confirmed that time series of cryptocurrency prices are characterised by a significant number of extreme observations (Katsiampa 2017). In such situations, it is important to choose the conditional error distribution appropriately. The literature suggests that a Student's t-distribution may be more appropriate than a normal distribution as it better reflects the presence of fat tails in financial data (Cont 2001). The use of a Student's t-distribution improves the efficiency of value-at-risk (VaR) estimation and improves the accuracy of predicting extreme events (Kuester 2005). Katsiampa (2017) conducted a comparison of the effectiveness of different GARCH models for the bitcoin market, indicating that GARCH(1,1) with a t-Student distribution has the best fit and volatility prediction accuracy. Similarly, Chu et al. (2017) confirmed the dominant role of this GARCH variant when modelling cryptocurrency volatility, highlighting its superiority in capturing the dynamic features of the series.

Complementing the econometric modelling, the Value at Risk (VaR) measure was also used to examine the assessment of the level of risk. The calculated VaR answers the question: what is the potential maximum loss (assuming a significance level) that should not be exceeded over a given time horizon? Formally, assuming a significance level α (e.g. 5% or 1%) and a horizon of one day, then VaRα is the cut-off value such that with probability (1–α) the actual loss will not exceed this value. The study uses the historical method to estimate VaR, which involves collecting the historical daily returns of the asset under study over the relevant time window (i.e. from 2016 to the end of Q1 2025) and determining the quantile of order α from the empirical distribution thus obtained. The advantage of the historical method is that there are no assumptions about the distribution (e.g. normal) of returns. Real market data are used for the calculation. A disadvantage may be the lack of updating against current volatility (if volatility is increasing, historical data from a softer period may underestimate risk). Therefore, the study also calculated VaR parametrically based on a GARCH(1,1) model with a t-student distribution (McNeil et al. 2005, pp. 283–291). For this purpose, the average level of over the sample period reflecting the typical level of variability from the sample was used.

In addition to VaR, the Expected Shortfall (ES) is also presented. ES (1–α) estimates the average loss assuming that the loss has already exceeded the VaR threshold. Methodologically, the historical version counts the average of the worst α% of historical return observations.

The dogmatic method, commonly used in legal sciences, was also utilised as a research approach for conducting the analyses.

2. Empirical results and discussion

Table 2 summarises the key parameters of the GARCH(1,1) models with Student's t-distribution for the six assets analysed: two cryptocurrencies (BTC, ETH), two currency pairs (EUR/USD, USD/PLN) and two equity indices (S&P500, WIG20).

In the sample, cryptocurrencies (BTC, ETH) achieved a sum of α+β=0.999, which means that periods of high volatility in these markets are extremely persistent (very high volatility persistence). A comparable level is also found in the S&P500 index, where the α component (short-term shock response) is higher than in cryptocurrencies (0.166 vs 0.101–0.151). Despite this, BTC and ETH have significantly higher ω, i.e. the initial variance condition (they were the only assets in the table to reach significance for this parameter). This suggests a certain baseline level of volatility, noticeable even in the absence of market shocks.

One of the key factors influencing risk assessments is the so-called 'fat tails'. This is informed by the *shape* parameter showing how strongly the distribution of returns deviates from normal in terms of extreme events (for low levels of this parameter). A high *shape* level in the range 3.22–3.34 for cryptocurrencies indicates extremely fat

tails and therefore an increased frequency of extreme price fluctuations. Although the distribution of the S&P500 is also leptokurtic (shape 5.48) – to a noticeably lesser extent than for cryptocurrencies. The WIG20 index and the EUR/USD and USD/PLN currency pairs presented noticeably higher *shape* levels, suggesting that extreme volatility is statistically less likely than in the cryptocurrency market.

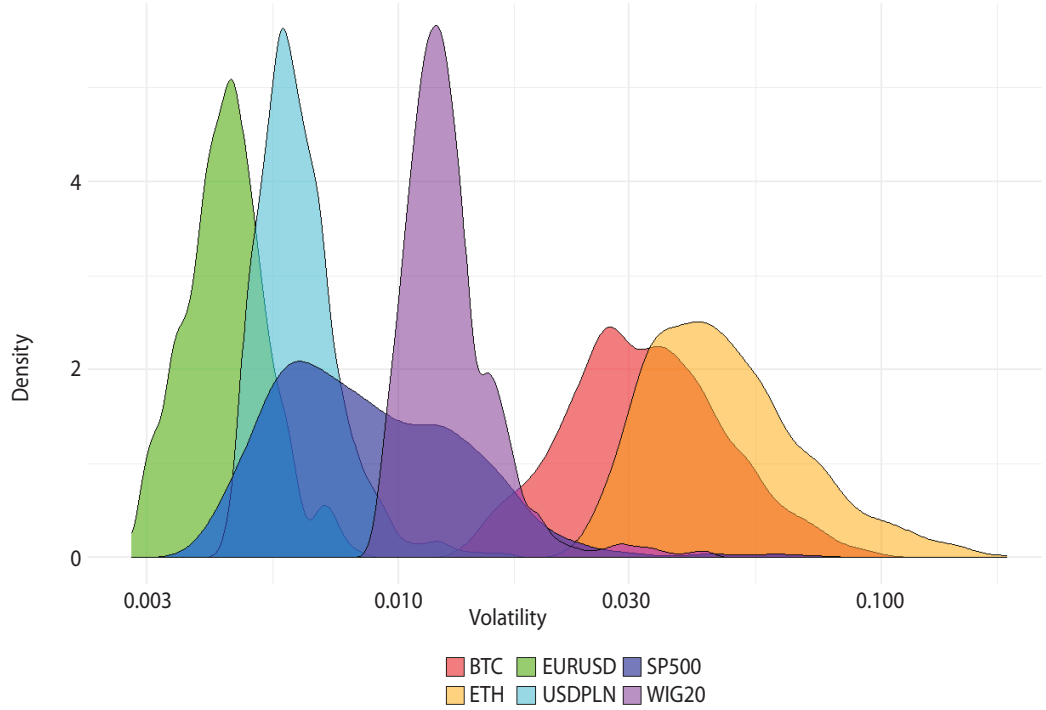
Table 2. Comparison of parameters of GARCH(1,1) models for the assets analysed

Asset	μ (constant in the average equation)	ω (initial condition of variance)	α (shock response)	β (persistence of variability)	Shape (thickness of tails)
BTC	0.00137***	0.00002**	0.10140***	0.89760***	3.22256***
ETH	0.00102	0.00008**	0.15136***	0.84764***	3.34473***
EUR/USD	-0.00003	~0	0.03425***	0.95922***	9.51623***
USD/PLN	-0.00009	~0	0.07170***	0.88958***	10.01976**
SP500	0.00094***	~0	0.16610***	0.83288***	5.47750***
WIG20	0.00029	~0	0.05633**	0.92011***	8.11741***

Significance levels:* p<0.05,** p<0.01,*** p<0.001.

Source: own calculations based on data from the period under review.

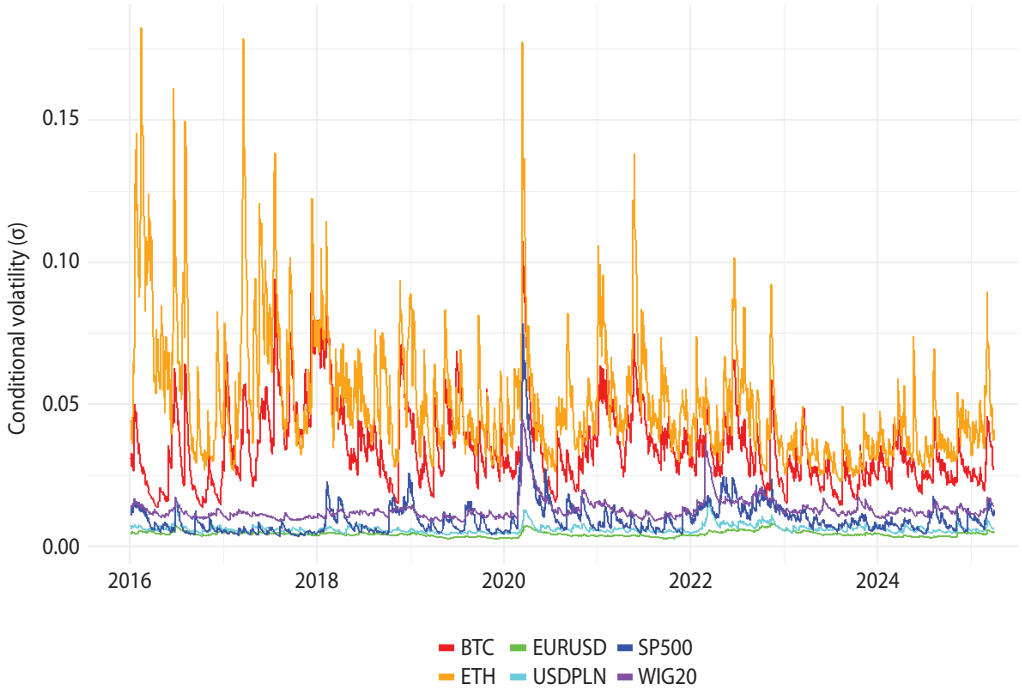
Figure 1. Comparison of volatility distributions of individual assets



Source: own compilation based on GARCH(1,1) model estimations.

The differences in the levels of occurrence of extreme volatility are evident in Figure 1, showing a comparison of the volatility distributions of all the assets studied. This graph shows that ETH and BTC regularly adopt higher volatility values (on a daily basis) than the other assets.

Figure 2. Comparison of the conditional volatility of selected financial assets



Source: own compilation based on GARCH(1,1) model estimations.

As can be seen from the data presented in Figure 2, episodes of extremely high volatility occur much more frequently for cryptocurrencies and reaches around 10–15% of the daily standard deviation, while the conditional volatility of the other assets studied oscillates within a few per cent (stock indices) or less (currency pairs) over the period studied. The results presented here indicate a significantly higher market risk in the cryptocurrency market than in traditional equity or currency markets.

In order to complement the conclusions obtained from the GARCH(1,1) model, a calculation was made of the VaR level, which is one of the key risk measures used in modern finance, as it quantifiably describes what loss – with a certain probability – will not be exceeded in a given time horizon. Calculations were carried out in a historical variant and a parametric variant based on conditional volatility from the GARCH(1,1) model.

Table 3. VaR and ES estimates (historical approach)

Assets	VaR(5%)	ES(5%)	VaR(1%)	ES(1%)
BTC	-5,55%	-8,80%	-10,87%	-13,92%
ETH	-7,41%	-11,91%	-14,92%	-19,81%
EURUSD	-0,73%	-0,97%	-1,06%	-1,45%
USDPLN	-1,00%	-1,38%	-1,61%	-2,04%
SP500	-1,74%	-2,82%	-3,33%	-4,84%
WIG20	-2,10%	-3,07%	-3,33%	-5,12%

Values in the table indicate logarithmic daily loss.

Source: own elaboration.

Table 4. VaR and ES estimates in parametric terms (GARCH(1,1))

Assets	VaR(5%)	ES(5%)	VaR(1%)	ES(1%)
BTC	-7,86%	-12,95%	-14,88%	-22,62%
ETH	-11,48%	-18,42%	-21,37%	-31,78%
EURUSD	-0,82%	-1,09%	-1,25%	-1,52%
USDPLN	-1,16%	-1,51%	-1,76%	-2,12%
SP500	-1,86%	-2,86%	-3,12%	-4,28%
WIG20	-2,41%	-3,32%	-3,76%	-4,72%

Values in the table indicate the logarithmic daily loss.

Source: own elaboration based on GARCH(1,1) model estimations.

The results obtained confirm that, during the period studied, cryptocurrencies (BTC and ETH) exhibited by far the highest risk, understood as the possibility of large daily declines in value. This is evidenced by both the VaR and ES values calculated using the historical approach (Table 3) and the results of parametric estimation based on the conditional volatility of the GARCH(1,1) model (Table 4).

In the historical approach, which uses an empirical distribution of returns, ETH achieves a VaR(5%) close to -7.41% and VaR(1%) is as high as -14.92%, suggesting a significant probability of losses of several per cent on a one-day basis. Similarly high risks are observed for BTC (-5.55% and -10.87% at the respective confidence levels). For currency pairs (EUR/USD, USD/PLN), VaR indications are noticeably lower, not exceeding a few per cent, which means that on most days losses of more than -1% or -2% are rare. The market situation of the indices (S&P500 and WIG20)

in terms of VaR measures (1.7–2.1% at the 5% level and up to around 3.3% at the 1% level) ranks indirectly between cryptocurrencies and currencies.

In contrast, parametric analysis (Table 4), in which VaR and ES levels are determined based on estimated conditional volatility from GARCH(1,1) models and Student's t-distribution, further highlights the increased vulnerability of cryptocurrencies to extreme price fluctuations. In particular, Ether (ETH), with a VaR(5%) of -11.48% and an ES(5%) of over -18%, shows the greatest sensitivity to sharp price movements. The differences between the historical and parametric method in percentage terms are small for the more stable markets (e.g. EUR/USD, USD/PLN), meaning that the realistically observed return distribution is close to what the GARCH model predicts. In the case of BTC and ETH, however, the inclusion of high volatility persistence and fat tails results in higher VaR and ES values than in the historical approach.

The potential for daily high negative returns in cryptocurrency markets carries the risk of rapid and steep capital losses, which, with high turnover and shallow markets, can lead to escalating crisis phenomena. In contrast, lower, relatively stable VaR parameters in the currency segment and on the main indices indicate a lower risk of deep declines in the short term.

At the same time, it is worth emphasising that the assessment of the impact of the cryptocurrency market on the risk to financial markets cannot be conducted solely from a quantitative perspective. The regulatory aspect is also important, especially in view of the growing number of crypto-related instruments (e.g. futures contracts, ETFs) and the potential interest in the cryptocurrency market by banking sector players and investment firms. To date, however, relatively few studies have been produced that combine the rigour of statistical and econometric methods with detailed regulatory analysis, making the issue of addressing the risks arising from the increased volatility of cryptocurrencies one that requires a new, interdisciplinary approach. This article therefore includes not only an examination of the price volatility of selected cryptocurrencies and its implications for risk in financial markets, but also conducts an analysis of regulatory risk factors in the context of the current regulatory framework.

3. Regulatory risk of cryptocurrencies BTC and ETH

3.1. Introductory remarks

Regulatory risk, understood as an element of the broader category of legal risk, occupies an important place in the analysis of risks associated with cryptocurrencies. Regulatory risk is related not only to changes in the legal environment, but also includes situations where there is a lack of relevant regulations or their application is a source of interpretation problems The source of risk in this aspect is also the jurisdictional diversity, which includes different rules for carrying out transactions,

recording and settling them in the laws of different countries, as well as the potential vindication of claims (Kuźniak 2008). In order to identify regulatory risks, a normative analysis of cryptocurrencies should be carried out using the research methods of legal science. The scope of the analysis should include the juridical nature of cryptocurrencies and the legal relations of trading. The scope of analysis determined in this way directs the structure of considerations to the issues of the essence of cryptocurrencies and the normative layer, i.e. the legal solutions currently in force in this area will complement the previously conducted economic analysis with a regulatory aspect. The research method used in this layer of the study is the dogmatic-legal method consisting in the analysis of selected legal regulations. The subject of the analysis is therefore the content of the law in force as well as its interpretation conducted in doctrine and jurisprudence on the subject of assessing the regulation of cryptocurrencies, with particular emphasis on BTC and ETH. The aim of applying this method is to establish what norms are in force in the legal system what the practice of applying these norms looks like and to formulate conclusions through the prism of regulatory risk to market security. The analyses assume that the complexity of legal relations in the field of cryptocurrencies requires the application of regulatory methods belonging to different branches of law.

3.2. Regulatory issues regarding the concept of cryptocurrency

The analysis of the issue of the legal essence of cryptocurrencies such as BTC and ETH involves an intertwining of two closely related issues: the concept and its juridical nature. These issues are characterised by a rather high complexity due to their treatment as a phenomenon of the nature of digital technology, the economic sphere and also the legal sphere (Michna 2018, p. 4). However, characteristic of the cryptocurrency plane is the occurrence of regulatory deficits already at the conceptual level, which constitute a significant source of regulatory risk The reason for this state of affairs is the difficulty in the unambiguous qualification of the cryptocurrency creation process, but also the diversity of functions performed by them, including considering them in the context of money (Marshal 2019, p. 110). An additional source of difficulty in defining the concept and juridical nature of BTC and ETH is their association with a network (Bitcoin and Ethereum, respectively) that is not itself the subject of rights and obligations (Wnęk 2023, p. 37). Cryptocurrencies in legal literature are also conceptually juxtaposed with virtual currencies and digital currencies as money in virtual form (Skorupka, Urbanowicz-Sobczak, and Zawłocki 2024:856). At this point, it should be noted that the Polish legislator has not explicitly defined cryptocurrency but has formulated a legal definition of virtual currency. A relevant regulation in this regard is contained in Article 2(2)(26) of the Act of 1 March 2018 on the prevention of money laundering and terrorist financing (2018). However, this definition is not universal and was formulated for the purposes of this particular law.

Although they are a means of exchange and perform a thesesurisation function, they nevertheless lack the legal tender attribute necessary to be considered as money. By contrast, BTC and ETH can be considered private money, which is not issued by a specific entity, but created/issued (*mining*) by the network itself. Cryptocurrencies such as BTC and ETH undoubtedly perform the function of a measure of value other than money under civil law (Zacharzewski 2014, p. 1133) .

An unambiguous definition of cryptocurrencies is also not contained in the Regulation of the European Parliament and of the Council (EU) 2023/1114 of 31 May 2023 (hereinafter: MiCA Regulation) on cryptocurrency markets. The EU legislator has admittedly introduced a definition of the term 'crypto-asset', which is a digital representation of a value or right that can be transferred and stored in electronic form using distributed ledger technology or similar technology. This definition is broad and includes cryptocurrencies in the form of BTC and ETH (ESMA 2024, p. 17). The Regulation provides for three categories of assets: asset-linked tokens (so-called ARTs), e-money tokens (so-called EMTs) and cryptocurrencies other than asset-linked tokens and e-money tokens, including utility tokens. Due to the nature of BTC and ETH, in particular related to the lack of central issuer attribution, these cryptocurrencies will not be subject to the issuance obligations contained in the MICA such as apply to EMTs, ARTs or utility tokens. However, this does not mean that the trading and storage of these cryptocurrencies will not be regulated. In this aspect, the provisions of the MICA regulation related to *Crypto Asset service Providers* (CASPs) will apply. Indeed, CASP providers may provide crypto-related services by, inter alia, storing cryptoassets, operating trading platforms and managing cryptocurrency wallets on behalf of and for third parties.

It should be emphasised that the formulation of legal definitions in legal science may be fraught with risks in terms of the effectiveness and practicality of such regulation. As noted aptly in the doctrine, an overly detailed definition entails the risk that only a slight change in the algorithm or the way it functions would lead to the exclusion of a specific definition from the scope of the legal definition and thus from the scope of regulation. A general definition, on the other hand, could lead to a situation in which other virtual currencies, which should not be included in this definition (Mazur 2024, p. 205), would also have to be qualified as cryptocurrencies. In addition, new concepts are emerging to create further cryptocurrency systems based on a model similar to Bitcoin or Ethereum (Behan 2022, p. 241). However, the lack of definition of the concept of cryptocurrency in the legal sciences does not preclude the description of its exemplary characteristics (relationship to crypto technology, ease of transfer, anonymity of use and the possibility of de-anonymisation, convertibility, interchangeability, irreversibility, security, but also the manner of issuance and linkage to other values and the indication that their value is not guaranteed, their acceptance is an expression of the community's trust in the concept itself and they are stored by a decentralised distributed database system (Behan 2022, p. 242).

3.3. Directions for classifying cryptocurrencies at the regulatory level

Despite the identified definitional problems of cryptocurrencies under private law, they are the subject of legal relations of circulation. This is because freedom of contract allows parties to create legal relations in which cryptocurrency is an object of performance and may even perform a function analogous to money. Under criminal law, cryptocurrency is not treated as money, another legal tender, a document or a financial instrument. It is also not treated as a property right or an asset, nevertheless it may constitute the object of a prohibited act (Blazowska 2024, p. 153).

In civil law, the treatment of BTC and ETH as things and consequently their inclusion in the rules of legal transactions is problematic. Also other theoretical civil law concepts qualifying cryptocurrency as a property right, debt, work or financial instrument are not without doubts (Szewczyk 2018, p. 243; Wnęk 2023, pp. 55–64; Zacharzewski 2014, p. 1133). A broader discussion of the doubts relating to the jurisprudential nature of cryptocurrencies is beyond the scope of this paper, so it should be limited to stating that there is no uniform position in the legal doctrine on the jurisprudential nature of cryptocurrencies. This state of affairs fosters a multiplicity of conceptual categories and further contributes to ambiguity by making interpretation difficult.

The rulings of the judicature also do not provide a clear answer regarding the legal qualification of cryptocurrencies. All the more so as they relate to a fragment of cryptocurrency trading, which are fiscal issues. The Supreme Administrative Court, in a judgment of 12 July 2022, II FSK 3094/19, held that cryptocurrencies do not have a materialised form and are not managed by any central institution or central system, as they exist as a certain numerical value recorded in a computer system. Instead, trading in cryptocurrencies, in the court's view, is an intermediary service, where the seller acts as an intermediary between the persons making changes to the register of the bitcoin system (the so-called miners) and the person for whose benefit the change in the register is made (i.e. the 'buyer'). In another judgment of 6 March 2018, II FSK 488/16, the Supreme Administrative Court held that bitcoin in the practice of civil law relations is a type of property and in a judgment of 4 August 2022, II FSK 3150/19, it referred to the issue of possession of BTC stating that it is the possession of a cryptographic key allowing a given user to make an entry in the public register operating within the bitcoin network. On the other hand, the issues of the creation of a cryptocurrency are addressed by the judgment of the Supreme Administrative Court of 2 September 2021, II FSK 651/21, in which the court held that the process of digging a cryptocurrency is similar to the process of creating a thing or a work that is the subject of copyright. In the case of cryptocurrencies, the effect of 'digging' is to obtain a property right that did not previously exist. The case law on the qualification of cryptocurrencies is therefore not clear-cut and does not always remain consistent with the pronouncements of the doctrine of law This is an important factor generating increased regulatory risk, which may negatively affect the security of the financial market.

3.4. Regulatory risk and financial market security

Financial market security is one of the main objectives of the legislator's interference with the free functioning of trading mechanisms. This interference, in the case of the crypto-asset market, does not cover the entire market, but focuses on selected areas of its functioning, creating organisational and functional bases for trading so as to ensure a high level of their integrity. The modalities of impact take the form of different regulatory models, which either restrict access to participate in trading or regulate specific behaviours (prohibition model), or impose additional obligations on market participants related to the functioning of trading, exchange and storage platforms (organisational model). As highlighted by the EU legislator in recital 4 of the MiCA Regulation, the lack of rules in this regard exposes holders of these cryptocurrencies to risks and may cause a significant threat to market integrity. Although investments in cryptocurrencies do not fall under the prohibition model, i.e. in simpler terms they are not prohibited, they nevertheless entail far-reaching risks stemming also from the lack of legal certainty, which for the security of market trading is fundamental. BTC and ETH are not regulated at a level that makes it possible to clearly define their juridical nature, even though they are included in the broad legal category of crypto-assets. The value of both cryptocurrencies essentially refers to how much the purchaser is able to pay for them and whether they accept them as a means of performance. In addition, the link to technology makes it difficult to set boundaries to protect participants in the trading of these assets.

Regulatory certainty is an important prerequisite for the safe operation of trading. These regulations should allow for effective redress and ensure that investors are adequately protected. In this respect, a particularly high regulatory risk is revealed in its jurisdictional aspect related to the functional sphere of crypto-asset trading, i.e. the execution of transactions. The rules that are applied in one country do not necessarily apply in another (Kuźniak 2008, p. 94). In legal sciences, attention is drawn to the difficulties in determining the law governing the relations of international trading in the digital space, which lead to the formulation of the concept of a separate quasi-legal system for the sphere of digital trading, the so-called *lex cryptografica* system based on the assumption of "*code is law*" (Świerczyński 2024, p. 171). These concepts certainly only increase regulatory risk in the context of market security. This is because they create solutions that compete with traditional trade regulation instruments.

In concluding remarks on regulatory risk, it is worth noting that the lack of applicable regulations for cryptocurrencies and their price volatility were explicitly indicated in the judgment of the Supreme Administrative Court of 11 October 2023, II GSK 883/20 as their features in the context of the subject of investment. The analysis of the normative plane of cryptocurrencies therefore leads to the conclusion that the current state of regulation of BTC and ETH is a source of regulatory risk. Additional sources of this risk are the lack of a central entity issuing cryptocurrencies (for the cryptocurrencies analysed in the paper, i.e. BTC and ETH), their functioning in IT networks outside the market understood as a place of concentration of the supply and demand side, and the jurisdictional risk resulting from the lack of unambiguously

clear criteria to indicate the law applicable to the qualification and trading of cryptocurrencies The evolution of the market of cryptocurrencies requires in-depth legal research into the essence of this category of cryptocurrencies not only in the domestic dimension, but also at the level of international law.

Summary and conclusions

Cryptocurrencies, as one of the most dynamically developing forms of digital assets in the financial sector in recent years, have repeatedly demonstrated their capacity to generate significant risks for financial markets. The analyses presented in this paper, covering both traditional volatility measures and the estimation of GARCH(1,1) models with Student's t-distribution, as well as computed values of Value at Risk (VaR) and Expected Shortfall (ES), clearly show that the cryptocurrencies examined (BTC and ETH) are characterised by high volatility metrics and a susceptibility to sharp daily losses. In the historical approach, ETH exhibited VaR(1%) figures reaching several percentage points, while under the parametric approach – additionally accounting for fat-tailed return distributions – the forecasted extreme losses (ES) were even higher, exceeding -30%. Similarly elevated risk exposure of BTC confirms that both major cryptocurrencies distinctly differ from traditional financial instruments such as currency pairs (EUR/USD, USD/PLN) and stock indices (S&P500, WIG20), for which analogous VaR and ES measures are much lower.

The results obtained thus support the hypothesis that cryptocurrencies – especially in their current phase of development and with current, often ambiguous regulations – have a destabilising rather than stabilising function in financial markets, thus contributing to an increase in risk. Of key importance here is the coupling of price and regulatory risk, which undermines the predictability of market processes and decisions and, given the technological aspect of the cryptocurrencies analysed (BTC, ETH) and their international nature, makes it difficult to adopt a uniform and consistent legal framework. In the authors' opinion, with the current legal status and development dynamics of the selected cryptocurrencies, i.e. BTC and ETH, as well as in the light of the market risk analysis conducted, they should be seen as speculative instruments rather than stable assets in investment portfolios. Their high price volatility, cross-border and decentralised nature, as well as their complex legal nature exacerbated by the lack of uniformity of legal qualification in trading, hinder their effective inclusion in a single regulatory framework in the future and, for non-professional investors, represent a particular source of risk that may become the subject of numerous legal claims in the future.

It should be noted that during periods of high trading volume and low liquidity, even relatively small shifts in investor sentiment can trigger a series of sharp price swings. Although, under normal market conditions, BTC or ETH may offer some diversification benefits (due to its low correlation with the returns of traditional financial assets). Numerous studies indicate that the aforementioned stabilising effect disappears in moments of crisis. GARCH models suggest that a collapse in the cryptocurrency

market can easily propagate through volatility channels and increasing correlations between cryptoassets and equity markets and other financial market segments. If such a collapse occurs during macroeconomic stress, the rapidly increasing volatility of cryptocurrencies can accelerate capital outflows, amplifying volatility in other markets.

In addition, the analysed GARCH(1,1) models with Student's t-distribution showed that cryptocurrencies have a higher probability of extreme events, which are not accounted for by simple normal distribution assumptions. Moreover, the results showed that periods of high volatility persist for exceptionally long periods of time. These issues have obvious implications for regulatory policy and monitoring of market phenomena. The high unpredictability of cryptocurrency prices requires special attention from regulators – not only because of possible losses for individual investors – but above all because of potential feedbacks between this segment and traditional financial market segments. Furthermore, due to the peculiarities of BTC and ETH, the provisions of the MICA Regulation will only be applicable to a limited extent, thus not providing sufficient protection for investors in this market.

In conclusion, the conducted research confirms that – with the current state of development and regulatory risks – the cryptocurrency market does not fulfil a stabilising function, representing a significant source of risk, which increases especially during periods of unexpected external shocks. Thus, the further development of the cryptocurrency market will require not only the refinement and harmonisation of regulatory solutions, in order to mitigate regulatory risks, but also the continuation of research into volatility, correlation structure and the identification of potential directions of financial capital flows, in order to effectively mitigate and manage risks in financial markets.

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