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OF ECONOMICS
AND BUSINESS

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Behavioural factors and informational efficiency of the Bitcoin market

Abstract of doctoral dissertation

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1. Research problem and justification of its selection

Informational market efficiency is a crucial research stream in finance. In an efficient market, information is available very quickly for all market participants. When investors make investment decisions based on a reliable analysis of such information, the market is 'efficient'. This means that prices reflect all available information, resembling the random walk (Fama, 1970). Thus, in an efficient market, investors can make more informed investment decisions, which in turn result in the efficient allocation of capital.

In reality, investors have limited knowledge and time, which makes it difficult to quickly preprocess market information. This may increase their tendency to use mental shortcuts (heuristics) instead of analysing information reliably, leading to a lack of market efficiency. Thus, investors' irrationality is related to a lack of market efficiency. This relationship is of particular importance for assets whose market valuations are being driven by speculation. Examples of such assets are cryptocurrencies. In recent years, these particular assets have attracted great attention due to their specific characteristics, including the lack of adequate supervision by any authorities and the high volatility. In such an environment, the process of making rational investment decisions becomes extremely challenging. Thus, cryptocurrency investors may act highly irrationally when making investment decisions. Consequently, the behavioural factors[1] may have a large impact on the price of cryptocurrency, resulting in a lack of market efficiency. Nevertheless, the relationship between behavioural factors and the cryptocurrency market efficiency has not yet been the subject of in-depth analysis. In the context of cryptocurrencies, it is impossible to clearly define a set of publicly available information that should be reflected in their prices. Therefore, this dissertation focuses on the level of market efficiency in a weak form, i.e. the degree to which the price behaviour reflects a random walk.

Previous studies have demonstrated that the level of cryptocurrency market efficiency varies over time (Urquhart, 2016; Bariviera, 2017; Caporale et al., 2018; Köchling et al., 2019a). Recently, researchers have focused on the association between behavioural factors and the level of cryptocurrency market efficiency. However, the extant literature has not yet provided conclusive evidence regarding the existence of this relationship (Chu, Zhang, & Chan, 2019; Mokni et al., 2024).

[1] Factors that hinder making rational investment decisions, e. g. investor sentiment.

The dissertation attempts to fill the research gap concerning the correlation between behavioural factors and the level of cryptocurrency market efficiency. Previous studies in this field (Chu, Zhang, & Chan, 2019; Mokni et al., 2024) have not included such factors as investor attention and the anchoring heuristic. However, these behavioural factors have an impact on the investment decisions of cryptocurrency investors (Kristoufek, 2013; Urquhart, 2017). Furthermore, there is no comprehensive conclusion regarding the association between investor sentiment and the level of cryptocurrency market efficiency.

So far, numerous studies in this area have focused almost exclusively on the level of cryptocurrency market efficiency. However, the current and past levels of market efficiency can be dependent and move into a cyclical pattern (Lo, 2004). This dissertation thus seeks to explore the association between behavioural factors and the changes in the level of cryptocurrency market efficiency in relation to the previous period, which was defined as the dynamics of market efficiency. Given that Bitcoin is the most popular and largest virtual currency in terms of market capitalisation, this digital asset was selected as a representative of the cryptocurrency market for the empirical study.

2. Research objectives and hypotheses

The main goal of the dissertation was to assess the relationship between selected behavioural factors and the informational efficiency of the Bitcoin market. This research aimed to achieve several specific objectives, which included:

1. Synthesising existing research on the cryptocurrency market efficiency,
2. Systematising the state of knowledge on the impact of irrational investor behaviour on the cryptocurrency market,
3. Assessing the usefulness of market efficiency tests for conducting research,
4. Defining methods for measuring behavioural factors,
5. Measuring the level of Bitcoin market efficiency in the weak form,
6. Assessing the relationship between anchoring heuristic, investor attention, sentiment and the dynamics of Bitcoin market efficiency.

This study attempted to verify three research hypotheses regarding the relationship between behavioural factors and the dynamics of Bitcoin market efficiency. The basis for

formulating the hypotheses was an original scheme that presented the impact of changes in market conditions on the dynamics of market efficiency (Diagram 1).

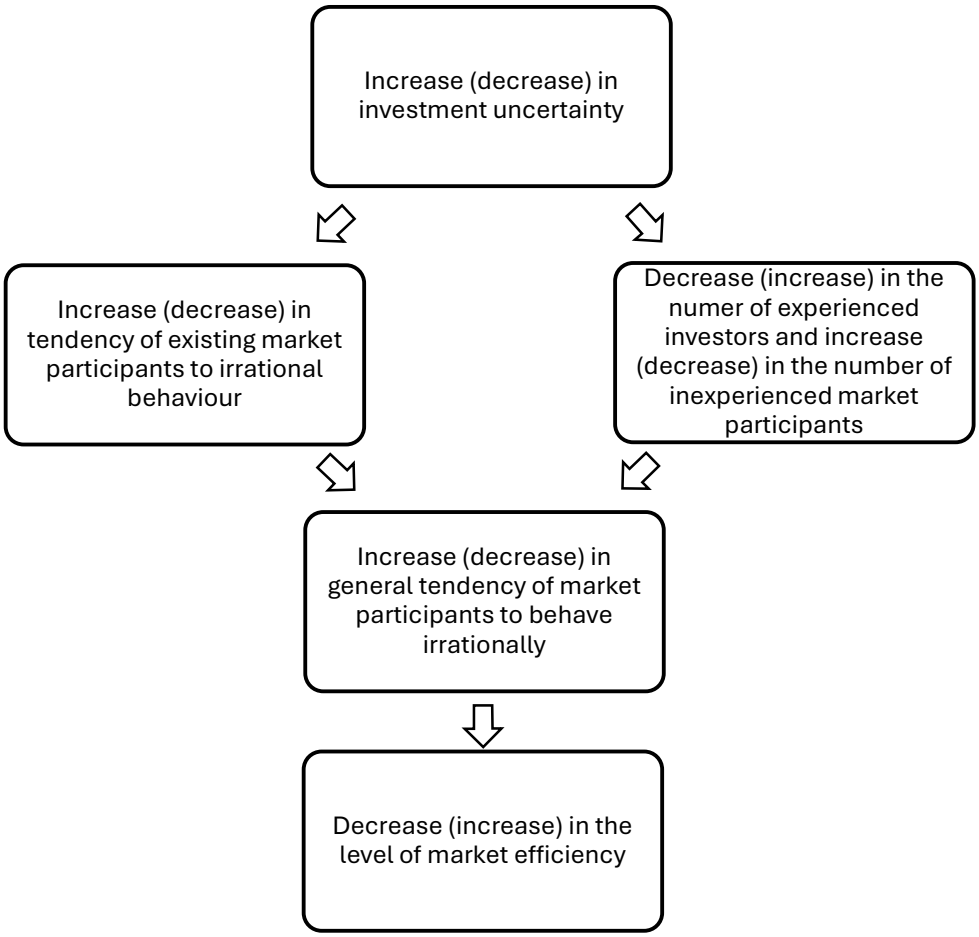

Diagram 1. The impact of changing market conditions on the dynamics of market efficiency
Source: Own work

As demonstrated in Diagram 1, an increase (decrease) in investment uncertainty may contribute to an increase (decrease) in the tendency of market participants to irrational behaviour and/or changes in the number of experienced and inexperienced investors. Investors with less experience are more likely to exhibit irrational behaviours, and so their prevalence may result in the reinforcement (or weakening) of the general tendency of market participants to behavioural biases. Consequently, the level of market efficiency may change over time. Additionally, given the tendency for individuals to respond more strongly to potential losses than to equivalent gains (Kahneman & Tversky, 1979), it was expected that negative sentiment would have a greater impact on investor behaviour than positive sentiment. Therefore, two detailed hypotheses were formulated as part of the second hypothesis. All verified hypotheses were as follows:

H1: An increase (or decrease) in investor attention in the Bitcoin market is associated with a decrease (or increase) in the level of Bitcoin market efficiency.

H2: An increase (or decrease) in investor sentiment is associated with a decrease (or increase) in the level of Bitcoin market efficiency.

H2A: An increase (or decrease) in positive investor sentiment is associated with a decrease (or increase) in the level of Bitcoin market efficiency.

H2B: An increase (or decrease) in negative investor sentiment is associated with a decrease (or increase) in the level of Bitcoin market efficiency.

H3: An increase (or decrease) in the tendency of investors to succumb to anchoring heuristics is associated with a decrease (or increase) in the level of Bitcoin market efficiency.

3. The structure of the dissertation

The dissertation consists of four chapters. The first section begins with the introduction of the theory of market efficiency, encompassing such concepts as the Efficient and Adaptive Market Hypotheses (AMH), as well as the Fractal Market Hypothesis. This theoretical framework provides a foundation for the discussion of the findings. The chapter also presents the various methods for measuring market efficiency and reviews them critically, thus allowing for the selection of the most suitable methods for empirical research. The further part of this chapter characterises the cryptocurrency market, thereby enabling to understand how specific features of cryptocurrency may affect its informational efficiency. The chapter concludes with the presentation of outcomes of the systematic review concerning the cryptocurrency market efficiency, thereby allowing for the precise identification of the research gap.

The second chapter is devoted to behavioural finance. The first section describes examples of irrational investor behaviour in the financial market. The subsequent section covers the systematisation of the measures of behavioural factors. This chapter also presents the findings of a systematic literature review on the role of behavioural factors in the cryptocurrency market. The final section describes the implications of the Adaptive Market Hypothesis and the results of prominent studies in this field. This theoretical framework provides a foundation for the development of hypotheses.

The third chapter of the thesis is devoted to the presentation of the methodological approach. The initial section presents and describes the scheme of the impact of changing market conditions on the dynamics of market efficiency. The following section discusses a methodology for analysing the dynamics of market efficiency. The chapter also presents the details of the measurement of selected behavioural factors and control variables.

The fourth chapter is devoted to the presentation of the results of the empirical study. The first section covers the analysis of the dynamics of Bitcoin market efficiency. The subsequent section presents and interprets the results of the model estimation regarding the association between behavioural factors and the dynamics of Bitcoin market efficiency. This enables the verification of the research hypotheses. The following section describes the findings of additional analyses that focus on the relationship between behavioural factors and Bitcoin market efficiency, with the use of different measures than the Hurst exponent. The chapter concludes with a discussion of the findings, especially in the context of the various structures of Bitcoin investors. The final section of the dissertation summarises the findings, with particular emphasis on the conclusions, implications and limitations of the study. The last part outlines a number of perspectives for future research.

4. The design of the empirical study

The empirical research consisted of several stages. The first step was the measurement of the dependent variable (the dynamics of Bitcoin market efficiency), which was defined as the difference between subsequent absolute deviations of the Hurst exponent from its reference value (0.5). This can be expressed by the following formula:

$$Zm\_ef_t = -(|H_t - 0.5| - |H_{t-1} - 0.5|) \quad (1)$$

where Zm_ef_t means the change in the level of market efficiency during month 't' in relation to the previous month 't-1', H_t denotes the value of the Hurst exponent during period 't'. Positive (negative) values of the dependent variable indicate an increase (decrease) in the level of Bitcoin market efficiency relative to the previous month. The Hurst exponent values were estimated using Multifractal Detrended Fluctuation Analysis (MF-DFA) based on hourly Bitcoin returns obtained from the Bitstamp exchange over the period from December 2013 to June 2023.

In the second stage, the explanatory variables were measured based on various time-series data. Investor attention in the Bitcoin market was approximated using monthly and daily

indices of Google searches for the word 'bitcoin' (GSV). The investor sentiment was determined based on monthly Google search indices for words and phrases with negative and positive connotations, related to economics and finance, as inspired by Da et al. (2015). In this manner, the negative ($FEARS$) and positive ($GREED$) investor sentiment indexes were measured separately. The measure of investors' propensity to succumb to anchoring heuristics was the deviation of the average monthly Bitcoin price from its historical maximum over the previous 12 months ($W52$). The control variables were as follows: Bitcoin market capitalisation (MC) and market liquidity proxied using Amihud's (2002) measure ($ILLIQ$), trading volume (Vol), and the Volatility Index (VIX).

In order to verify the research hypotheses, the present study applied ADL (Autoregressive Distributed Lag) and ARMA (Autoregressive Moving Average) models. All ADL models used Newey-West (1987) heteroskedasticity and autocorrelation consistent standard errors and were estimated using the Ordinary Least Squares (OLS). For estimating the ARMA model parameters, the Maximum Likelihood Estimator (MLE) was utilised. The basic form of the model was as follows:

$$Zm\_ef_t = a_0 + a_1 Zm\_ef_{t-1} + a_2 Zm\_ef_{t-2} + \beta_1 \Delta GSV_t + \beta_2 FEARS_t + \beta_3 GREED_t + \beta_4 \Delta W52_t + \beta_5 \Delta ILLIQ_t + \beta_6 \Delta ILLIQ_{t-1} + \beta_7 \Delta Vol_t + \beta_8 \Delta MC_t + \beta_9 \Delta VIX_t + \varepsilon, \quad (2)$$

To provide a more comprehensive picture of the relationship between behavioural factors and the dynamics of Bitcoin market efficiency, this research also applied two additional measures of market efficiency: the variance ratio test statistic and the fractional differencing parameter using the estimator proposed by Geweke and Porter-Hudak (1983).

5. Main findings

In financial markets, the large price changes are frequently associated with high uncertainty episodes, such as economic crises. The present study showed that some cryptocurrency uncertainty events coincide with large changes in the dynamics of Bitcoin market efficiency, which quickly reverted. Thus, from this perspective, the Adaptive Market Hypothesis appears to adequately reflect the behaviour of cryptocurrency investors. The dynamics of Bitcoin market efficiency is presented in Figure 1.

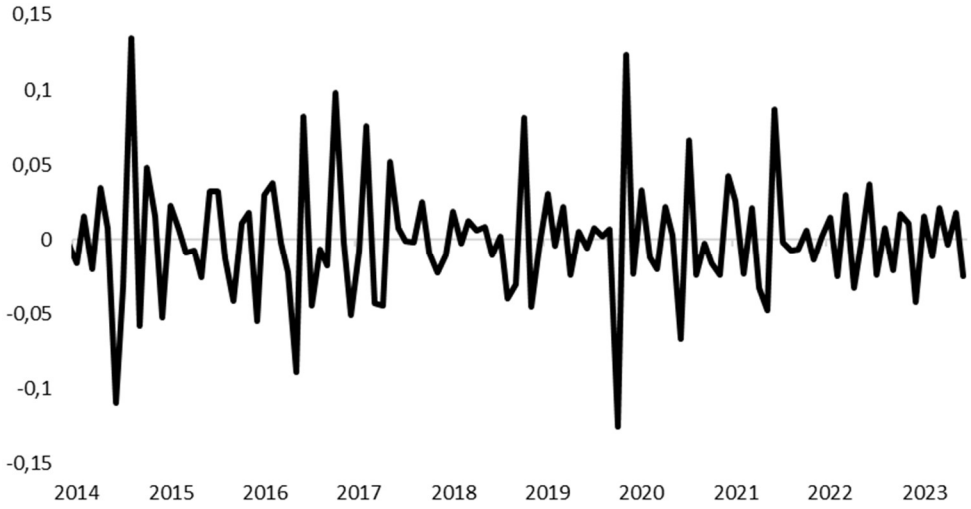

Figure 1. Monthly changes in the level of Bitcoin market efficiency

Source: Own work

According to the AMH, the changes in the market conditions are expected to result in a strengthened association between the dynamics of Bitcoin market efficiency and behavioural factors. The latter relationship was verified based on parameter estimates of the ADL and ARMA models. The results of the estimated models are reported in Table 2.

The conducted empirical research did not support the hypotheses H1, H2 and H3. However, the estimates of the ADL model parameters with the Hurst exponent showed that an increase in positive investor sentiment is correlated with an increase in the level of Bitcoin market efficiency (and other way around). However, the sign of the parameter estimate of positive investor sentiment was opposite to that expected under hypothesis H2A, which can be explained by the behaviour of inexperienced investors. It is possible that an increase in positive sentiment causes an increase in the number of less experienced investors due to their greater tendency to behavioural biases (Bashall et al., 2018). Consequently, the level of market liquidity may increase, and this is positively correlated with the level of Bitcoin market efficiency, as supported by the findings.

The negative relationship between behavioural factors and the dynamics of Bitcoin market efficiency has not been confirmed in the case of the other models. The outcomes of ADL models with various measures of market efficiency did not change the main conclusions regarding the association between behavioural factors and the dynamics of Bitcoin market efficiency. The reliability of the results was also confirmed by the coefficient estimates of the ARMA model. The estimated coefficients for the control variables, including Bitcoin market liquidity and trading volume, were consistent with those reported in previous studies.

Table 2. The results of estimating the models regarding the association between behavioural factors and the dynamics of Bitcoin market efficiency

Model type	**ADL**	**ADL**	**ADL**	**ARMA**
Measure of market efficiency	*H*	*AVR*	*GPH*	*H*
Variable	**Coefficient**			
Constant	-0.00034 (0.00195)	0.00479 (0.07029)	0.08416 (0.11096)	-0.00029 (0.00030)
Zm_ef_(t-1)	-0.58394*** (0.07971)	-0.53075*** (0.08183)	-0.67287*** (0.11564)	-0.13673 (0.14060)
Zm_ef_(t-2)	-0.43502*** (0.07330)		-0.62697*** (0.16389)	-0.34772*** (0.11800)
Zm_ef_(t-3)			-0.33468** (0.12931)	-0.14702 (0.12639)
Zm_ef_(t-4)			-0.25591** (0.11787)	-0.23582** (0.11257)
Zm_ef_(t-5)			-0.15822 (0.09828)	-0.20686** (0.10542)
Zm_ef_(t-6)				-0.26609*** (0.10308)
MA(1)				-0.82653*** (0.11583)
ΔGSV_t	-0.00089 (0.00998)	-0.09493 (0.46562)	0.45314 (0.67018)	-0.00417 (0.00687)
FEARS_t	-0.00153 (0.00747)	-0.11274 (0.30395)	-0.30486 (0.41961)	-0.00058 (0.00223)
GREED_t	0.01214* (0.00722)	0.25430 (0.25858)	-0.19218 (0.40270)	0.00791 (0.00569)
ΔW52_t	0.00575 (0.01549)	-0.08791 (0.65280)	-0.43554 (0.96611)	0.00262 (0.00501)
ΔILLIQ_t	0.00846* (0.00431)	0.02924 (0.16177)	0.35124* (0.19387)	0.00741** (0.00353)
ΔILLIQ_(t-1)	0.00244 (0.00349)	0.09198 (0.13551)	-0.01790 (0.21805)	-0.00646* (0.00340)
ΔVol_t	0.01018 (0.00719)	0.48234* (0.26184)	0.55178 (0.41292)	0.00993** (0.00473)
ΔMC_t	-0.00553 (0.01423)	-0.33261 (0.59405)	-0.92822 (0.73415)	-0.00398 (0.00579)
ΔVIX_t	-0.00373 (0.01519)	-0.83668 (0.71017)	-0.91411 (0.76989)	0.00530 (0.01126)
Observations	112	113	109	108
Adjusted R^2	0.325	0.243	0.328	
AIC				-518.79
BIC				-469.70

Notes: *'H' means the Hurst exponent, 'AVR' is the variance ratio test statistic, and 'GPH' denotes the fractional integration parameter estimated using GPH. ***, **, * denote statistical significance at the level of, respectively, 1%, 5%, 10%.*

6. Concluding remarks

The empirical results have important theoretical implications. The findings suggest that an increase in positive investor sentiment is related with an increase in the level of Bitcoin market efficiency. If an increase in positive investor sentiment results in a rise in the number of inexperienced investors, then the diversity in the investment horizons of Bitcoin market participants may increase, causing a rise in the market liquidity. As demonstrated by the results, an increase in the level of market liquidity leads to a higher degree of informational efficiency. The findings also highlight that positive investor sentiment is the most prominent

driver of the dynamics of Bitcoin market efficiency among different behavioural factors. Thus, the AMH could be extended by including the distinction in investor behaviour between positive and negative sentiment, as well as the role of diversity in the investment horizons of market participants in shaping informational efficiency.

The findings of the study can be applied in practice. This research demonstrates that Bitcoin is not informationally efficient, as manifested by the autocorrelation of returns. Consequently, Bitcoin prices can be predicted based on their historical prices. The findings also suggest that behavioural factors do not play a crucial role in this phenomenon. Thus, regardless of the intensity of behavioural factors, historical prices of Bitcoin may be valuable information for investors in the context of the profitability of investment strategies.

Another implication of the study comes from the fact that the Hurst exponent was used to capture market efficiency. Previous research has suggested that the large changes in the Hurst exponent value (or transitions from long-term to short-term memory of returns) precede substantial price declines due to market crashes (Grech & Mazur, 2004). Such events have the potential to cause strong panic or fear among investors. However, the findings reveal that the Hurst exponent values are unrelated to behavioural factors. Thus, large changes in the value of the Hurst exponent may predict sharp drops in Bitcoin prices.

The results of the dissertation suggest several directions for future research. The present study has not confirmed the association between the monthly informational efficiency of Bitcoin and behavioural factors. Hence, future works could potentially analyse this relationship in different time frequencies. A promising avenue for further research is also the utilisation of measures of market efficiency that reflect different dimensions of the random walk than linear increase in variance over time and independence of returns. Future research in this area could also include different behavioural biases, such as social media sentiment and investors' attention to environmental slogans. Another possibility is to extend the scope of the current research beyond Bitcoin. The characteristics of other cryptocurrencies have the potential to trigger investors' irrational behaviour, which should impact the dynamics of market efficiency. The results of the dissertation also open promising new avenues of research that could deepen the understanding of the importance of behavioural factors for the relationship between investment uncertainty and the level of market efficiency.