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Managing economic profitability and operational efficiency by applying blockchain technology

Upravljanje ekonomskom profitabilonošću i operativnom efikasnošću primenom blockchain tehnologije

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Abstract

In the modern business environment, digital transformation is a key factor of sustainable competitiveness. The aim of this paper is to empirically examine how the level of blockchain technology adoption affects the management of operational efficiency and company profitability. The research was conducted on a sample of 100 companies from the EU, the United Kingdom, and the Western Balkans, with the final analytical sample including 76 companies that implemented blockchain technology and 24 companies that didn't install these technologies. Using descriptive statistics, correlative analysis, multiple linear regression, and mediation analysis, the results showed that blockchain technology doesn't have a statistically significant direct impact on the management of operational efficiency and profitability. However, in the sample, a positive pattern was observed, suggesting potential long-term effects. Operational efficiency was confirmed as a strong predictor of profitability (r = 0.991), but its mediation effect was not statistically confirmed. This research provides a realistic insight into the effects of digital technologies and emphasizes the importance of organizational maturity.
Keywords: *blockchain technology, operational efficiency, economic profitability, digital transformation*

Sažetak

U savremenom poslovnom okruženju, digitalna transformacija postaje ključni faktor održive konkurentnosti. Cilj ovog rada je empirijski ispitati kako nivo primene blockchain tehnologije utiče na upravljanje operativnom efikasnosti i profitabilnosti kompanija. Istraživanje je sprovedeno na uzorku od 100 kompanija iz EU, Ujedinjenog Kraljevstva i zapadnog Balkana, pri čemu je konačni analitički uzorak obuhvatio 76 kompanija koje su implementirale blockchain tehnologiju, a 24 kompanije koje su isto obuhvaćene nisu instalirale ove tehnologije. Primenom deskriptivne statistike, korelacione analize, višestruke linearne regresije i mediacione analize, rezultati pokazuju da blockchain tehnologija nema statistički značajan direktan uticaj na upravljanje operativne efikasnosti i profitabilnosti. Međutim, uočen je pozitivan obrazac u uzorku, što ukazuje na potencijalno dugoročne efekte. Operativna efikasnost potvrđena je kao snažan prediktor profitabilnosti (r = 0,991), ali njen mediacioni efekat nije statistički potvrđen. Istraživanje pruža realističan uvid u efekte digitalnih tehnologija i naglašava značaj organizacione zrelosti.
Ključne reči: *blokčejn tehnologija, operativna efikasnost, ekonomska profitabilnost, digitalna transformacija*

1. Introduction

In the contemporary business environment, digitalization has become one of the key drivers of organizational transformation and the management of modern enterprises (Mambetova et al., 2021). When combined with globalization and increasing labor mobility, it creates pressure for continuous improvement of corporate performance and shapes new patterns of behavior, decision-making, and competitiveness. The application of modern technologies aims to improve performance, competitiveness, and the sustainable development of companies in the coming period, under conditions of global competition. "Digital transformation entails the integration of digital technologies into all aspects of business operations, enabling hospitality establishments

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to improve operational efficiency, optimize processes, and enhance the customer experience" (Vukolić et al., 2025, p. 2). Within this broader context, blockchain technology has emerged as one of the most revolutionary innovations of the 21st century. As such, blockchain has found applications across multiple industries, most notably in finance, but also in logistics, healthcare, public administration, and other sectors. Furthermore, it has an increasing impact on various spheres of business, especially in financial and industrial management (Antanasković et al., 2025, p. 1).

Despite its growing popularity and expanding use cases, there is still a noticeable lack of empirical, quantitatively oriented research that examines the real effects of blockchain adoption on company performance, particularly its influence on operational efficiency and profitability. Existing studies are largely conceptual, theoretical, or based on case analyses, while the number of publications relying on real-world company data remains limited. This research gap represents the core focus of this paper: to what extent, and in what way, does the level of blockchain adoption influence the operational efficiency and profitability of modern companies.

Building on these considerations, this study focuses on investigating the actual business impact of blockchain implementation. More specifically, we examine how different levels of blockchain adoption affect operational efficiency and profitability. To address this research question, we conducted an empirical study using quantitative and exploratory methods on a sample of 100 companies from the European Union, the United Kingdom, and the Western Balkans. The analysis relies on multiple regression models and mediation techniques, complemented by nonlinear transformations of variables. The overarching aim is to provide an unbiased and realistic assessment of whether blockchain adoption, across different levels of implementation, contributes to improvements in operational performance and financial outcomes.

The structure of the paper is as follows. After the introduction, the second chapter provides a review of the relevant literature on blockchain technology and business performance. The third chapter outlines the research methodology, including the sample, variables, and statistical techniques used in the empirical analysis. The fourth chapter presents the results, including a graphical and tabular interpretation of the findings and their implications for the formulated hypotheses. The final chapter summarizes the main conclusions, offers practical recommendations for managers and policymakers, and outlines directions for future research.

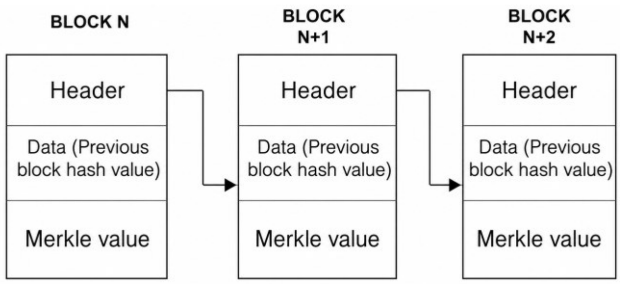
2. Literature review

Blockchain technology is widely recognized as one of the most significant technological developments emerging from the broader wave of digital transformation. Introduced in October 2008, it is defined as a decentralized, distributed, and cryptographically secured database that enables safe, transparent, and immutable recording of transactions among multiple parties, without the need for a central intermediary. Initially created to support cryptocurrencies such as Bitcoin, blockchain has since gained broad relevance not only in finance but also across many other industries (Zsarnoczky, 2018).

At its core, blockchain is an advanced data-management technology that enables transparent movement, sharing, and storage of information within a peer-to-peer business network. The foundation of any blockchain system is its decentralized database, which ensures transparency, traceability, and resistance to manipulation. This directly increases trust among participants, strengthening the integrity of business processes (Antanasković et al., 2025).

Blockchain operates by grouping information into blocks and linking them into a chain, creating a continuous and secure digital ledger. Because the data is distributed across many computers within the network, the integrity of stored information is preserved and the possibility of manipulation significantly reduced. One of its defining features is immutability: once stored, data cannot be retroactively changed, making blockchain particularly suitable for business systems and industrial applications. "The blockchain concept was presented by Satoshi Nakamoto in the year 2008 by using consensus protocol. The blockchain functions as a secure, decentralized digital ledger that stores information about transactions, including time, date, price, and participants. Data integrity, security, trustworthiness, and decentralization are blockchain's four main qualities, which are intended to increase trust and safety" (Minović, 2017). As illustrated in Figure 1, each block within the blockchain chain contains data, a unique identifier, and the hash value of both the preceding and the current block.

Figure 1. Blocks in the Blockchain Chain



Source: Adapted from Iansiti and Lakhani (2017).

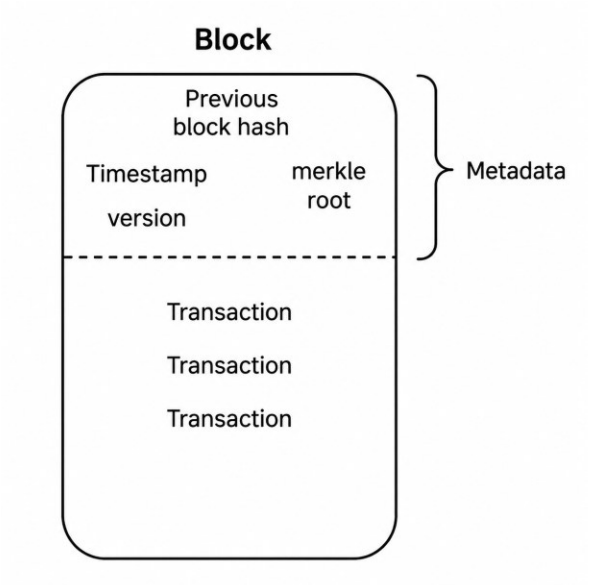
The structure of individual blocks may differ depending on the blockchain platform used - for example, Ethereum-based blocks differ from those on Solana (Kayikci & Khoshgoftaar, 2024).

In general, each block contains the following key elements (Matejić et al., 2025):

– Data saved in the form of a sequence of characters;
– A unique identifier;
– The hash value of the previous block;
– The hash value of the current block, representing a digital "fingerprint" of the stored data.

Each block includes a header with essential metadata such as version, timestamp, reference to the previous block, identification number, technical parameters, and the Merkle root. The body of the block contains the transactions themselves and the number of entries recorded. The detailed structure of an individual block is illustrated in Figure 2.

Figure 2. Architecture of a block



Source: Adapted from Sheth & Dattani (2019).

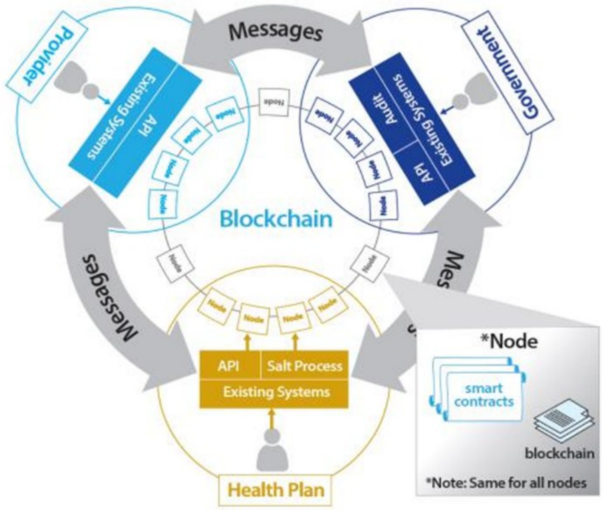
“Cryptography lies at the heart of blockchain technology. It ensures the security of transactions and protects data confidentiality. Each block contains the hash of the previous block, which preserves data integrity and prevents unauthorized changes. Additionally, cryptographic keys are used to authenticate network participants, preventing abuse and unauthorized access” (Antanasković et al., 2025).

Because every block includes the hash of the previous one, altering a single block would require changing every subsequent block, making manipulation practically impossible. The Merkle root, the cryptographic hash at the top of the Merkle tree, enables fast and secure verification of data accuracy within the block.

To maintain the integrity of a decentralized network without a central authority, blockchain relies on consensus mechanisms. These protocols allow network participants to collectively validate new transactions and blocks (Xiao et al., 2020). The two most widely known mechanisms are Proof-of-Work and Proof-of-Stake. Both mechanisms enable the network to reach agreement on the accuracy of the ledger, eliminating the need for a central entity. “Blockchain is a system where the need for a central authority to verify a transaction is eliminated” (Ikeda & Hamid, 2018).

Following the initial success of Bitcoin, blockchain began to gain widespread attention. New cryptocurrencies and platforms emerged, including Ethereum, known for the introduction of “smart contracts” (Rozario & Thomas, 2019), which significantly expanded the potential use of blockchain beyond finance. Smart contracts enable automated execution of predefined rules, making blockchain applicable in different industries. The application of smart contracts in healthcare is illustrated in Figure 3.

Figure 3. Blockchain application of smart contracts in healthcare



Source: Adapted from Stagnaro (2017).

Distributed Ledger Technology (DLT) represents a broader concept within which blockchain is one specific type. Unlike blockchain, DLT does not necessarily rely on blocks or linear chains of data. Instead, it is based on a decentralized database simultaneously managed by multiple participants. Because all participants hold copies of the database, transparency increases, while the risk of manipulation decreases. Transaction-validation costs are minimized since participants synchronize through a shared system. In this way, DLT enables more efficient and secure data exchange within business networks, even though it is not always strictly tied to blockchain technology (Alt & Gräser, 2025). Given this structure, every blockchain is a DLT system, but not every DLT system is a blockchain.

As previously said, the components of blockchain systems, including blocks, decentralized architecture, cryptography, consensus mechanisms, and DLT, together form a secure, transparent, and efficient platform for data management and transaction processing. These features provide organizations with opportunities to optimize processes, reduce costs, and improve trust, thereby enhancing operational efficiency and profitability. Its key features, security, transparency, and speed, make it the basis of the digital transformation of business in the 21st century and an essential factor of competitive advantage in the modern business environment (Smith, 2019).

Operational efficiency is commonly defined in the literature as the relationship between outputs and costs, or the company’s ability to maintain or increase value creation while keeping costs at the same or lower levels (Neely et al., 1995). Porter defines operational efficiency as “deliver greater value to customers or create a comparable value at lower costs or both” (Porter, 1996).

Profit is defined as the difference between total revenue generated and total costs, that is, the portion of revenue that remains after all expenses have been settled, and it serves as an indicator of a company's long-term sustainability. A company's profitability represents its ability to generate a positive difference (profit) relative to the resources invested, and is considered the ultimate indicator of effective management and the sustainability of the chosen business model. In empirical research, profitability is most commonly measured using one of the following indicators: return on assets (ROA), return on equity (ROE), profit margin, and EBITDA (Ross et al., 2019).

Modern literature increasingly points to a connection between the use of blockchain technology and business performance, particularly in terms of improvement. Its application, through decentralization, greater transparency, reduced transaction costs, elimination of intermediaries, process automation, and the use of smart contracts can contribute to enhancing business quality and the sustainability of the business model, as demonstrated in the previously cited sources such as Xiao et al., 2020; Kayikci & Khoshgoftaar, 2024. However, numerous empirical limitations are still evident. While it is undeniable that blockchain technology and its application has the potential to enhance business performance, the literature also points to several obstacles (regulatory, technological such as interoperability issues, lack of standardization, etc.) that hinder and slow down its widespread adoption (Hughes et al., 2019).

Empirical researches that have directly examined the relationships between blockchain technology adoption and financial performance are still rare. Queiroz and Wamba (2019) found, on a sample of companies fm India and US, that the main barriers to widespread blockchain adoption are the lack of standardization, regulatory uncertainty as organizational resistance. Kouhizadeh et al. (2021) proved that blockchain can contribute to the sustainability of supply chains, but that the effects are only visible after a longer period of integration. Clohessy and Acton (2019) identified organizational factors as key moderators of the impact of blockchain on performance. Saberi et al. (2019) emphasize that, even if blockchain has the potential to reduce transaction costs and increase transparency, most companies are still in the experimental phase of its implementation. These findings indicate the need for cautious interpretation of blockchain effects, and they form the theoretical basis for setting hypotheses of the paper.

Taking into account all the previously stated facts, the scientific basis for examining the impact of blockchain technology implementation on improving a company's business performance is reflected in the following logical connections:

- Level of blockchain technology adoption → improvement of operational processes (faster workflows, lower costs, better data management);
- Improvement of operational processes → increase in operational efficiency (fewer resources used for the same or higher output value);
- Increased operational efficiency → higher profitability (lower unit cost, higher revenue, better margins).

This paper examines these relationships on a sample of modern European companies.

3. Data and methodology

The research was implemented on a sample of 100 companies from the European Union, the United Kingdom, Switzerland, and the Western Balkans during the period of 2023 and 2024, supplemented with additional research performed in the first half of 2025. This means that the study relies on a cross-sectional design, i.e., the data reflect a single time snapshot.

The empirical research was carried out from 2023 to 2025. Primary data were collected through a survey questionnaire during 2023 and 2024 with the aim of determining the level (intensity) of blockchain technology adoption in the observed companies. Secondary research, based on the analysis of financial statements, was conducted in 2025, after the official publication of the 2024 financial reports. Based on these data, the indicators of operational efficiency and profitability were calculated and used in the subsequent empirical analysis.

The sample is dominated by companies primarily from the financial sector, followed by logistics and technology, because a significant number of firms in these areas had already implemented blockchain technology to varying degrees. In the primary research phase, managers at different hierarchical levels were anonymously surveyed. The secondary research was conducted using publicly available data related to operational efficiency and profitability indicators of the sampled companies. The underlying assumption of the research framework is that blockchain technology can have multiple effects on the quality and sustainability of business operations. In this context, the sample was formed according to the principle of convenience sampling, with the requirement that companies must have available data for calculating operational efficiency and profitability indices, which serve as the dependent variables and are an essential part of the complete sample. This approach is scientifically grounded in research on new technologies and innovation, where limiting factors often include low transparency and limited availability of relevant data (Etikan et al., 2016). Because of this, we state with high confidence that the size and diversity of the sample enable the derivation of relevant conclusions, since strictly random samples are practically unattainable in research dealing with emerging technologies and digitalization.

The research problem is to examine the influence of blockchain technology adoption, as a core driver of digital transformation, on operational efficiency and profitability. The goal of the research is to empirically analyze, using a quantitative sample of 100 companies from various industries and with different intensities of blockchain implementation, the direct effect of blockchain adoption (as a tool) on operational efficiency and

profitability. At the same time, the research aims to investigate the mediating role of operational efficiency between the level of blockchain implementation and company profitability. In this context, the following hypotheses have been formulated:
H1: The level of blockchain technology adoption has a positive, nonlinear, and statistically weak effect on increasing operational efficiency in modern companies.
H2: The level of blockchain technology adoption does not have a direct effect on increasing company profitability; rather, the actual effect depends on the implementation phase of blockchain technology and the company's technological maturity.
H3: Operational efficiency represents an important determinant of profitability as well as a partial mediator between blockchain adoption and increased company profitability.

In the third hypothesis, the starting assumption is that the effect of blockchain technology on profitability can be indirect, rather than purely direct. For this reason, the intention was to test the mediating role of operational efficiency. In other words, blockchain technology is expected to influence profitability indirectly by improving operational efficiency.

To empirically verify the stated hypotheses, multiple regression models with nonlinear variable transformations were applied (Sarstedt & Mooi, 2014), as well as mediation analysis (Preacher & Hayes, 2008; Baron & Kenny, 1986; Hayes, 2018), allowing the identification of both direct and indirect effects of blockchain technology on operational efficiency and company profitability.

From the initial sample of 100 companies, the final analytical sample included 76 companies. The elimination criterion for the 24 companies was that they didn't have blockchain technology implementation (level 0). With respect to the aim of the paper, which is to examine the effects of different levels of blockchain implementation, companies without implementation of it cannot contribute to the analysis of the variability of the independent variable. Having this in mind, they are excluded from the regression and mediation analyses, but they are maintained in the descriptive analysis of Table 1. All descriptive statistics in Table 2 and subsequent regression analyses refer exclusively to the analytical sample of 76 companies with blockchain implementation levels 1 to 3. This limits the possibility of reporting findings about the effect of blockchain comparing it to complete non-adoption of the technology, which is acknowledged as a limitation of the study.

The conducted research is quantitative, empirical, and explanatory, meaning that, based on the stated objective, the study tests causal relationships in accordance with the formulated hypotheses (Saunders et al., 2019). Within the empirical analysis, multiple regression and mediation analysis were applied, including nonlinear transformations of variables (squared terms) with the goal of identifying nonlinear effects.

Table 1. Sample Characteristics

Sample	Sample Category	N	Share in the sample (%)
Size of the company			
	Small	29	29
	Middle	40	40
	Big	31	31
Country (Region)			
	EU	88	88
	West Balkan	5	5
	Switzerland	5	5
	United Kingdom	2	2
Sector			
	Financial	58	58
	Industry	8	8
	IT	5	5
	Logistic	4	4
	Energy	2	2
	Consulting	12	12
	Pharmacy	3	3
	Other	8	8
Manager level			
	Top	24	24
	Middle	61	61
	Lower	15	15
Blockchain level			
	0-without	24	24
	1-low level	14	14
	2-middle level	24	24
	3-high level	38	38

Source: Authors

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In the initial phase of the analysis, correlation analysis was applied to examine the strength and direction of relationships between variables, followed by multiple regression and mediation analysis (Hair et al., 2019). The independent variable is the level of blockchain technology adoption (Blockchain Level), while the dependent variables are operational efficiency (Operational Efficiency) and profitability (Profitability). To examine potential nonlinear relationships, squared variables (BL^2, OE^2) were included in the models. This allows testing for saturation effects and changes in the marginal impact of blockchain technology on operational and financial performance.

To measure the intensity of blockchain technology adoption, a Likert scale (Hair et al., 2019) is used with the following values: 0–no adoption, 1–low level of adoption, 2–medium level of adoption, and 3–high level of adoption, i.e., full integration of this technology into business processes. The selected 0–3 interval aims to provide a precise categorization of adoption intensity, ensuring that respondents' answers are unambiguous and clearly differentiate the degree of adoption. In this way, respondent subjectivity is reduced, their hesitation minimized, and the likelihood of obtaining imprecise responses is lowered. In situations where constructs are conceptually well-defined, ordinal scales with fewer levels can achieve good reliability. Additionally, the Likert scale makes it possible to convert qualitative information on the level of blockchain adoption obtained from respondents into quantitative values suitable for statistical modeling (Boone & Boone, 2012).

The questionnaire for assessing the level of implementation of blockchain technology contained the following questions: (1) Does your company use blockchain technology? (yes/no); (2) To what extent is blockchain integrated into core business processes? (scale 0-3, where 0 means no implementation, 1 – experimental phase or pilot project, 2 – partial implementation in certain departments, 3 – full integration into key business processes); (3) What types of blockchain applications does the company use? (smart contracts, supply chain management, financial transactions, other). The respondents were managers at different hierarchical levels (top, middle, lower management). The answers were compared with publicly available information on the companies' technological maturity (reports, press releases) to reduce the bias of self-assessment. Construct validation was carried out through a preliminary study on 10 companies (pilot test), where a high agreement between the managers' assessment and the actual situation was determined (Cohen's kappa = 0.82).

Construct validity is ensured through the theoretical grounding of the variable "level of blockchain technology adoption" in the relevant literature (Clohessy & Acton, 2019; Saberi et al., 2019), in accordance with the standard methodological approach to construct validity (Cronbach & Meehl, 1955; Hair et al., 2019).

In this paper, operational efficiency was measured using numerical values from published financial statements and expressed as an operational efficiency index (Agencija za privredne registre, n.d.-a, n.d.-b; Handelsregister, n.d.; Narodna banka Srbije, n.d.; Neely et al., 1995; Ross et al., 2019; Unternehmensregister, n.d..). Specifically, a composite efficiency index was constructed based on the standardized values of selected indicators such as ROE, ROA, profit margin, and asset turnover. To enable comparability across companies, individual indicator values were transformed to a 0 (lowest) -100 (highest) efficiency scale. Standardization was performed using min–max normalization, while operational efficiency was calculated using the following formula:

Formula of the composite efficiency index (EI):

$$EI_i = \sum_{j=1}^{n} w_j \cdot x_{ij}^{norm} \tag{1}$$

where:

EI_i – operational efficiency index for the ***i***th company

n – number of selected indicators (e.g., ROA, ROE, profit margin, asset turnover)

w_j – weight of indicator ***j*** in the index (if all indicators are equally important $w_j = \frac{1}{n}$)

x_{ij}^{norm} – normalized value of indicator ***j*** for company ***i***,

transformed to the 0 - 100 interval using min–max normalization:

$$x_{ij}^{norm} = \frac{x_{ij} - x_j^{min}}{x_j^{max} - x_j^{min}} \cdot 100 \tag{2}$$

where:

x_{ij} – original value of indicator ***j*** for company ***i***

x_j^{min}, x_j^{max} - minimum and maximum value of the indicator within the sample

Profitability, as the second dependent variable in the study, was also measured using a composite index formed on the basis of financial indicators typically used to assess profitability. The profitability index was constructed by transforming the standardized values of indicators such as net profit margin, EBITDA ratio, ROA, and ROE (Agencija za privredne registre, n.d.-a, n.d.-b; Hair et al., 2019; Handelsregister, n.d.; Narodna banka Srbije, n.d.; Ross et al., 2019; Unternehmensregister, n.d.). The same min-max normalization approach was applied to ensure comparability across companies. The construction of the profitability index follows the OECD methodology for composite indicators (OECD, 2008; Saberi et al., 2019), while the selection and interpretation of indicators are aligned with standard financial literature (Hair et al., 2019; Ross et al., 2022). The final profitability index value represents the arithmetic mean of the normalized profitability indicators.

Formula of the profitability index (PI):

$$PI_i = \sum_{j=1}^{m} w_j \cdot P_{ij}^{norm} \tag{3}$$

where:

PI_i – profitability index for company ***i***

m – number of profitability indicators (in this study *m = 3*: ROA, ROE, net profit margin)

w_j – weight of indicator ***j*** (in the case of equal importance $w_j = \frac{1}{m}$)

P_{ij}^{norm} - normalized value of profitability indicator ***j*** for company ***i***, obtained using min-max normalization:

$$P_{ij}^{norm} = \frac{P_{ij} - P_j^{min}}{P_j^{max} - P_j^{min}} \cdot 100 \tag{4}$$

At the end of the sample description, we note several methodological limitations that the authors considered when interpreting the results, even though the sample size allows the application of advanced statistical models:

– The sample was formed using convenience sampling, which limits the generalizability of the results. However, this approach is methodologically justified in research on new technologies where complete databases are unavailable and data transparency is limited (Etikan, Musa, & Alkassim, 2016).
– The use of a Likert scale for categorizing blockchain adoption levels carries the risk of subjective responses from survey participants. Nevertheless, this methodology is widely used and acceptable in studies on technological maturity where more precise quantitative indicators are not available (Boone & Boone, 2012).
– Due to the cross-sectional nature of the study, it is not possible to track changes over time.
– The extremely high correlation between operational efficiency and profitability may partially reflect the methodological construction of composite indices based on overlapping financial indicators. A potential limitation of this study stems arises from the construction of composite indices for operational efficiency and profitability. Specifically, both indices are partially based on similar financial indicators (e.g., ROA, ROE, profit margin), which may result in a high level of correlation between these variables. Consequently, the strong relationship observed between operational efficiency and profitability should be interpreted with caution, as it may partially reflect methodological overlap rather than a purely independent empirical association.
– The sample was not randomly selected, but rather formed through purposive (convenience) approach. This was a deliberate methodological choice, given that blockchain technology is not uniformly adopted across industries. Its most intensive application is concentrated in specific sectors, particularly finance. Therefore, including companies with a higher level of blockchain adoption was necessary to ensure sufficient variability in the key independent variable. A fully random sample would likely include a large number of firms with minimal or no blockchain implementation, thereby limiting the ability to detect meaningful relationships between blockchain adoption, operational efficiency, and profitability.

Despite these limitations, the sample provides sufficient analytical value for examining complex relationships between blockchain adoption and business performance.

The empirical part of the research is based on the application of descriptive statistics (Hair et al., 2019), correlation analysis, multiple linear regression analysis (Hair et al., 2019), and mediation analysis (Baron & Kenny, 1986). The models are structured so that the independent variable represents the level (intensity of adoption) of blockchain technology (the so-called *Blockchain level*), while the dependent variables are operational efficiency and profitability. The regression models also include second-order terms (BL^2, OE^2) in order to test for the presence of saturation effects and changes in the marginal impact of blockchain adoption on the examined company performance measures, both operational and financial.

The mediating effect of operational efficiency on the relationship between blockchain adoption level and profitability is tested using sequential regression models in accordance with the approach of Baron and Kenny (1986), with the inclusion of nonlinear specifications as a robustness check.

In all conducted statistical analyses, a standard significance level of $p < 0.05$ was applied. The results of the empirical tests are presented in the section “Results”, while their detailed interpretation and theoretical linkage to the relevant literature are provided in the section “Discussion”.

Based on these starting points, the following models were formulated:

H1: To test the nonlinear effect of the level of blockchain adoption on operational efficiency, the following model was specified:

$$OE_i = \alpha_0 + \alpha_1 BL_i + \alpha_2 BL_i^2 + u_i \tag{5}$$

where:

OE_i operational efficiency of company ***i***

BL_i - level of blockchain adoption in company ***i***

BL_i^2 - squared level of blockchain adoption, allowing identification of nonlinear and saturation effects

α_1 - baseline (linear) effect of blockchain level on efficiency

α_2 - additional quadratic effect (indicating whether the impact accelerates or slows down as blockchain adoption increases)

u_1 - error term for company ***i*** (all variation not explained by the variables in the model)

In the presented model, operational efficiency is modeled as a nonlinear function of the level of blockchain adoption. The model consists of both linear and quadratic terms in order to identify nonlinear and saturation effects arising from different intensities of blockchain implementation.

H2: To test the nonlinear effect of the level of blockchain adoption on profitability, the following model was specified:

$$PR_i = \beta 0 + \beta 1 BL_i + \beta 2 BL_i^2 + ei \tag{6}$$

where:

PR_i **-** operational efficiency of company ***i***

BL_i - level of blockchain adoption in company ***i***

BL_i^2 - squared level of blockchain adoption, which enables the identification of nonlinear and saturation effects

$\beta 0$ - baseline (linear) effect of the blockchain adoption level on efficiency

$\beta 1$ - additional quadratic effect (indicating whether the impact accelerates or slows down as the level of blockchain adoption increases)

$\beta 2$ - error term of the model for the company

ei - error term of the model

In the presented model, profitability is structured so that a higher level of blockchain adoption does not increase profitability proportionally or uniformly; rather, its impact becomes more pronounced only after a certain threshold of blockchain implementation is reached.

H3: To test the mediation model with nonlinearities in the effect of operational efficiency on profitability, the following model was specified:

$$PR_i = \gamma 0 + \gamma 1 BL_i + \gamma 2 BL_i^2 + \gamma 3 OE_i + \gamma 4 OE_i^2 + \xi i \quad (7)$$

where:

PR_i profitability of company ***i*** (dependent variable)

BL_i, BL_i^2 - blockchain level and its nonlinear transformations

OE_i - operational efficiency (mediator)

OE_i^2 - squared operational efficiency (indicating whether the returns from additional efficiency improvements increase or diminish)

$0\gamma 0$ - constant

$\gamma 1, \gamma 2$ - direct effects of the blockchain adoption level on profitability (linear and quadratic)

$\gamma 3$ - baseline (linear) effect of operational efficiency on profitability

$\gamma 4$ - quadratic effect of operational efficiency

ξi – error term of the model

The mediation regression model incorporates multiple linear regression analyses in order to identify potential saturation effects and changes in the marginal impacts of the level of blockchain adoption.

4. Results

In this section, we present the results of the empirical analysis obtained through descriptive statistics, correlation analysis, multiple linear regression, and mediation analysis. The results are organized in a sequence that follows the formulated research hypotheses, with particular emphasis on identifying linear and nonlinear effects of blockchain adoption as well as testing the mediating role of operational efficiency.

Table 2 shows the basic descriptive statistical indicators for the variables included in the study. In addition to the variables themselves, the table provides the mean, standard deviation, and minimum and maximum values. Descriptive statistics were conducted exclusively on companies with an identified level of blockchain adoption in order to ensure the relevance and interpretability of the statistical results. Including companies that do not use blockchain technology would not contribute to the representativeness of the findings due to the absence of variability in the key independent variable.

Table 2. Descriptive statistical indicators

Indicators	Min	Max	Average	Standard deviation
Blockchain Level	1.00	3.00	2.32	0.77
Operational Efficiency	68.40	78.60	71.01	3.45
Profitability	13.64	18.46	14.69	1.79

Note: The standard deviation was calculated as the sample SD (n–1), with N = 76. Blockchain Level ranges from 1 (low adoption) to 3 (high adoption), based on the frequencies reported in Table 3: 14 companies at level 1, 24 at level 2, and 38 at level 3.

Source: Authors

Tables 1 and 2 present the overall descriptive statistics for the analyzed sample. The mean value of operational efficiency is 71.01, with a standard deviation of 3.45, indicating a moderate level of dispersion among the observed companies. The profitability index records a mean of 14.69 and a standard deviation of 1.79, suggesting relatively stable profitability levels within the sample. The average level of blockchain adoption is 1.97, reflecting heterogeneous degrees of blockchain implementation across companies.

The results show that companies with a low level of blockchain adoption (Level 1) exhibit the lowest average operational efficiency (69.46) and profitability (13.86). Companies operating at a medium level of adoption (Level 2) demonstrate higher average operational efficiency (71.43) and profitability (14.88). Similar average values are observed among companies with high levels of blockchain adoption (Level 3), where operational efficiency reaches 71.30, while profitability remains at 14.88.

Overall, the descriptive statistics suggest an increase in both operational efficiency and profitability when moving from a low to a medium level of blockchain adoption, followed by stabilization at higher adoption levels.

The results of the descriptive analysis by levels of blockchain adoption reveal a clear upward trend in both operational efficiency and profitability as the level of blockchain implementation increases. While companies with a low level of adoption achieve lower and more stable outcomes, the medium and high adoption levels are characterized by higher average values but also greater variability, indicating the importance of the quality and manner of blockchain implementation.

Table 4 presents the Pearson correlations between the variables: intensity of blockchain adoption (BL), operational efficiency (OE), and profitability (PR). The correlation between operational efficiency and profitability is extremely high (r = 0.991, p < 0.001), that indicate a nearly perfect linear relationship. However, as it is previously noted, this finding partly reflects the overlap in the construction of the composite indices. The correlations between the level of blockchain and operational efficiency (r = 0.169, p = 0.142) and blockchain and profitability (r = 0.186, p = 0.108) aren't statistically significant, but they show a positive direction of the relationship within the sample. Based on this, we draw the conclusion that operational efficiency is the primary driver of profitability in the observed sample, while the impact of blockchain adoption is positive but not the dominant factor influencing operational efficiency and profitability.

Table 3. Descriptive statistics of variables by levels of blockchain adoption

Blockchain	N	OE Avg.	OE St. Dev.	OE Min	OE Max	Profit Avg.	Profit St. Dev.	Profit Min	Profit Max
0 (No adoption)	24	–	–	–	–	–	–	–	–
1 (Low)	14	69.46	1.19	68.40	72.60	13.86	0.36	13.64	14.86
2 (Medium)	24	71.43	3.85	68.40	78.60	14.88	1.98	13.64	18.46
3 (High)	38	71.30	3.79	68.40	78.20	14.88	1.98	13.64	18.42
Total (valid N)	76	71.01	3.45	68.40	78.60	14.69	1.79	13.64	18.46

Source: Authors

Table 4. Correlation between variables

Variable	Blockchain Level	Efficiency	Profitability
Blockchain Level	1.000 (p < 0.001)	0.169 (p = 0.142)	0.186 (p = 0.108)
Operational Efficiency	0.169 (p = 0.142)	1.000 (p < 0.001)	0.991 (p < 0.001)
Profitability	0.186 (p = 0.108)	0.991 (p < 0.001)	1.000 (p < 0.001)

Source: Authors

Table 4 presents the Pearson correlations between the variables: intensity of blockchain adoption (BL), operational efficiency (OE), and profitability (PR). The correlation between operational efficiency and profitability is extremely high (r = 0.991, p < 0.001), that indicate a nearly perfect linear relationship. However, as it is previously noted, this finding partly reflects the overlap in the construction of the composite indices. The correlations between the level of blockchain and operational efficiency (r = 0.169, p = 0.142) and blockchain and profitability (r = 0.186, p = 0.108) aren't statistically significant, but they show a positive direction of the relationship within the sample. Based on this, we draw the conclusion that operational efficiency is the primary driver of profitability in the observed sample, while the impact of blockchain adoption is positive but not the dominant factor influencing operational efficiency and profitability.

Testing the specified regression models yields the following results:

H1: The impact of blockchain technology on operational efficiency.

Table 5. The impact of blockchain technology on operational efficiency

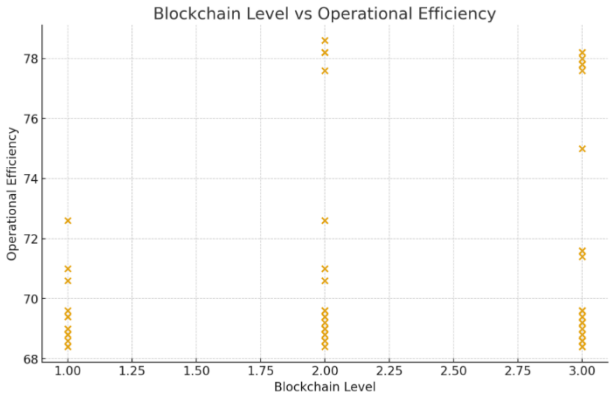
Variable	Coefficient	p-value
Constante (α0)	69.84	< 0.001
BL	0.29	0.224
BL^2	-0.11	0.183
R^2	0.046	-

Source: Authors

The coefficient of determination is $R^2 = 0.046$, indicating a low degree of explained variance in operational efficiency. The regression model is not statistically

significant ($p > 0.05$), meaning that no direct effect of the level of blockchain adoption on operational efficiency can be confirmed in the analyzed sample. At the same time, a weak positive trend is observed, which justifies the formulation of the first hypothesis in terms of a weak and potentially long-term effect.

Figure 4. The impact of Blockchain technology on operational efficiency



Source: Authors

In the displayed graph, the points are dispersed, i.e., there is no clear upward trend, which confirms the weak influence of blockchain on operational efficiency.

H2: Implications of blockchain technology on profitability.

The results of the regression analysis show that the model constant has a statistically significant value ($\beta_0 = 14.02$, $p < 0.001$), while the coefficients related to the level of blockchain adoption are not statistically significant (BL: $\beta = 0.18$, $p > 0.05$; BL²: $\beta = -0.07$, $p > 0.05$). The coefficient of determination is $R^2 = 0.038$, indicating a very low proportion of explained variance in profitability within the observed model.

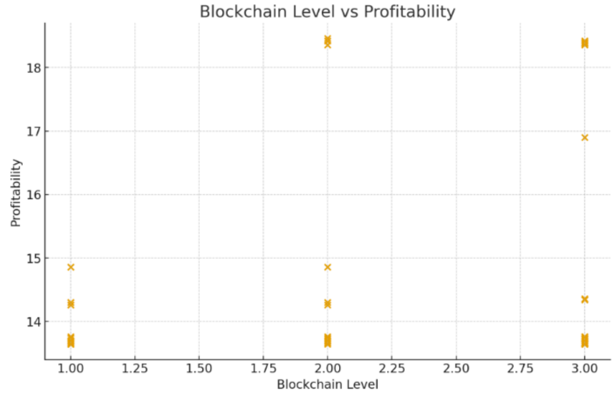
Table 6. Implications of blockchain technology on profitability

Variable	Coefficient	p-value
Constante (β0)	14.02.	< 0.001
BL	0.18	0.221
BL^2	-0.07	0.209
R^2	0.038	-

Source: Authors

These findings confirm the second hypothesis: at the current stage of blockchain adoption in the analyzed companies, there is no statistically significant direct effect of the level of blockchain implementation on profitability.

Figure 5. The implication of blockchain technology on profitability



Source: Authors

From the graph, we can see that there is no clear upward trend, meaning that blockchain does not exhibit a visible direct financial effect, i.e., there is no observable impact on profitability in the sample. H3: The mediating role of operational efficiency.

Table 7. The mediating role of operational efficiency

Path	Description of the relationship	Coef. (β)	p-value	SE	95% CI	Result
A	Blockchain → Operational Efficiency	0.759	0.156	0.532		Weak and statistically insignificant
B	Operational Efficiency → Profitability	0.512	< 0.001	0.046		Strong and statistically significant
C	Blockchain → Profitability (Total effect)	0.431	0.119	0.275		Statistically insignificant
C¹	Blockchain → Profitability (Direct effect, with OE)	0.044	0.251	0.038		Direct effect remains insignificant
AxB	Indirect effect (Bootstrap, 5000 samples)	0.387	-	0.269	[-0.142; 0.916]	Not statistically significant (CI includes zero)

Note: The indirect effect was estimated using bootstrap resampling with 5,000 iterations (Preacher & Hayes, 2008). The 95% confidence interval includes zero, indicating that the indirect effect is not statistically significant. Therefore, formal mediation is not confirmed.

Source: Authors

To test the mediation effect, the approach of Baron and Kenny (1986) was used with an additional bootstrap analysis (5000 samples) to estimate the indirect effect (Preacher & Hayes, 2008). The results of the bootstrap analysis show that the indirect effect of blockchain on profitability through operational efficiency was $\beta = 0.387$, with a 95% confidence interval [-0.142; 0.916] that includes zero, indicating that the indirect effect is not statistically significant. The standard error of the indirect effect was 0.269. Since the confidence interval includes zero, the conditions for formal mediation are not met. Although there is a positive pattern in the sample, we cannot confirm that operational efficiency statistically significantly mediates the relationship between the level of blockchain adoption and profitability.

The results of the mediation analysis indicate that operational efficiency has a strong and statistically significant effect on profitability, while the level of blockchain adoption does not exhibit a statistically significant direct effect, neither before nor after including the mediator. Although the calculated value of the indirect effect is positive, the conditions for formally confirming mediation according to the Baron and Kenny (1986) approach are not fully met; therefore, the results are interpreted as indicative. In other words, an effect emerges through operational efficiency (OE), but without formal mediation. This suggests that blockchain technology does not directly affect profitability; rather, operational efficiency acts as the main transmission mechanism. However, due to the weak influence of blockchain adoption on OE, the mediation remains statistically limited.

Given that the third hypothesis assumes that operational efficiency is the key mechanism through which blockchain adoption may affect company profitability, the obtained results show that improvements in operational efficiency can be viewed as a transitional stage in the transformation process through which the effects of blockchain technology gradually transfer to financial performance. Although the indirect effect is statistically modest, the findings provide empirical support for the third hypothesis.

5. Discussion

By analyzing the results obtained from testing the proposed hypotheses on the research sample, we gain insight into the real extent of blockchain technology's impact on company performance. The results of this study indicate that blockchain adoption is associated with improvements in both operational efficiency and profitability; however, the relationship is clearly not strictly linear. Descriptive analysis shows a noticeable increase in both indicators when moving from a low to a medium level of blockchain adoption, followed by stabilization at higher adoption levels.

This result indicates a strong association between operational efficiency and profitability in the observed sample. However, as noted in the methodological section, this relationship should be interpreted with caution, given that the composite indices for operational efficiency and profitability partially overlap in their construction, as both include some of the same financial indicators (e.g., ROA, ROE, profit margin). Therefore, rather than interpreting operational efficiency as an independently confirmed causal driver of profitability, we describe it as a strong empirical association that reflects both the conceptual proximity of these constructs and the methodological choices made in index construction. This finding is consistent with numerous studies in the field of operations management, which demonstrate that process improvement, reduction of operational costs, and increased productivity represent key drivers of organizational profitability (Slack et al., 2022; Hill & Hill, 2023).

Since the regression coefficients aren't statistically significant ($p > 0.05$), we cannot confirm the existence of a direct effect of blockchain on operational efficiency nor profitability in the analyzed sample. However, the positive sign of the coefficients ($\beta = 0.29$ for OE and $\beta = 0.18$ for profitability) indicates a pattern that could become statistically significant with a larger sample or after a longer period of time. This is in line with the findings of Queiroz and Wamba (2019), who emphasize that the effects of blockchain are often delayed and that they depend on the stage of implementation.

When examining the level of blockchain adoption, a positive but weak and statistically insignificant direct effect is observed both on operational efficiency and on profitability. This result does not imply that blockchain technology is ineffective; rather, it reflects the current stage of its implementation in real business environments, where many companies in the sample are still in the experimental or partial adoption phase. This result does not imply inefficiency of blockchain technology; rather, it reflects the stage of its implementation in real business environments, given that many companies in the sample are still in the experimental or partial adoption phase. In practice, this means that the dominant effects of blockchain adoption relate to transparency, data security, trust, and the digitalization of business processes, but not yet to operational activities that generate higher profitability. Improvements in operational efficiency and profitability are observed at medium levels of blockchain adoption, followed by stabilization at higher levels of implementation. The relatively low values R^2 further confirm that blockchain adoption alone explains only a limited proportion of performance variability, which is expected given its indirect and context-dependent effects.

The results of this study are consistent with existing research in the field of digital transformation, which emphasizes that the measurable effects of blockchain technology tend to become visible only after a longer period of institutional and organizational integration (Clohessy & Acton, 2019; Kouhizadeh et al., 2021).

Another conclusion derived from the results of the conducted research suggests that the analyzed companies are using blockchain as a supplementary technology rather than as a strategic infrastructural platform. Given that blockchain requires strong integration with business processes, information systems, and organizational structures, this mode of adoption limits the demonstration of its full potential. For these reasons, within the observed sample, we did not detect a statistically significant direct effect of blockchain on company performance; instead, its role appears to function as part of the infrastructural support for future business transformation.

Similar conclusions, that blockchain holds significant potential for improving sustainable supply chains, yet its adoption remains in an early phase and various obstacles persist, preventing the technology from fully realizing its impact, are found in Saberi et al. (2019), as well as in Queiroz and Wamba (2019), who similarly emphasize that the technological effects of blockchain are not currently strongly manifested. At present, blockchain emerges as an infrastructural or support technology that lays the groundwork for future improvements in supply chain performance, but its full effect has not yet been widely and empirically confirmed in practice (Queiroz & Wamba, 2019).

If we observe the relationship between the proposed hypotheses and the results obtained through their testing, we can conclude the following:

– Hypothesis H1, which assumes that the level of blockchain technology adoption has a positive, nonlinear, and statistically significant effect on increasing operational efficiency. Hypothesis H1 is partially supported in terms of the direction of the relationship, as the results indicate a positive pattern between blockchain adoption and operational efficiency. However, the effect is statistically insignificant in the current sample, suggesting that any potential impact may require a longer time horizon or more advanced stages of organizational integration to become measurable.
– Hypothesis H2, which states that blockchain technology does not have a direct impact on increasing the profitability of modern companies, but rather that its concrete effect depends on the stage of blockchain implementation and the company's level of technological maturity, is empirically confirmed.

This indicates that the financial effects of blockchain depend on the degree of its organizational integration.

– Hypothesis H3 receives only limited support. While operational efficiency shows a strong association with profitability, the indirect effect of blockchain adoption on profitability through operational efficiency is not statistically significant (bootstrap 95% CI includes zero). This suggests that, at the current stage of blockchain adoption in the observed sample, operational efficiency does not function as a statistically confirmed mediator. However, the positive pattern observed in the indirect effect points to a potential mechanism that may become more relevant in more mature stages of blockchain implementation. However, its mediating role between blockchain adoption and profitability remains statistically limited.

The primary scientific contribution of this study lies in its empirical demonstration that operational efficiency is a highly important determinant of profitability, while blockchain technology, at its current stage of adoption in real-world companies, does not exert a strong direct effect on financial outcomes.

Overall, the findings suggest that blockchain technology influences financial performance primarily through indirect, gradual mechanisms rather than immediate direct effects.

Finally, the study contributes to a balanced overall perspective on digital technologies and provides an empirically grounded argument against simplified narratives about their instant positive effects.

6. Conclusion

This research aimed to empirically examine the impact of different levels of blockchain technology implementation on the operational efficiency and profitability of modern companies. Based on the analysis of a sample of 76 companies that implemented blockchain, the following conclusions were drawn.

First, operational efficiency shows a strong association with profitability in the analyzed sample, indicating the importance of operational management for financial performance. However, the high correlation between these two variables ($r = 0.991$) is partly due to methodological overlap in their construction, since both composite indices include the same financial indicators (ROA, ROE, profit margin). Therefore, this finding should be interpreted as a strong association in the sample, and not as an independently confirmed causal relationship.

Second, the level of blockchain technology implementation doesn't have a statistically significant direct effect on either operational efficiency nor profitability. Although positive patterns were observed in the sample, they are insufficient to confirm the hypotheses of having a direct impact. This doesn't negate blockchain's potential, but rather indicates that its effects are conditioned by organizational maturity, implementation stage as the quality of integration into business processes.

Third, the mediating role of operational efficiency was not statistically confirmed (bootstrap 95% CI [-0.142; 0.916] includes zero), suggesting that blockchain does not affect profitability solely through improving operational processes, at least not at this stage of implementation. Although a positive pattern of indirect effect was observed, it is not strong enough to confirm statistically significant mediation.

The scientific contribution of this paper is reflected in providing a realistic, empirically based picture of the effects of blockchain technology, opposing simplified narratives about its immediate positive impacts. The practical implications direct managers to view blockchain not as a tool for quickly increasing profitability, but as a long-term infrastructural investment that requires simultaneous investment in operational optimization as in human resource development.

Limitations of the study include the use of a purposive sample, a cross-sectional design, and overlap in the construction of composite indices. Future research should include panel data, a larger number of sectors, and a clearer separation of the measurement of operational and financial performances. It should be emphasized that the composite indices of operational efficiency and profitability are partially use the same financial indicators (ROA, ROE, profit margin). The extremely high correlation between these two variables ($r = 0.991$) can be explained by this methodological overlap. Therefore, the strong relationship between operating efficiency and profitability should be interpreted cautiously, because it partly reflects the way the variables are constructed, and not a purely independent empirical relationship.

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