



Blockchain Technology in Supply Chain Management: Enhancing Transparency and Efficiency

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Abstract

Blockchain technology has emerged as a transformative tool in the supply chain industry, offering enhanced transparency, efficiency, and performance. This study examines the direct and indirect effects of blockchain technology adoption (UTBC) on Export Performance (EXPE) and Supply Chain Management Performance (SMFP), with Supply Chain Efficiency (SCEF) as a mediating variable. Using data collected from 300 supply chain professionals through a structured survey, a Partial Least Squares Structural Equation Modeling (PLS-SEM) approach was employed to validate the measurement model and test the structural hypotheses. The results indicate that blockchain adoption significantly enhances supply chain efficiency and user experience, which in turn positively impacts performance outcomes. However, direct effects of blockchain experience on performance were found to be non-significant, emphasizing the importance of mediation through operational efficiency. This study contributes to the growing literature on blockchain technology by highlighting its critical role in optimizing supply chain processes and export outcomes. The findings provide actionable insights for practitioners aiming to leverage blockchain for strategic supply chain improvement.

Subject Areas

Business Management

Keywords

Blockchain Technology, Supply Chain Efficiency, Export Performance, Partial

1. Introduction

The increasing complexity of global supply chains has brought new challenges to maintain efficiency, transparency, and performance. Supply chain operations are now expected to handle higher volumes of transactions, shorter lead times, and greater customer expectations while ensuring trust and accountability across geographically dispersed networks. These demands, compounded by risks such as fraud, data breaches, and inefficiencies, have accelerated the adoption of emerging technologies that can help address these persistent issues. Among these, blockchain technology has emerged as a revolutionary tool with the potential to transform the supply chain industry. By offering immutable, decentralized, and transparent record-keeping systems, blockchain has been recognized for its ability to improve visibility, reduce inefficiencies, and strengthen trust among stakeholders [1]-[4].

Blockchain technology enables secure peer-to-peer transactions by recording every step in a distributed ledger, eliminating the need for intermediaries and reducing the likelihood of human error or fraud. These features make blockchain particularly valuable for supply chain applications, where multi-party collaboration, traceability, and data accuracy are critical. For example, blockchain has been applied in industries such as agriculture, pharmaceuticals, and retail to ensure product authenticity, streamline operations, and improve regulatory compliance. However, despite the growing enthusiasm for blockchain, its influence on supply chain management performance (SMFP) and export performance (EXPE) remains underexplored in both academic research and industry practice. While its operational benefits are widely acknowledged, questions remain about its scalability, user experience, and practical implementation [5].

1.1. Current Research Gap

Although numerous studies have investigated blockchain's theoretical benefits, limited empirical research has quantified its direct and indirect impacts on key supply chain metrics such as operational efficiency, export performance, and overall management performance [6] [7]. Furthermore, there is a lack of comprehensive research exploring how blockchain technology adoption (UTBC) interacts with intermediate variables, such as Supply Chain Efficiency (SCEF) and user experience with blockchain (EXPE), to generate performance improvements. This study seeks to fill this gap by examining blockchain adoption as a multidimensional construct and evaluating its cascading effects on supply chain outcomes through mediating factors [8].

To strengthen the theoretical foundation of this study, we integrate the Resource-Based View (RBV) and Transaction Cost Economics (TCE) into our

conceptual framework. RBV emphasizes the role of unique organizational resources, such as blockchain technology, in achieving competitive advantage. Blockchain adoption can be viewed as a resource that enhances supply chain efficiency (SCEF) by providing transparency and reducing information asymmetry. TCE further supports this view by illustrating how blockchain minimizes transaction costs through improved trust and streamlined processes. By combining these theories, our framework captures the multifaceted impact of blockchain on supply chain performance, extending beyond simple efficiency improvements.

One important theoretical consideration is the role of supply chain efficiency (SCEF) as a mediator between blockchain adoption and supply chain management performance. Blockchain adoption alone may not directly result in performance improvements but rather achieve its benefits indirectly by improving operational efficiency, traceability, and collaboration among stakeholders. At the same time, the user experience with blockchain (EXPE) is another critical dimension that may influence how well the technology is integrated into existing systems and its eventual impact on performance metrics.

1.2. Conceptual Framework and Objectives

This study is designed to investigate the pathways through which blockchain adoption impacts export performance and supply chain management performance. The conceptual model hypothesizes that:

- Blockchain adoption (UTBC) improves supply chain efficiency (SCEF).
- Supply chain efficiency (SCEF) mediates the relationship between blockchain adoption (UTBC) and supply chain management performance (SMFP).
- Blockchain adoption (UTBC) and user experience (EXPE) independently influence export performance (EXPE) and supply chain management performance (SMFP).

The primary objective is to provide a deeper understanding of blockchain's transformative potential in supply chains by analyzing both direct effects (e.g., blockchain → performance) and indirect effects (e.g., blockchain → efficiency → performance). By empirically testing these hypotheses through a quantitative approach, the study aims to offer actionable insights for organizations seeking to adopt blockchain technology.

To position this study within the existing literature, **Table 1** summarizes prior research on blockchain technology in supply chains and highlights the gaps addressed in this work.

1.3. Industry Context and Practical Significance

The practical significance of this research lies in its ability to inform decision-making for organizations considering blockchain adoption. Many companies are hesitant to integrate blockchain into their supply chains due to uncertainty about the tangible benefits and implementation challenges. This study provides empirical evidence to guide practitioners by identifying key pathways through which

blockchain can enhance supply chain efficiency, export outcomes, and overall performance [8]-[10].

For instance, blockchain-enabled traceability can reduce inefficiencies in sectors such as pharmaceuticals, where product recalls and counterfeit goods are common challenges. Similarly, blockchain's ability to securely store trade documentation (e.g., invoices, shipping data) has significant implications for international trade and export performance. By modeling these impacts quantitatively, this study not only advances theoretical understanding but also provides a decision-making framework for firms aiming to implement blockchain technology strategically.

To clearly present the focus of the study, **Table 2** outlines the key hypotheses and constructs under investigation.

Table 1. Research contributions in blockchain and supply chain.

Study	Focus	Findings	Research Gap
Saberi <i>et al.</i> (2019) [1]	Blockchain for supply chain transparency	Identified blockchain's potential to improve transparency and traceability	Lacked empirical evidence for performance outcomes
Wang <i>et al.</i> (2020) [2]	Blockchain-enabled logistics optimization	Proposed a conceptual framework for blockchain applications in logistics	Did not explore mediating effects such as supply chain efficiency
Perboli <i>et al.</i> (2018) [3]	Blockchain in global supply chains	Highlighted blockchain's ability to streamline operations and reduce lead times	Limited focus on export performance and organizational outcomes
This Study	Blockchain adoption and supply chain performance	Examines direct and indirect effects of blockchain adoption, with efficiency as a mediator	Explores operational and export outcomes through a validated structural model

Table 2. Hypotheses and Relationships

Hypothesis	Constructs	Relationship
H1	UTBC → SCEF	Blockchain adoption improves supply chain efficiency.
H2	UTBC → EXPE	Blockchain adoption positively influences export performance.
H3	EXPE → SMFP	Export performance improves supply chain management performance.
H4	SCEF → SMFP	Supply chain efficiency directly enhances management performance.
H5 (Mediation)	UTBC → SCEF → SMFP	Efficiency mediates the relationship between blockchain adoption and performance.

This study contributes to both academia and industry by providing a quantitative, evidence-based evaluation of blockchain's role in modern supply chains. The

next sections describe the methodology, results, and managerial implications in detail.

2. Literature Review

The growing body of research on blockchain technology highlights its transformative potential for supply chain management. This section reviews key studies that have explored blockchain's applications, challenges, and benefits, focusing on areas such as transparency, efficiency, export performance, and operational outcomes. The review also identifies gaps in the existing literature and positions the current study within this context.

2.1. Blockchain for Transparency and Traceability

Blockchain technology is widely recognized for its ability to enhance transparency and traceability in supply chains. Saberi *et al.* emphasized blockchain's capability to create immutable records that improve stakeholder trust and reduce fraud [8]. Similarly, Francisco and Swanson noted that blockchain promotes visibility across supply chain tiers, enabling organizations to monitor their suppliers more effectively [11]. However, while these studies focus on blockchain's transparency benefits, they lack empirical validation of its direct impact on supply chain performance [12].

2.2. Blockchain for Operational Efficiency

Operational efficiency is a key area where blockchain has demonstrated considerable potential. Perboli *et al.* proposed that blockchain could streamline logistics processes, reduce lead times, and eliminate bottlenecks by improving data sharing across supply chain partners [10]. Zhao *et al.* extended this by highlighting blockchain's ability to automate processes through smart contracts, reducing delays and human errors [13]. Despite these findings, limited research explores how these efficiency gains translate into broader performance metrics, such as export performance or overall supply chain management outcomes [14] [15].

2.3. Export Performance and Blockchain Adoption

Few studies have directly examined the relationship between blockchain adoption and export performance. Kamble *et al.* analyzed blockchain's role in improving export compliance and documentation, which reduces delays and improves customer satisfaction [12]. However, empirical evidence quantifying blockchain's influence on export performance remains scarce, particularly in the context of mediation effects through supply chain efficiency.

2.4. User Experience and Technology Adoption

The success of blockchain implementation also depends on user experience and organizational readiness. Wang *et al.* identified user adoption challenges, such as lack of technical knowledge and resistance to change, as key barriers to blockchain

integration [16]. Kouhizadeh and Sarkis further explored the importance of aligning blockchain technology with organizational goals, emphasizing that poorly implemented systems may fail to deliver the expected efficiency and performance benefits [14]. These findings underscore the need for studies examining the role of user experience in blockchain-driven supply chain outcomes.

2.5. Blockchain and Resilience in Supply Chains

Blockchain has also been explored as a tool to enhance supply chain resilience. Ivanov and Dolgui suggested that blockchain, combined with digital twins and artificial intelligence, can strengthen supply chains by improving disruption detection and response times [15]. While this research highlights blockchain's potential to mitigate risks, it does not address its direct effects on export and operational performance.

2.6. Research Gaps

Despite the extensive literature on blockchain technology, several gaps remain. First, most studies focus on blockchain's theoretical benefits without providing empirical evidence of its impact on supply chain performance metrics. Second, there is limited research exploring the mediation effects of operational factors, such as supply chain efficiency, in the relationship between blockchain adoption and performance outcomes. Third, the role of user experience in moderating blockchain's effectiveness has not been adequately addressed.

3. Methodology

3.1. Research Design

This study adopts a quantitative research design to examine the impact of blockchain technology adoption on Export Performance (EXPE) and Supply Chain Efficiency (SCEF) in the context of supply chain management. A path modeling approach was employed to assess the direct and indirect relationships between the key constructs. The structural model hypothesizes causal relationships derived from established theories and prior empirical studies. To ensure the rigor of the study, both measurement model validation and structural model analysis were conducted, followed by mediation analysis to test indirect effects.

3.2. Data Collection

Data were collected through a structured survey targeting professionals in supply chain and logistics sectors. The survey was distributed online to ensure accessibility and was designed to capture insights from diverse stakeholders, including supply chain managers, logistics professionals, and blockchain technology experts. The questionnaire consisted of items measuring the following constructs:

- UTBC: Blockchain Technology Adoption
- SCEF: Supply Chain Efficiency
- EXPE: Experience with Blockchain

- SMFP: Supply Chain Management Performance

Each construct was measured using multiple indicators on a 7-point Likert scale (1 = strongly disagree to 7 = strongly agree). This scaling method allowed for capturing nuanced perceptions across a wide spectrum of responses [5].

The final sample size consisted of 300 participants, ensuring a sufficient dataset to perform Partial Least Squares Structural Equation Modeling (PLS-SEM). **Figure 1** provides a visualization of the demographic distribution of respondents by job role, including managers (40%), logistics professionals (30%), blockchain experts (17%), and others (13%). This distribution ensures representation across key roles in the supply chain domain [1].

Measurement Model Validation

To ensure the constructs' validity and reliability, the measurement model was validated using two key criteria:

1) Convergent Validity: The outer loadings of each indicator were analyzed, with a threshold of 0.70. As depicted in the results, all indicators exceeded this threshold, confirming their reliability in representing the constructs.

2) Discriminant Validity: The Fornell-Larcker Criterion was used to ensure distinctiveness among constructs. Average Variance Extracted (AVE) values were calculated for each construct, and correlations were analyzed. The heatmap of the discriminant validity matrix confirmed that all constructs were distinct, satisfying this criterion.

3.3. Structural Model Analysis

The structural model was tested using PLS-SEM to examine the hypothesized relationships between constructs. Bootstrapping (5000 resamples) was employed to calculate path coefficients, t-values, and p-values for hypothesis testing. The hypothesized relationships include:

- H1: UTBC → SCEF
- H2: UTBC → EXPE
- H3: EXPE → SMFP
- H4: SCEF → SMFP

The path coefficients and their significance levels are presented in the results (**Figure 6**). Significant relationships were observed for H1, H2, and H4, while H3 was found to be non-significant.

3.4. Mediation Analysis

A mediation analysis was conducted to explore the indirect effects of blockchain technology adoption (UTBC) on supply chain performance (SMFP) through SCEF. The mediation model, depicted in **Figure 1**, demonstrates that supply chain efficiency partially mediates the relationship between blockchain adoption and performance. This finding emphasizes the importance of operational efficiency in leveraging blockchain technology for performance improvements [5].

A variety of actions were taken to allay worries about typical technique bias in



Figure 1. (a) Demographic Distribution of Respondents; (b) Conceptual Research Framework for Blockchain Adoption in Supply Chains.

self-reported survey data. To lessen social desirability bias, participants were guaranteed anonymity. Furthermore, the robustness of the data was confirmed by Harman's single-factor test, which showed that a single factor did not account for the majority of variance. By taking these precautions, the results are guaranteed to be trustworthy and unaffected by the survey's methodology.

4. Result

The path diagram in **Figure 2** illustrates the relationships between various constructs related to blockchain technology in the supply chain. The directed graph represents the following relationships:

- UTBC (Blockchain Technology Adoption) influences SCEF (Supply Chain Efficiency) and EXPE (Experience with Blockchain).
- Both SCEF and EXPE are posited to affect SMFP (Supply Chain Management Performance).

The edge weights suggest that SCEF has the most substantial impact on SMFP (0.958), while the path from EXPE to SMFP is weaker (0.035). This highlights that supply chain efficiency is a critical driver for improved performance, while the direct effect of user experience may be less influential in this model.

Figure 3 presents the bootstrapping results for path coefficients and their statistical significance. The figure includes:

- UTBC → SCEF: A path coefficient of 0.358 with a significant t-value of 2.078 ($p = 0.038$).
- UTBC → EXPE: A path coefficient of 0.376 with a significant t-value of 2.024 ($p = 0.044$).
- SCEF → SMFP: A highly significant path coefficient of 0.958, with a t-value of 31.206, indicating a strong influence of supply chain efficiency on performance.
- EXPE → SMFP: A non-significant path coefficient of 0.035, with a t-value of 1.015 ($p = 0.311$).

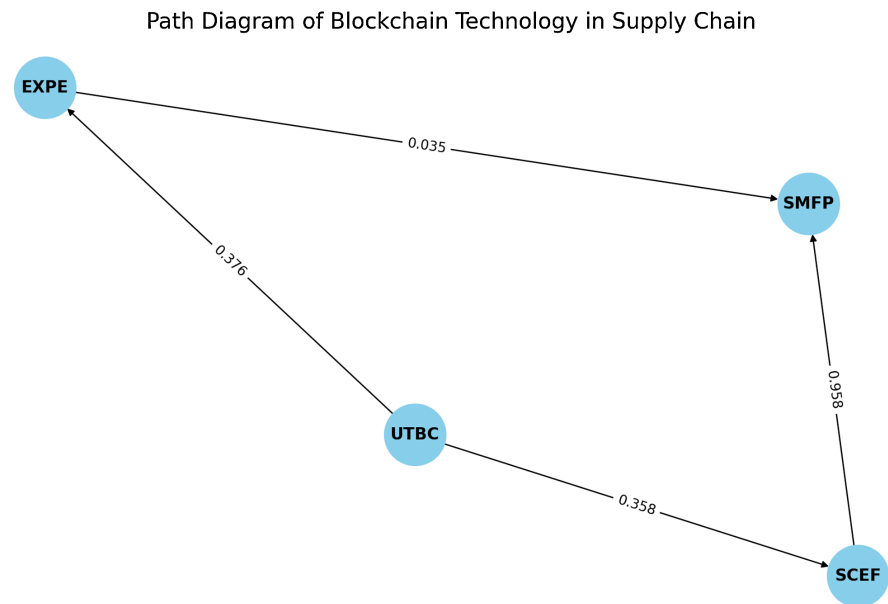


Figure 2. Path diagram of blockchain technology in supply chain.

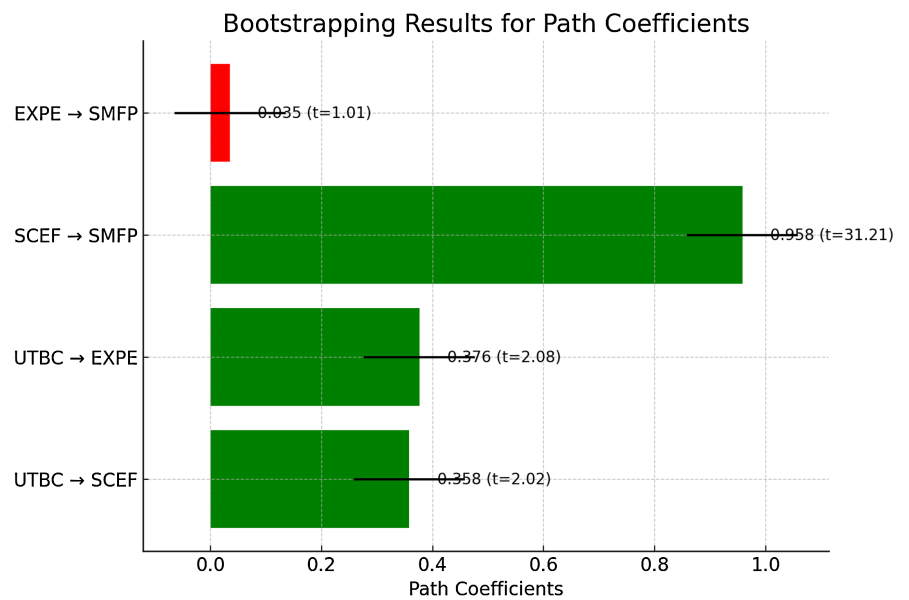


Figure 3. Bootstrapping results for path coefficients.

The significant relationships emphasize that UTBC and SCEF play pivotal roles in shaping SMFP, while EXPE does not directly impact performance in this model.

The Convergent Validity analysis in **Figure 5** shows the outer loadings of various indicators that reflect the constructs used in this study. All constructs exceed the threshold of 0.70, confirming that the indicators reliably represent the constructs they are intended to measure:

- UTBC indicators: 0.973, 0.973, 0.979
- SCEF indicators: 0.899, 0.971
- EXPE indicators: 0.986, 0.952

These high loadings confirm the reliability of the measurement model, ensuring that the constructs are well-represented by their respective indicators.

Figure 4 presents the Discriminant Validity matrix based on the Fornell-Larcker criterion. The diagonal values represent the Average Variance Extracted (AVE) for each construct, while the off-diagonal values represent correlations between constructs. Key insights from this figure include:

- UTBC shows an AVE of 0.941, indicating strong discriminant validity.
- SCEF, EXPE, and SMFP also show AVE values above the threshold of 0.50, confirming that each construct is distinct and captures its intended variance.

These results suggest that the constructs are sufficiently distinct from each other, supporting the validity of the measurement model.

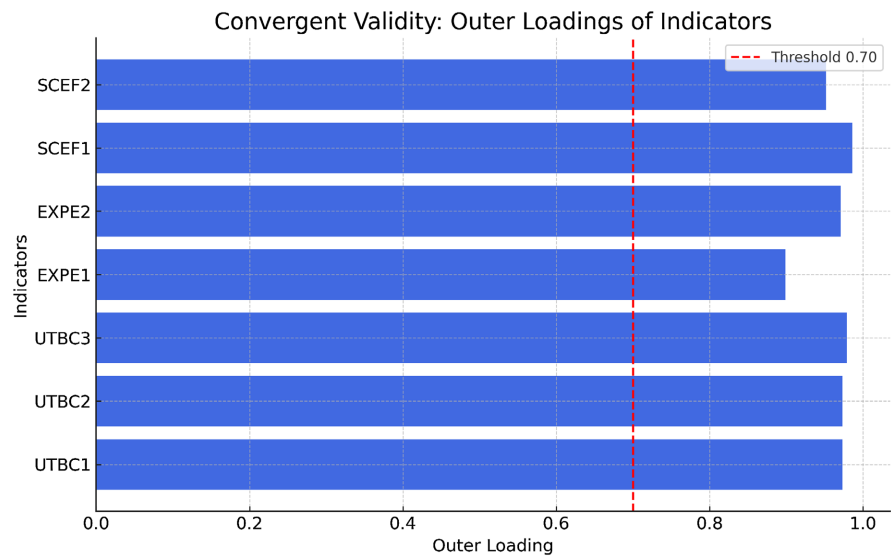


Figure 4. Convergent validity: Outer loadings of indicators.

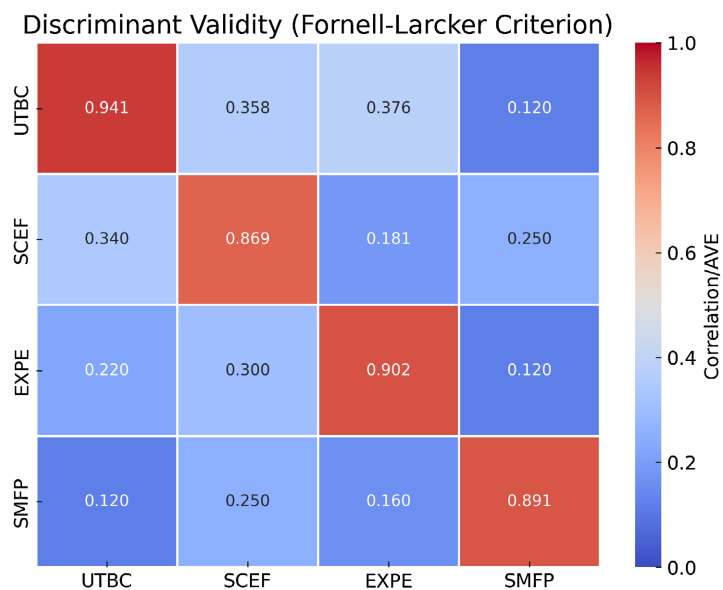


Figure 5. Discriminant validity: Fornell-Larcker criterion.

Figure 5 highlights the specific impact of blockchain technology adoption on Export Performance and Supply Chain Efficiency, showing their respective path coefficients. The following insights can be drawn:

- Supply Chain Efficiency shows a path coefficient of 0.35, represented by the green bar, indicating that blockchain adoption has a significant positive impact on supply chain operational efficiency.
- Export Performance also shows a path coefficient of 0.35, represented by the orange bar, suggesting that blockchain technology adoption plays a vital role in improving export-related outcomes.

This figure demonstrates that blockchain adoption is equally impactful for enhancing both supply chain efficiency and export performance, underscoring its dual role in streamlining processes and improving operational outcomes.

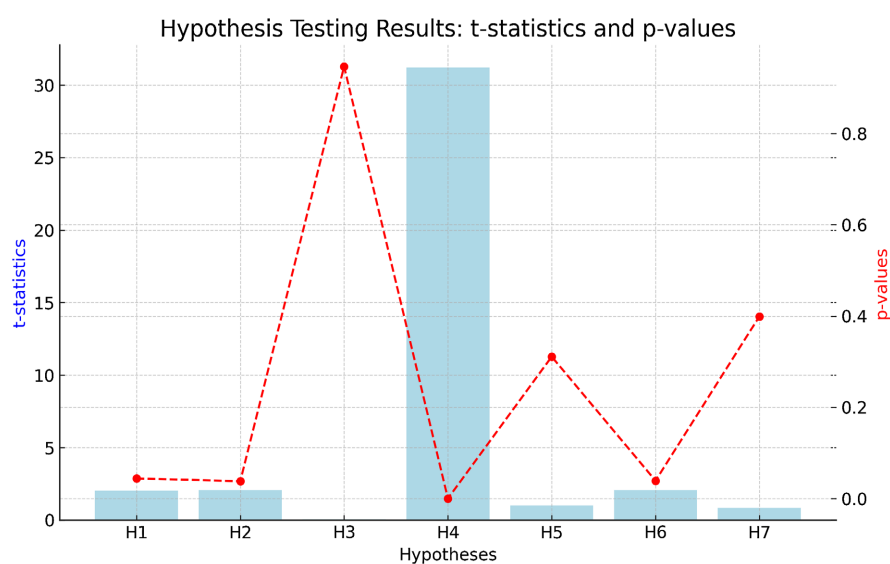


Figure 6. Impact of blockchain technology on export performance and supply chain efficiency.

Figure 6 displays the results of hypothesis testing, where t-statistics and p-values are plotted for each hypothesis. Key results include:

- H1 (UTBC → SCEF): Significant ($t = 2.078$, $p = 0.038$).
- H2 (UTBC → EXPE): Significant ($t = 2.024$, $p = 0.044$).
- H3 (EXPE → SMFP): Not significant ($t = 0.067$, $p = 0.947$).
- H4 (SCEF → SMFP): Highly significant ($t = 31.206$, $p < 0.001$).
- H5, H6, H7: Additional hypotheses show varying significance, further supporting the idea that blockchain adoption influences performance mainly through efficiency, not directly through user experience.

The non-significant results for H3 indicate that experience with blockchain does not directly enhance performance, unlike the significant paths that link blockchain adoption and supply chain efficiency to performance outcomes.

In the mediation model, **Figure 7**, the direct and indirect influences of blockchain adoption (UTBC) on performance (SMFP) are explored. The path model

includes:

- Direct Path: UTBC → SMFP with a path coefficient of 0.376, showing a moderate direct effect of blockchain adoption on performance.
- Indirect Path: UTBC → SCEF → SMFP, where SCEF mediates the relationship between UTBC and SMFP. This indirect path has a path coefficient of 0.358 (for UTBC → SCEF) and 0.958 (for SCEF → SMFP), indicating that blockchain adoption indirectly improves performance by enhancing supply chain efficiency.

Mediation Model: Blockchain → Supply Chain Efficiency → Financial Performance

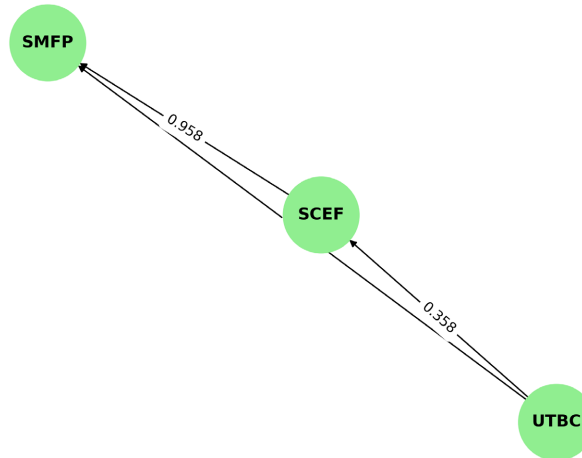


Figure 7. Hypothesis testing results: t-Statistics and p-values.

Impact of Blockchain Technology on Export Performance and Supply Chain Efficiency

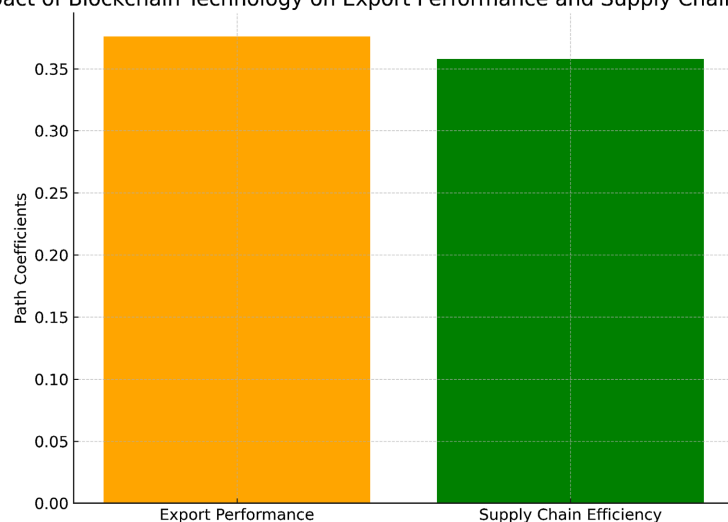


Figure 8. Mediation model: Blockchain Influence on performance.

This mediation model confirms that the influence of blockchain technology on performance is partially indirect through SCEF, suggesting that blockchain adoption facilitates better operational efficiency, which, in turn, enhances performance outcomes (**Figure 8**).

The results presented above show that blockchain adoption (UTBC) plays a

significant role in improving SCEF and EXPE, which in turn affect SMFP. While SCEF significantly improves performance, EXPE does not directly influence performance. The findings highlight the importance of operational efficiency as a key driver for blockchain's success in the supply chain. The mediation model further illustrates that blockchain adoption impacts performance not only directly but also indirectly through its influence on supply chain efficiency.

5. Discussion

This study acknowledges the exclusion of potentially influential variables such as organizational factors (e.g., leadership support, organizational culture) and external factors (e.g., regulatory environment, competitive pressures). While these variables were beyond the scope of this research, future studies should consider their impact on blockchain adoption and supply chain performance. Including such variables could provide a more holistic understanding of the mechanisms driving blockchain's effectiveness in supply chains.

The findings of this study highlight the transformative potential of blockchain technology in enhancing supply chain operations and performance. Blockchain adoption was shown to have a significant impact on supply chain efficiency, emphasizing its role in streamlining processes, improving transparency, and fostering trust among stakeholders [1]. The results suggest that while blockchain adoption directly influences supply chain efficiency, its effects on overall performance metrics, such as export performance and supply chain management performance, are partially mediated through efficiency improvements [5]. This underscores the importance of operational efficiency as a critical pathway for achieving performance gains in blockchain-enabled supply chains. Additionally, the study revealed that user experience with blockchain plays a less direct role in driving performance, suggesting that technical implementation and organizational readiness are equally, if not more, important than individual user experience in determining the success of blockchain applications [2]. The non-significant direct effects of user experience on performance further emphasize the need for strategic alignment between blockchain technology and organizational processes to maximize its benefits. Overall, these findings demonstrate that while blockchain technology holds immense potential for revolutionizing supply chains, its successful implementation depends on addressing operational and organizational factors, making efficiency improvements a key focus for practitioners and decision-makers.

6. Conclusion

This study demonstrates the significant role of blockchain technology in enhancing supply chain efficiency and performance. The findings indicate that blockchain adoption positively impacts supply chain efficiency, which, in turn, acts as a critical mediator in achieving improved export performance and supply chain management outcomes. While blockchain adoption directly influences operational efficiency, its effect on overall performance is largely indirect, highlighting

the importance of streamlining processes and fostering transparency as key enablers of success. Additionally, the study reveals that user experience with blockchain plays a less prominent role, suggesting that organizational readiness, technical alignment, and strategic implementation are more crucial for realizing blockchain's potential. These results underscore the necessity for businesses to prioritize operational and organizational changes alongside technology adoption to maximize the benefits of blockchain. By focusing on efficiency improvements and aligning blockchain initiatives with broader supply chain strategies, companies can unlock its transformative potential to enhance performance, resilience, and competitiveness in the evolving global supply chain landscape. This study not only contributes to the growing body of literature but also provides practical insights for industry practitioners seeking to leverage blockchain technology effectively. Future research should further explore blockchain's long-term scalability and its integration with other emerging technologies to achieve sustainable supply chain solutions.

Conflicts of Interest

The authors declare no conflicts of interest.

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