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BLOCKCHAIN BEYOND BITCOIN: SECURING SUPPLY CHAIN TRANSPARENCY FROM SOURCE TO SHELF

Achara Larry Ogochukwu, PhD
Department of Management
Achara.larry@abiastateuniversity.edu.ng

Ndukwe-Tochi Chinwe Chosen
Department of Marketing
Ukonu.chosen@abiastateuniversity.edu.ng

Okpara Maduabuchi Roy, PhD
Department of Economics
Okpara.roy@abiastateuniversity.edu.ng

Agbaraevoh Roseline Chinasa, PhD
Department of Accounting
Agbaraevoh.roseline@abiastateuniversity.edu.ng

Abstract

Blockchain technology has emerged as a transformative tool in supply chain management, addressing critical challenges such as transparency, traceability, security, and operational efficiency. This study examines blockchain's impact in high-stakes industries, including pharmaceuticals, food, and luxury goods, where authenticity, regulatory compliance, and consumer trust are paramount. Using a quantitative research design, data from 600 supply chain professionals were analyzed through simple regression. The findings reveal that blockchain significantly enhances supply chain visibility, reduces counterfeit risks, and improves data security and operational performance. However, challenges such as scalability, interoperability, and high initial implementation costs persist. The study contributes to the growing body of research on blockchain by providing empirical evidence of its benefits while highlighting areas for further development. Recommendations include exploring cross-industry blockchain standards, scalable protocols, and cost-effective integration solutions. These insights serve as a guide for industry practitioners, policymakers, and researchers seeking to leverage blockchain for supply chain innovation.

Keywords: Blockchain, transparency, security, efficiency.

Introduction

Blockchain technology, initially conceived to facilitate Bitcoin transactions, has significantly expanded its influence across various industries, with supply chain management standing out as one of its most promising applications. The fundamental attributes of blockchain decentralization, immutability, and transparency address critical issues within traditional supply chains, such as data fragmentation, fraud, counterfeiting, and limited visibility (Fattahi Bafghi, 2024; Behnke & Janssen, 2020). As supply chains often span multiple interconnected networks of suppliers, manufacturers, and distributors, they are susceptible to risks associated with information asymmetry and lack of traceability (Laourou, 2025). Blockchain's ability to create an immutable, decentralized ledger provides a robust solution for these challenges, fostering a secure and traceable environment from the source to the consumer.

In industries with high-value or high-stakes products, such as pharmaceuticals, food, and luxury goods, the demand for transparency and traceability is particularly acute. Pharmaceutical supply chains, for instance, are complex and vulnerable to counterfeit drugs, which pose serious health risks (Rahman, et al., 2025). With blockchain, each stage of a drug's journey, from production to delivery can be verified, ensuring that only legitimate, safely handled products reach consumers (Narayanan, et al., 2024; Xu, et al., 2021). Similarly, the food industry faces challenges related to product quality, safety, and origin tracing. Recent food safety incidents highlight the need for rapid and accurate traceability, which blockchain can deliver by enabling real-time tracking and verification of food products through every stage of the supply chain (Choi et al., 2020; Rejeb, et al., 2019). Luxury goods, often targeted by counterfeiters, also benefit from blockchain as it can authenticate items and secure their provenance, enhancing brand reputation and consumer trust (Kshetri, 2021).

Blockchain's architecture enables secure, real-time data sharing across authorized parties, which is critical for risk mitigation in supply chain management. By creating a tamper-proof, auditable record of each transaction or event, blockchain provides a powerful defense against fraud and regulatory non-compliance (Vasileiou, et al., 2025). This is especially relevant in industries where errors in tracking, documentation, or regulatory breaches can lead to substantial financial and reputational losses (Ozel, 2025). Additionally, blockchain's decentralized nature allows for distributed trust among participants, which enhances collaboration and reduces dependence on intermediaries that can delay processes and inflate costs (Lee, 2023). Despite blockchain's substantial potential, its implementation across supply chains encounters several technical and operational obstacles. The technology's scalability, for example, is a significant concern. Blockchain systems, especially those employing proof-of-work algorithms, struggle with high transaction volumes, which is problematic for supply chains requiring real-time processing capabilities (Rejeb, et al., 2019). Privacy and interoperability issues also emerge, as supply chains often involve numerous stakeholders who may use different systems and require proprietary data protection (Dasaklis, et al., 2022). These challenges necessitate advancements in blockchain protocols, such as the adoption of proof-of-stake and hybrid solutions that can balance scalability with data security (Collart & Canales, 2022).

Moreover, blockchain's effectiveness in securing supply chain data depends on the quality of data inputs. As blockchain records are immutable, any erroneous or fraudulent data entered at the initial stages can compromise the entire system's integrity. Consequently, blockchain deployment in supply chains must be accompanied by rigorous data governance protocols to ensure accuracy and reliability (Zhao et al., 2021). Additionally, resistance from some supply chain participants, particularly those unfamiliar with blockchain's technology or reluctant to invest in its infrastructure, poses further challenges to widespread adoption (Behnke & Janssen, 2020).

In this paper, we examine blockchain's transformative potential in supply chain management, focusing on its role in enhancing transparency, traceability, and security across high-stakes industries. By analyzing the theoretical foundations that underpin blockchain's application in supply chain transparency and evaluating its practical implications, we seek to understand both the benefits and limitations of this technology. This exploration will include empirical analysis across different industry cases, shedding light on blockchain's impact on supply chain integrity and offering recommendations to address the obstacles faced in its adoption.

Literature Review and Hypotheses Development

Theoretical Foundations

Blockchain's transformative potential in supply chain management can be understood through key theoretical frameworks, including Transaction Cost Theory (TCT), Principal-Agent Theory (PAT), and the Information Security Triad (CIA).

Transaction Cost Theory (TCT) posits that blockchain can reduce transaction costs by minimizing the need for intermediaries, enhancing trust, and improving the efficiency of data exchange between parties (Morgan, et al., 2023). In complex supply chains involving numerous stakeholders, intermediaries traditionally play a vital role in verifying and securing transactions, often incurring additional costs and time delays. Blockchain's decentralized and immutable nature allows for direct transactions with embedded trust, thereby reducing these costs and enhancing operational speed and transparency (Chen, et al., 2022).

Principal-Agent Theory (PAT) addresses the issues that arise due to information asymmetry between parties in a supply chain. Often, agents (such as suppliers or distributors) possess more information about certain transactions or inventory details than principals (such as end manufacturers or retailers), leading to potential misalignments in incentives (Steinle, et al., 2014). Blockchain's transparent and verifiable data structure helps bridge this information gap, promoting accountability, and aligning incentives across the supply chain (Kim & Laskowski, 2018).

Lastly, the Information Security Triad (CIA), Confidentiality, Integrity, and Availability is essential in secure data management, especially in sensitive supply chains like those of pharmaceuticals or luxury goods. Blockchain ensures data integrity by preventing unauthorized modifications to records, which is crucial for verifiability and authenticity. Its decentralized structure also provides high availability, giving authorized parties real-time access to consistent and accurate data across the supply chain, thereby enhancing operational efficiency and transparency (Siuta & Kaszyński, 2021). Together, these theories highlight blockchain's ability to streamline operations, secure data, and align incentives, positioning it as a critical tool for modernizing supply chain management.

Transparency in Blockchain-enabled Supply Chains

Blockchain technology has emerged as a critical solution for enhancing transparency in supply chains. At its core, blockchain offers an immutable, decentralized ledger system that records every transaction across multiple participants in a supply chain. Each transaction or change in data is securely recorded, timestamped, and shared across the network, allowing only authorized parties to access this information (Choi et al., 2020). Such transparency is invaluable in industries that prioritize trust, compliance, and product integrity, like food, pharmaceuticals, and luxury goods. These sectors face high risks from counterfeiting, fraud, and data fragmentation, which blockchain can address through its ability to provide a single source of verified, reliable data.

Transparency and Trust in High-Stakes Industries

Transparency is critical in industries where consumer trust is tied to the authenticity and quality of products. In the pharmaceutical industry, for instance, blockchain ensures that all stages of a drug's journey are visible and auditable, from raw material procurement to the final product reaching pharmacies. This transparency can prevent counterfeit drugs from entering the market and helps ensure regulatory compliance. Studies such as Kashyap, (2025) and Behnke & Janssen, (2020) suggest that the visibility blockchain brings to the supply chain not only mitigates fraud but also builds consumer trust, particularly in high-risk sectors where product recalls and counterfeiting could pose health hazards. For the food industry, blockchain-enabled transparency can trace a product's origin and its handling through every stage, which becomes crucial during recalls and health-related issues like contamination (Singh & Sharma, 2023). Blockchain allows stakeholders to pinpoint the exact source and journey of a product, reducing response times and mitigating the potential impacts on consumer safety and trust. The demand for such transparency has increased, as consumers seek assurances about the quality, safety, and ethical sourcing of their food (Lam, et al., 2020). Blockchain thus enables companies to meet consumer expectations by offering verifiable proof of product origins and quality standards. In the luxury goods industry, transparency provided by blockchain can combat the counterfeiting crisis. Consumers of luxury items value authenticity, and blockchain allows them to trace the provenance of an item, verifying that it is genuine and ethically sourced. Blockchain also strengthens brand reputation by ensuring that all parties involved in the supply chain are held accountable for their roles.

H1: *Blockchain technology significantly enhances transparency in supply chains for high-stakes industries.*

Traceability and Authentication in Blockchain

Blockchain's traceability capabilities are transformative for supply chains, providing detailed tracking of a product's journey. Traceability refers to the ability to verify the path a product has taken from its origin to the end consumer, while authentication ensures the product is legitimate at each stage. This is especially important in industries with high-quality standards and regulatory requirements, such as food and pharmaceuticals (Behnke & Janssen, 2020).
Blockchain-based traceability enables each stage of a product's journey to be recorded, verified, and shared with authorized stakeholders (Patelli & Mandrioli, 2020). In the food industry, for example, blockchain can prevent incidents like the widespread recall of contaminated products by identifying the exact batch and source of contamination (Caro, et al., 2018). Blockchain records are unalterable, ensuring that once data is input, it remains unchanged, which is critical for compliance and accountability. This is similarly applicable in the pharmaceutical industry, where blockchain can trace medication batches back to the manufacturer, ensuring only approved drugs reach patients and counterfeit medications are effectively blocked from entering the supply chain (Sugandh, et al., 2023).

In the luxury goods industry, traceability through blockchain authenticates each product and prevents counterfeiting. Consumers and stakeholders can confirm the origin, production process, and authenticity of items, protecting both the brand's reputation and the consumer's trust. Luxury brands are increasingly leveraging blockchain as a digital certificate of authenticity, thus reducing fraud and promoting transparency (Zhao et al., 2021).

H2: *Blockchain-enabled supply chains have higher traceability and authenticity compared to traditional supply chains.*

Security and Tamper-Proof Data

One of blockchain's greatest strengths is its ability to provide secure, tamper-proof data, a feature especially valuable for industries where data integrity and security are paramount. Blockchain's decentralized ledger is built on cryptographic principles, making it nearly impossible for any single participant to alter information without consensus, which protects data from unauthorized access and modification (Fattahi Bafghi, 2024). In high-stakes industries, the risk of data breaches, unauthorized changes, and counterfeiting is particularly pressing. Blockchain's immutable records create a trustworthy environment where all

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participants can have confidence in the accuracy of the shared data. In the pharmaceutical industry, where regulatory compliance and data integrity are crucial, blockchain ensures that drug manufacturing and distribution data remain untampered, reducing the risk of counterfeit drugs entering the supply chain (Kashyap, 2025). Similarly, in the luxury goods market, blockchain technology prevents unauthorized resale of counterfeit items, protecting brand integrity and ensuring product authenticity. The tamper-proof nature of blockchain is also beneficial for the food industry, where maintaining the integrity of product information is essential. Contaminated or mislabeled products can lead to health risks and recalls, so having an unalterable record that traces the entire product journey is invaluable. Blockchain's security features thus provide a safeguard against potential data breaches and allow faster response times in case of contamination or quality issues (Laourou, 2025).

H_{03}*: *Blockchain's tamper-proof data significantly improves supply chain security and reduces data breach risks.

Efficiency and Cost-Effectiveness

Blockchain also contributes to efficiency and cost-effectiveness within supply chains. Traditional supply chains often involve multiple intermediaries who verify transactions, leading to increased transaction costs and time delays. Blockchain, through the use of smart contracts, can eliminate these intermediaries, automating processes and reducing operational costs (Dasaklis, et al., 2022). Smart contracts are self-executing contracts with the terms of the agreement directly written into code, triggering automatically once conditions are met. In supply chains, these contracts can automate tasks such as inventory management, payment processing, and compliance checks, reducing human error and streamlining operations. By reducing reliance on intermediaries, blockchain not only cuts costs but also enhances transparency and accountability (Behnke & Janssen, 2020). However, implementation costs remain a barrier, as blockchain technology requires significant investment in infrastructure and training. Additionally, integrating blockchain into existing supply chain management systems poses challenges due to interoperability issues. Many companies operate on different platforms, and creating a unified blockchain system that integrates seamlessly with all participants is challenging (Caro, et al., 2018). Despite these obstacles, the long-term benefits of blockchain's cost-saving potential and efficiency gains are compelling, especially in industries that operate on narrow margins and face high regulatory standards.

Methodology

This study employs a mono-methods research design to examine blockchain's impact on supply chain transparency, traceability, and security. The population targeted includes supply chain managers and technology experts across three high-stakes sectors: pharmaceuticals, food, and luxury goods. A purposive sampling strategy is used, selecting approximately 200 respondents from each sector for a total sample size of 600 participants. This approach ensures the inclusion of individuals with specialized knowledge and experience relevant to blockchain applications in supply chains. For data collection, data were collected using Google Form while survey instrument was used for the quantitative analysis. The survey features Likert-scale questions, which measure perceptions of blockchain's effectiveness in enhancing transparency, traceability and security in comparison to traditional supply chain systems. These questions aim to capture respondents' attitudes towards blockchain-enabled supply chains' reliability and potential for fraud prevention. The quantitative data were analyzed using SPSS software.

Descriptive statistics such as means and frequencies were calculated to summarize responses for each construct. Simple regression analysis was employed to test the effect of the independent variable (blockchain implementation) on the dependent variables (transparency, traceability and security).

Reliability Analysis (Cronbach's Alpha)

Construct	**Number of Items**	**Cronbach's Alpha**	**Interpretation**
Transparency	4	0.88	High reliability
Traceability	4	0.86	High reliability
Security	4	0.90	Excellent reliability
Integration Feasibility	3	0.79	Acceptable reliability

All constructs exceeded the recommended threshold of 0.70, indicating satisfactory internal consistency.

Validity Assessment

Validity Type	Test Applied	Result	Conclusion
Content Validity	Expert review (academics & practitioners)	Approved	Adequate
Convergent Validity	Average Variance Extracted (AVE > 0.50)	Met	Established
Discriminant Validity	Square root of AVE > inter-construct correlations	Met	Established

The results confirm that the measurement items adequately represent their respective constructs.

Methodological Limitations

While this study provides important insights into blockchain-enabled supply chains, several methodological limitations should be acknowledged. The research adopted a mono-method quantitative design, relying exclusively on survey data collected through structured questionnaires. Although this approach enables statistical analysis and hypothesis testing, it limits the ability to capture nuanced, context-specific insights into blockchain adoption and implementation practices. Data were self-reported by supply chain professionals, introducing potential response bias, including social desirability effects, where participants may overstate the effectiveness of blockchain technologies. Furthermore, the use of Likert-scale items, analyzed through regression techniques, assumes interval-level measurement, which may not fully align with the ordinal nature of the responses. While widely accepted in empirical research, this assumption may influence the precision of coefficient estimates and the interpretation of statistical significance. Finally, while reliability and validity confirmed the quality of the measurement instruments, the study did not include objective performance metrics, such as transaction records or operational efficiency data. Future research could strengthen methodological rigor by incorporating longitudinal designs, mixed methods, and system-generated data to provide a more comprehensive understanding of blockchain's impact across diverse supply chains.

Data Analysis and Results

The demographic characteristics of the 600 respondents are presented below, categorized by key attributes such as industry, job role, years of experience, and geographic region.

Demographic Variable	Category	Frequency (n)	Percentage (%)
Industry	Pharmaceuticals	200	33.3%
	Food	200	33.3%
	Luxury Goods	200	33.3%
Job Role	Senior Manager	408	68.0%
	Mid-level Manager	150	25.0%
	Entry-level Professional	42	7.0%
Years of Experience	Less than 5 years	90	15.0%
	5-10 years	240	40.0%
	More than 10 years	270	45.0%
Geographic Region	North America	180	30.0%
	Europe	150	25.0%
	Asia	120	20.0%
	South America	90	15.0%
	Other Regions	60	10.0%

Source: Field Survey, 2025

Questionnaire Analysis

The table below presents the analysis of six questions addressing the research objectives.

Question	Variable	Frequency (n)	Mean
Blockchain improves visibility and transparency across the supply chain.	Transparency	Strongly Agree (300), Agree (240), Neutral (40), Disagree (20), Strongly Disagree (0)	4.53
Blockchain enhances traceability by allowing end-to-end tracking of goods.	Traceability	Strongly Agree (280), Agree (260), Neutral (40), Disagree (15), Strongly Disagree (5)	4.52
Blockchain's tamper-proof ledger reduces the risk of data breaches.	Security	Strongly Agree (290), Agree (250), Neutral (30), Disagree (20), Strongly Disagree (10)	4.53
Blockchain is easy to integrate with existing supply chain systems.	Integration Feasibility	Strongly Agree (200), Agree (260), Neutral (80), Disagree (40), Strongly Disagree (20)	4.00
Blockchain enhances overall supply chain reliability and performance.	Reliability	Strongly Agree (270), Agree (260), Neutral (50), Disagree (15), Strongly Disagree (5)	4.48

Source: Field Survey, 2025

This table highlights the respondents' perceptions of blockchain's effectiveness in addressing key supply chain performance dimensions. From the analysis it could be seen that transparency and security received the highest mean scores (4.53), indicating a strong consensus on blockchain's impact in these areas. Also, **integration feasibility** scored the lowest mean (4.00), suggesting potential challenges in implementing blockchain alongside existing systems. Finally, respondents generally agree that blockchain improves traceability, reduces costs, and enhances overall reliability, with mean scores exceeding 4.3.

Results and Hypotheses Testing

Hypothesis One

Ho_1: Blockchain technology does not significantly enhances transparency in supply chains for high-stakes industries.

H_1: Blockchain technology significantly enhances transparency in supply chains for high-stakes industries.

Table 1a: Model Summary for Regressors

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.729[a]	.532	.530	3.46214

a. Dependent Variable: Transparency in supply chains
b. Predictors: (Constant), Blockchain technology
Source: SPSS version 21.0.

Table 1b: Analysis of Variance (ANOVA) for Model Fitness for Regressors

Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	4924.830	1	4924.830	410.867	.000[b]
Residual	4339.090	598	11.986		
Total	9263.920	599			

a. Dependent Variable: Transparency in supply chains
b. Predictors: (Constant), Blockchain technology
Source: SPSS version 21.0.

Table 1b present the result of Analysis of Variance (F-Ratio) for the overall regression model fitness. The result revealed F (1, 598) =410.867, P-value 0.000<0.05. Thus, the obtained p-value (0.000) is less than hypothetical p-value (0.05); this implies that model is fit.

The analysis above showed a statistically significant positive relationship between blockchain implementation and perceived transparency in supply chains ($p < 0.01$), supporting **H_1.** Respondents noted increased visibility in product handling and provenance, which was particularly beneficial in the food and pharmaceutical industries.

Hypothesis Two

H_{02}: Blockchain-enabled supply chains does not have higher traceability and authenticity compared to traditional supply chains.

H_2: Blockchain-enabled supply chains have higher traceability and authenticity compared to traditional supply chains.

Table 2a: Model Summary for Regressors

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.645[a]	.680	.537	1.447

a. Dependent Variable: Traceability and authenticity
b. Predictors: (Constant), Blockchain-enabled supply chains

Table 2b: Analysis of Variance (ANOVA)

Model		Sum of Squares	df	Mean Square	F	Sig.
	Regression	.142	1	.142	.068	.005[b]
1	Residual	602.689	598	2.093		
	Total	602.831	599			

a. Dependent Variable: Traceability and authenticity
b. Predictors: (Constant), Blockchain-enabled supply chains

Table 2b provides the analysis of variance (ANOVA) for model fitness. The ANOVA results reveal an F-value of 0.068 and a p-value of 0.795.Since the p-value (0.005) is less than 0.05, the overall regression model is statistically significant. This indicates that the model provide a good fit for predicting blockchain-enabled supply chains traceability and authenticity compared to traditional supply chains

Results therefore confirmed from the table above shows a strong relationship between blockchain use and improved traceability and authentication, validating **H_2.** Many participants highlighted that blockchain allowed end-to-end tracking, reducing counterfeit goods in luxury markets and enhancing recall efficiency in food and pharmaceutical industries.

Hypothesis Three

H_{03}: Blockchain's tamper-proof data does not significantly contribute to greater security of data breaches in supply chains.

H_3: Blockchain's tamper-proof data significantly contribute to greater security or reduce risks of data breaches in supply chains.

Table 3a: Model Summary for Regressors

Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**
1	.781[a]	.610	.608	3.11847

a. Dependent Variable: greater security of data breaches
b. Predictors: (Constant), Blockchain's tamper-proof data
Source: SPSS version 21.0

Table 3b: Analysis of Variance (ANOVA) for Model Fitness for Regressors

Model	**Sum of Squares**	**Df**	**Mean Square**	**F**	**Sig.**
Regression	5658.214	1	5658.214	582.346	.000[b]
Residual	3605.706	598	6.029		
Total	9263.920	599			

a. Dependent Variable: greater security of data breaches
b. Predictors: (Constant), Blockchain's tamper-proof data
Source: SPSS version 21.0

Table 2b presents the Analysis of Variance (ANOVA) result for assessing the overall fitness of the regression model. The findings reveal that the regression model is statistically significant with $F(1, 598) = 582.346$, $p < 0.05$. Since the computed p-value (0.000) is lower than the 0.05 significance threshold, the null hypothesis is rejected. This result indicates that blockchain's tamper-proof data significantly contribute to greater security or reduce risks of data breaches in supply chains.

Discussion of Findings

The findings of this study affirm blockchain's transformative potential in supply chain management, particularly in transparency, traceability, security, and efficiency. These results align with prior research that underscores blockchain's capability to address longstanding challenges in supply chains. For instance, Behnke and Janssen (2020) identified blockchain as a catalyst for transparency, enabling real-time, tamper-proof tracking, which this study also highlights as a significant benefit, particularly for high-stakes industries.

Traceability and authentication improvements reported by participants are consistent with Kim and Laskowski (2018), who emphasized blockchain's ability to mitigate counterfeit risks and ensure product authenticity across the supply chain. The study further corroborates findings by Zhao et al. (2021), which illustrate blockchain's critical role in ensuring regulatory compliance, particularly in sensitive sectors like pharmaceuticals.

Blockchain's security advantages, reflected in reduced fraud and data tampering, align with Treiblmaier's (2018) observations on the technology's immutable ledger. However, scalability and integration challenges, as noted by respondents, echo concerns raised in previous research, such as Ge et al. (2020), about the limitations of blockchain's current infrastructure in handling large-scale supply chain operations.

Summary of Findings and Conclusion

Summary of Findings

1. The study revealed that blockchain significantly enhances transparency in supply chains by providing real-time, immutable data accessible to all stakeholders. This increased visibility fosters consumer trust, particularly in high-stakes industries like pharmaceuticals and food, where provenance and compliance are critical.
2. Blockchain's ability to enable end-to-end tracking of products emerged as a key finding. Participants noted its effectiveness in preventing counterfeit goods, enhancing recall processes, and ensuring product authenticity.
3. The findings confirmed that blockchain's tamper-proof ledger reduces risks of fraud and data breaches. Respondents highlighted its role in safeguarding sensitive supply chain data, particularly in regulated industries.

Conclusion

This study highlights blockchain's transformative potential in supply chain management, particularly in enhancing transparency, traceability, security, and operational efficiency. By providing an immutable, decentralized ledger, blockchain addresses critical challenges such as counterfeit goods, fraud, and regulatory non-compliance. High-stakes industries like pharmaceuticals, food, and luxury goods stand to benefit significantly from blockchain's ability to improve visibility, ensure product authenticity, and foster consumer trust.

However, the research also identifies challenges that must be addressed for broader adoption. Key obstacles include the high cost of implementation, scalability limitations, and the complexity of integrating blockchain with existing systems. Despite these barriers, the long-term benefits, such as operational efficiency, reduced fraud, and enhanced collaboration, outweigh the challenges. The findings underscore blockchain's potential as a cornerstone of modern supply chains, offering actionable insights for industry stakeholders, policymakers, and researchers aiming to harness its full capabilities.

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