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Closing the supply chain loop: enablers, strategies, and outcomes of blockchain implementation in reverse logistics

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The inefficiencies of conventional reverse logistics have prompted the implementation of systems that facilitate circularity in supply chain logistics. This study examines how the application of blockchain in reverse logistics enhances circular supply chain management (CSCM). It specifically delineates the motivations for blockchain adoption by logistics firms, their operational strategies for its application in reverse logistics, and the consequent impacts on CSCM. Employing an inductive approach and integrating Transaction Cost Economics (TCE) and Porter's Value Chain (PVC) theories, we thematically analysed business news and expert opinions on 24 logistics firms obtained from LexisNexis. The study identifies four internal and four external drivers for blockchain adoption, three key use strategies, and five CSCM outcomes. Three propositions emerged from the interplay of drivers, strategies, and outcomes of blockchain use in reverse logistics. The findings provide new justifications for blockchain adoption by logistics companies, offering managers strategies to enhance supply chain circularity. A limitation is the relatively small sample size, which could be expanded in future studies as blockchain technology gains more prominence in logistics.

Keywords: blockchain; circular economy; circular supply chain management; reverse logistics; transaction costs; value chain

1. Introduction

Driven by the need to increase the efficacy of total quality management by eliminating waste from production and consumption patterns, it has become exigent for businesses to set-up systems that promote circular economy goals (Gupta & Singh, 2024). The logistics industry, being one of the prime actors of waste generation (Sikder et al., 2024), necessitates closing the loop actions in its supply chains if the sector must ensure efficient handling of product from suppliers to end-users as well as material returns from customers to the origin. Logistics service providers are therefore transitioning from traditional linear systems to circular systems. For example, logistics giant, DHL has embraced this revolution by leveraging expertise, innovative logistics, and new supply models to enhance consumer behaviour, product return, and the deliberate orchestration of circularity in complex supply chains (DHL, 2022).

The advent of blockchain technology in logistics marks a significant shift in management practices, transforming traditionally executed tasks through technological disruptions. Blockchain, a promising technology, can enhance the alignment between business and society by altering conventional production and consumption processes. The smart contracts, decentralisation, and immutability of blockchain foster social and environmental

sustainability in logistics supply networks (Chauhan et al., 2022), helping businesses advance circular economy principles.

While research in digitally enabled supply chain circularity is still nascent, it has been established that the infusion of blockchain into reverse supply chain networks fosters sustainability (Jraisat et al., 2023a). Moreover, achieving sustainability and circularity in supply chains involves collaboration and information-sharing among multiple stakeholders towards the elimination of traditional processes (Jraisat et al., 2023b) to improve the environment, and industry 4.0 technologies have a huge role to play in this (Roshan et al., 2024; Sahoo et al., 2023). Notwithstanding, pragmatic understanding of the strategies for blockchain integration into circular supply chains remains limited, thus underscoring the significance of empirical research in blockchain-enabled circular economy through reverse logistics.

Among the existing circularity models – circular product design, sorting and pre-processing, reverse logistics, and use, reuse, share, and repair – this study examines blockchain technology's role in coordinating reverse logistics. Specifically, the objective of this research is to tease out the enablers, strategies and outcomes of blockchain application in reverse logistics. Consequently, we raise the research question:

RQ: How does blockchain implementation in reverse logistics enable CSCM?

Justifying technology adoption demands that managers answer the 'why, how, and what' questions (Yang et al., 2021). Given the limited understanding of blockchain in reverse logistics, this study seeks to answer these questions regarding blockchain's application in reverse logistics, thus contributing to the literature in three important ways: It advances theory by connecting Transaction Cost Economics (TCE) with Porter's Value Chain (PVC) to explain how logistics transaction cost governance affects supply chain circularity; it offers empirical evidence on the precursors, operational strategies, and effects of blockchain use in reverse logistics; just as it proposes three recommendations for future research on blockchain applications in the logistics sector.

The remaining parts of this paper are structured as follows: Section 2 reviews the literature on blockchain and CSCM, Section 3 outlines the methodology, Section 4 displays the results, which are subsequently discussed in Section 5, while section six concludes the study.

2. Literature review

2.1. *Blockchain and CSCM in logistics*

Blockchain is one of the key technologies for driving innovation (Abu Huson et al., 2024) which remains a prerequisite for circularity in SCM. By aiding stakeholder coordination (Nandi et al., 2020), enhancing transparency in recycling (Kouhizadeh et al., 2020), and facilitating product value recapture and waste conversion within supply networks (Choi et al., 2021), blockchain integration fosters a zero-waste supply chain, thus bolstering overall supply chain circularity. However, without adequate stakeholder collaboration, blockchain alone is insufficient for a successful circular economy transition. CSCM requires designs embedded with circular economy values to regenerate resources, restore product value, and preserve the environment, balancing business and societal goals. Efficient logistics systems, particularly reverse logistics, are essential for improving supply chain circularity.

Utilising blockchain in logistics, particularly in returns management, can facilitate the shift from traditional linear production systems to a circular economy (Koshta et al., 2022). Blockchain significantly contributes to supply chain circularity within logistics sector, especially during the pandemic, where virtual interactions and technology-driven SCM

were prevalent. Blockchain's application in circular supply chains enhances the traceability of goods and services and improves visibility across the value chain. For example, it bolsters returns management in reverse logistics by increasing data security and enabling easy retrieval of product information (Di Paola, 2024), thus aiding in product flow tracking (Hong & Hales, 2021) and facilitating product movement back to the manufacturer for proper disposal.

Blockchain reduces transaction costs, minimises the carbon footprint, and improves supply chain communication (Upadhyay et al., 2021). Key features of blockchain like trust and traceability enhance circular supply chains by improving product recycling, redistribution, and remanufacturing (Centobelli et al., 2022). Additionally, blockchain boosts supply chain localisation, agility, and digitalisation through smart contracts, enhancing traceability and responsiveness (Nguyen et al., 2021).

Transport companies can leverage blockchain to improve collaboration and develop innovative market penetration strategies (Dong et al., 2021). Blockchain employs cryptographic encryption to create tamper-proof digital information, ensuring transaction security. Successful blockchain implementation in logistics requires consideration of both internal and external organisational factors (Choi & Siqin, 2022).

Research in blockchain – circular economy integration is still evolving; while some studies have explored this link using some core management theories such as the practice-based view (PBV) (Khan et al., 2021), ecological modernisation theory (Kouhizadeh et al., 2020), and resource-dependency theories (Nandi et al., 2020), it is noteworthy that these theories largely ignore the associated transaction costs of the key value chain activities involved in the engagement of blockchain for circularity in reverse logistics. Meanwhile, maximising the full potentials of blockchain in logistics requires an efficient governance of reverse logistics' transaction costs (Wang et al., 2025). Consequently, this study leverages an integration of transaction cost economics (TCE) (Roeck et al., 2020) and Porter's value chain (PVC) theory (Nagy et al., 2018) in explicating how blockchain integration into reverse logistics fosters circularity objectives by effectively administering transaction costs. This theoretical integration becomes pertinent due to three main considerations: Contemporary research on TCE highlights its suitability for explaining blockchain's role in efficiently governing transaction costs in supply chains (Ketokivi & Mahoney, 2020). TCE addresses the opportunistic tendencies stemming from uncertainties in transactional relationships, such as those in logistics collaborations (Huo et al., 2018). Moreover, PVC explains the benefits organisations derive from strategic activities, including using emerging technologies for competitive advantage (Porter, 2011).

2.2. *Transaction cost economies of reverse logistics activities*

Transaction costs encompass all costs associated with a business exchange except the product or service price, including expenses for prospecting, information gathering, transportation, monitoring, and evaluation. TCE posits that the risk of opportunism can be mitigated by choosing the appropriate governance structure for a transaction (Meinlschmidt et al., 2018). Two key TCE assumptions are bounded rationality, which suggests that managers have limited cognitive abilities, and opportunism, indicating that decision-makers act in self-interest and may benefit through deceptive intentions (Roeck et al., 2020). Scholars argue that blockchain reduces opportunistic behaviour, enhances transparency, and lowers transaction costs in supply chain relations (Schmidt & Wagner, 2019).

TCE explains governance costs in transactional relationships marked by uncertainties, such as third-party logistics (Huo et al., 2018). High potential for opportunistic behaviour

exists in reverse logistics if the product returns process is not well-coordinated. Consequently, mid-range TCE theories are necessary in logistics (Treiblmaier, 2018) to identify key reverse logistics activities and the impact of blockchain technology on managing these activities. This study extends TCE by integrating it with Porter's value chain (PVC) theory.

PVC theory asserts that a firm's internal structure is crucial for competitive advantage, highlighting that focusing on key activities that increase price or reduce costs can enhance value (Strakova et al., 2020). Essentially, PVC identifies strategic activities as the source of competitive advantage. Companies develop capabilities by integrating new technologies into their activities (Porter, 2011, p. 40).

To analyse the competitive advantages from supply chain integrations, existing studies have combined TCE with RBV theories (Mellat-Parast & Spillan, 2014; Monios & Bergqvist, 2016). However, this theoretical mix overlooks capabilities derived from internal activities and the differences in inbound and outbound logistics in supply chain relationships. Focusing on reverse logistics, we combine TCE and PVC theories to create a framework that identifies transaction costs and reverse logistics activities as sources of value improvement in the supply network. We demonstrate that by managing strategic reverse logistics activities with blockchain technology, firms can reduce opportunism in the process, thereby lowering transaction costs and enhancing value.

3. Methodology

To identify the enablers, strategies and consequences of blockchain deployment in reverse logistics, our study adopts interpretivism research philosophy. Interpretivism is more appropriate in this context since our aim is to enhance the understanding of a complex, socially constructed phenomenon and not to verify hypothesis or test theory (Towers et al., 2020). Following this reasoning, given the emerging nature of research in circular economy and blockchain, and motivated by our research objective which is to identify the enablers, strategies and outcomes of blockchain implementation in reverse logistics, we adopt an inductive approach which involves the examination of research questions using qualitative methods, then including an iterative process between theory and empirical data. Induction is commonly used in early-stage research to develop propositions (Nandi et al., 2020). This exploratory method helps identify the precursors, strategies, and outcomes of blockchain application in reverse logistics. Empirical data were consistently gathered from third-party (3PL) and fourth party (4PL) logistics providers.

3.1. *Data collection and analysis*

The dataset includes the top 50 largest logistics firms, as ranked by Transportation Topics based on annual revenues in the United States. The base year chosen was 2020, the most recent ranked year available at the time of the study.

The 50 companies were input into *LexisNexis*, a prominent electronic repository of classified corporate data widely used in business research (Reiter, 2020). LexisNexis includes not only business news but also expert opinions on blockchain adoption across various industries. In accordance with our research aims, we denoted three criteria in the LexisNexis database: the company must use blockchain technology in its supply chain, practice reverse logistics, and be committed to circular economy objectives. Only 24 companies met our specified criteria and were included in our search. Thus, applying the keywords 'blockchain', 'circular economy', and 'reverse logistics' on LexisNexis, delineating the timeframe as the last five years, to capture contemporary information,

our initial search yielded a total of 552 business news, which we then refined by removing duplicates and items that were not published in English languages, thus leaving us with 326 items. We focuses on 'Logistics' sector and further defined the object as 'business news' to eliminate items that were irrelevant to our research scope and we were left with 96 business news items which formed our final dataset. Our research process is summarised in Figure 1.

Among the 24 firms, 22 (92%) are 3PL companies, and two (8%) are 4PL providers. These firms have an average industry experience of 58 years. Key services include transportation (air, land, and sea freight), integrated SCM, e-commerce, customs brokerage, and reverse logistics like returns carrier shipping and product disposition. Table 1 provides a summary of the logistics firms, which are anonymized with codes from A to X.

Our data analysis entailed aligning empirical data with our theoretical framework. Using an inductive approach, we immersed ourselves in literature on blockchain in the circular economy and our guiding theoretical framework: the transaction cost of reverse logistics activities. We imported the 96 business news and expert opinions into Nvivo 12 for content analysis (Yang et al., 2021) following the six steps of thematic analysis in Braun and Clarke (2006). Our objective is to formulate research propositions to guide

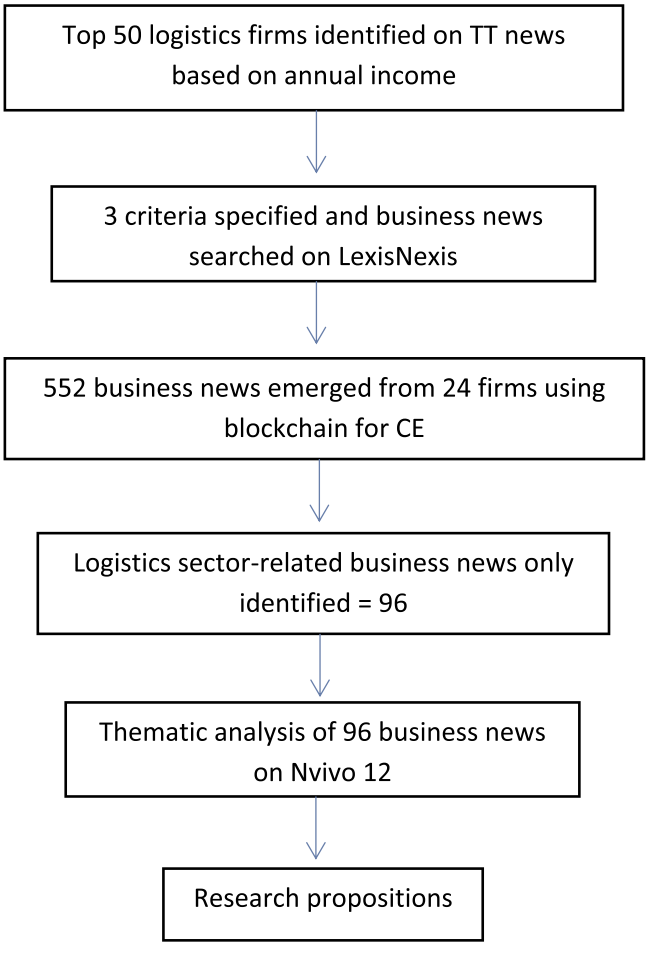

Figure 1. Research framework (adapted from Nandi et al., 2020).

Table 1. Company information.

Company	Year founded / years of experience	Logistics service type
A	1971 (51)	3PL
B	1951 (71)	3PL
C	1976 (46)	3PL
D	1907 (115)	4PL
E	1890 (132)	3PL
F	2007 (15)	3PL
G	2005 (17)	3PL
H	1932 (90)	3PL
I	1976 (46)	3PL
J	1979 (43)	3PL
K	1930 (92)	3PL
L	1971 (51)	3PL
M	1978 (44)	3PL
N	1969 (53)	3PL
O	1961 (61)	3PL
P	1905 (117)	3PL
Q	1969 (53)	4PL
R	1977 (45)	3PL
S	1950 (72)	3PL
T	1948 (74)	3PL
U	1992 (30)	3PL
V	2005 (17)	3PL
W	1968 (54)	3PL
X	2008 (14)	3PL

future research, demonstrating content analysis's effectiveness in extracting significant insights from systematic text examination (Nguyen et al., 2021).

We thoroughly reviewed the contents of the 96 business news to familiarise ourselves with the dataset. The initial codes were created using line by line coding (Oguntegbe et al., 2022) involving a systematic evaluation of the data in line with our research questions, without manipulating the original contents of the dataset. We then consolidated similar codes, iterating between empirical data and relevant literature until data saturation was achieved. To ensure data reliability, we repeatedly performed theoretical sampling (Nandi et al., 2020), comparing our underlying theories with empirical data to eliminate bias. Next, we created second-order themes by grouping codes with similar patterns and thematic meanings. These emerging themes were re-examined to ensure congruency between the themes and underlying codes and were finally grouped into aggregate dimensions: 'drivers', 'strategies', and 'outcomes', based on our analytical framework.

4. Results

Blockchain adoption is an emerging research topic in LSCM, with many logistics firms still in the early stages or yet to adopt this technology. To explore the contribution of blockchain to CSCM through reverse logistics, we first identify the primary reverse logistics services provided by the firms in our study: returns authorisation, customer product collection, returns carrier, disposition of returned products, and recycling.

For instance, firm G reports carrying out returns authorisation as a reverse logistics activity:

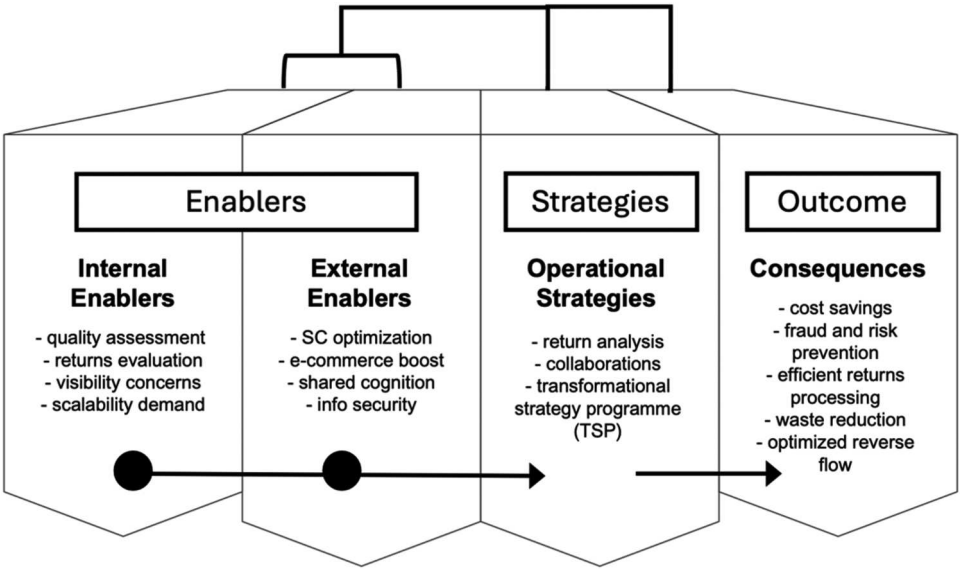

Figure 2. Conceptual framework of blockchain implementation in reverse logistics.

> We offer reverse logistics management services, including issuing return authorizations, return carrier shipping labels, receipt of product, crediting customer accounts and disposition of returned product (Company G, as reported on *LexisNexis*).

We thematically analyse business news on logistics firms with blockchain-enabled circular supply chain structure to identify the precursors, strategies, and outcomes of blockchain adoption. The findings are summarised in the conceptual framework shown in Figure 2.

The results of the qualitative content analysis are presented in this section.

4.1. *Enablers of blockchain adoption in reverse logistics (Why?)*

Understanding the factors motivating logistics companies to adopt blockchain in reverse logistics is crucial for aligning operational strategies with these drivers to meet supply network objectives. The enablers of blockchain implementation in reverse logistics are categorised into internal and external factors, as shown in Table 2.

4.1.1. *Internal enablers*

We identify four internal drivers of blockchain adoption in reverse logistics: quality assessment, return evaluation, transport visibility concerns, and the e-commerce boost.

Quality assessment. Six logistics companies (B, C, D, E, J, and M) report the use of blockchain in assessing product quality and early detection of counterfeits goods. Blockchain provides a superior quality-control system that reduces transaction costs and enhances operational efficiency for logistics providers, and this rationale has led many transport and logistics companies to adopt blockchain technology.

Evaluation of returns. The evaluation officers of four logistics firms (A, T, L, and M) use blockchain to ascertain the veracity of customers' claims on returned goods before authorising their return to origin. The potential of blockchain for return evaluation encourages its adoption by logistics managers, as blockchain's immutability ensures that stored information cannot be altered, and this is crucial for assessing product returns.

Table 2. Enablers of blockchain adoption by logistics firms.

Enabler	Companies ID
Internal	
• Quality assessment	B, C, D,E, J, M
• Returns evaluation	A,T, L,M
• Transport visibility concerns	C, E, F, G, L, *P*
• Scalability demand	F, K, N, R, S, T
External	
• Supply chain optimisation	A, B, C, D, E G, H, M,R,, T, L *P*, Q.
• E-commerce boost	C, D, E G, H, T
• Shared cognition among partners	C, D, Q
• Information security	F, I, K, N, R

Transport visibility concerns significantly drive blockchain adoption in reverse logistics. Logistics operators handling both forward and reverse transportation often face visibility issues, particularly with longer shipping durations. Blockchain offers a transparent and secure data storage system, enhancing product movement tracking and this is consistent with the rationale of six logistics firms (C, E, F, G, L, and P) for blockchain adoption.

Scalability demand. The entry of numerous logistics companies into e-commerce has significantly heightened customer demand. Consequently, logistics firms (F,K, N, R,S,T) face increased pressure to scale operations and broaden service offerings. To address this, providers are utilising digital technologies such as blockchain for order and return management, enabling them to serve a greater number of customers efficiently.

4.1.2. *External enablers*

External drivers are elements originating from forces external to the firm. Our qualitative analysis identifies four external precursors to blockchain utilisation in logistics, including supply chain optimisation, e-commerce growth, mutual understanding among partners, and information security.

Supply chain optimisation. The primary external driver for blockchain adoption in logistics is the need to optimise supply chains. A large proportion (54%) of the firms in our sample use blockchain to enhance efficiency and information sharing with partners. Firms A, B, C, D, E G, H, M, R, T, L P, and Q noted that blockchain aids supply chain planning by balancing demand and supply.

E-commerce boost. Logistics companies C, D, E G, H, T partner with tech companies using blockchain technology and proprietary software to provide brands a transparent and community-driven marketplace. This initiative allows the firms to boost ecommerce capabilities.

Shared cognition among partners. The need for a common understanding among partners drives blockchain adoption in logistics companies C, D and Q. Blockchain's use of cryptography creates a common language across different systems, which is a key reason why managers of these firms opt for blockchain.

Information security. Recognising the fact that blockchain-encrypted messages can only be decrypted by recipients who have the corresponding key and requisite knowledge of algorithm knowledge has driven firms F, I, K, N, and R to adopt blockchain. Given the need for confidentiality in product shipping data, logistics managers see blockchain as crucial for data security, hence, the need for its adoption.

4.2. *Operational strategies of blockchain-enabled reverse logistics (How?)*

Implementing blockchain in reverse logistics involves various activities necessitating distinct strategies to achieve operational efficiency. Results show that *returns analysis* is a key strategy for logistics firms. This analysis identifies the optimal disposal method for each returned product, whether it is returned to the vendor, restocked, liquidated, recycled, or salvaged. Such strategies eliminate waste streams and reduce losses by addressing loopholes in returns management processes. Table 3 outlines the strategies for blockchain implementation in reverse logistics.

Another strategy employed by some logistics companies is collaborations. As exemplified by the data extract:

> We also leverage strategic partnerships to provide our clients with access to distributed returns centres (Company J, on LexisNexis).

This involves forming partnerships to implement blockchain technology across various distribution outlets of logistics operators. Distribution centres gather information on returned products and transfer it to a central facility established by the firm. Additionally, 4PL logistics companies collaborate with 3PL providers to use blockchain for integrating the backward logistics segment of their supply chains. Another strategy is organising Transformation Strategy Programmes (TSP) to train managers on driving supply chain circularity with digital technologies.

4.3. *Consequences of blockchain implementation in reverse logistics on CSCM (What?)*

Our empirical analysis reveals that blockchain use in reverse logistics impacts CSCM in five principal ways: cost savings, fraud prevention, efficient returns processing, waste reduction, and optimised reverse flows.

Cost savings. A significant portion of orders is returned, leading to higher logistics costs. However, as evidenced by this data extract:

> Blockchain reduces freight costs for our client, improves customer service and reduces complexity and cost in our facilities from handling inbound returns (Company M, on LexisNexis).

Table 3. Strategies for blockchain deployment in reverse logistics.

S/N	Strategy	Meaning	Companies ID
1	Returns analysis	A careful examination of returned products by verifying their information on the blockchain to detect possible defects for onward recommendation of the best disposition method for each product.	A, D, F, I, O, S, W
2	Collaborations	Individual firms partnering on the blockchain to achieve common purposes such as supply chain optimisation, reverse flow optimisation or fraud prevention.	C, E, J, *P*, T U, X
3	Transformation Strategy Programme (TSP)	A programme designed to hone managers' digital transformation skills for the development of effective business models to enable effective implementation of blockchain in logistics.	B,G, H,V, S

Table 4. Strategy-outcome matching.

S/N	Strategy	Outcome	Companies ID
1	Return analysis	Efficient returns processing, waste reduction,	A,D,F,I,O,S, W
2	Collaboration	Optimised reverse flows, Fraud and risk prevention	C,E, J, *P*,T U, X
3	Transformation Strategy Programme (TSP)	Cost savings	B,G, H,V, S

Blockchain coordination in reverse logistics reduces the cost of managing product returns. *Efficient returns processing*. Using blockchain for coordinating reverse logistics activities enhances the efficient processing of returned goods. Specifically, eight logistics firms cited its use in resolving invoicing disputes.

Optimised reverse flow. Most of the logistics companies in our dataset assert that blockchain aids product recalls, particularly for manufacturing and engineering items, thereby enhancing goods' recovery potential.

Waste reduction. Logistics firms coordinate reverse logistics with blockchain and this significantly reduces resource wastage due to the provision of timely product information updates for stakeholders.

Fraud prevention. Finaly, logistics service providers are of the opinion that the risks involved in reverse logistics surpasses that in forward logistics, and therefore opt to mitigate black-market activities with the use of blockchain, significantly reducing information asymmetry and counterfeiting, and enhancing the transparency of reverse logistics.

Aligning the corporate strategies utilised by logistics companies with the corresponding outcomes produces the output in Table 4. According to our dataset, companies employing returns analysis as a strategy for using blockchain in reverse logistics achieved efficient returns processing and waste reduction. This underscores the effectiveness of returns analysis in enhancing returns process efficiency and minimising waste.

Similarly, companies that opted for collaboration achieved notable success in reverse flow optimisation and fraud prevention by removing unnecessary intermediaries and identifying unauthorised transactions. Finaly, firms that enrolled their managers in TSP for blockchain implementation in reverse logistics saved transaction costs, as TSP enabled managers to develop innovative business models for transforming reverse logistics using blockchain technology.

5. Discussion and implications

Providing valuable insights for enhancing supply chain circularity through blockchain implementation in reverse logistics has been the key focus of this study. Recent studies have highlighted the usefulness of blockchain for general quality enhancement (Muruganandham et al., 2023) and performance improvements in outbound logistics (Naclerio & De Giovanni, 2022). We extend this line of reasoning by positing that blockchain implementation in reverse logistics is equally crucial for improving supply chain circularity. Therefore, our results have identified the enablers, strategies, and implications of blockchain engagement in reverse logistics with Figure 2 depicting the inter-relationship among these three dimensions.

Implementing blockchain for circularity in reverse logistics starts with adoption rationales, driven by internal firm activities or external factors. Efficient outcomes are ensured when firms employ a strategy aligned with their supply chain circularity objectives. Hence, our first proposition:

Proposition 1. *Blockchain adoption in reverse logistics is influenced by internal and external enablers, with the chosen implementation strategy greatly impacting the efficiency of firms' supply chain circularity efforts*.

Supporting the hypothesis of Chauhan et al. (2022), we found that blockchain's features can improve communication among supply chain stakeholders, enhance transparency in returns management, extend product shelf-life by reducing waste, and promote environmental-friendly practices. Consequently, we propose that:

Proposition 2. *Logistics firms streamline reverse logistics processes through collaborations on the blockchain, thus reducing resource wastage and preventing fraud by effectively analysing returned products towards an optimised reverse flow*.

This underscores blockchain technology's effectiveness in lowering transaction costs within a firm's reverse logistics. Cost reduction is seen in waste minimisation and value chain optimisation. Implementing blockchain for circular economy in logistics requires consideration of both forward and reverse logistics. The reverse logistics segment entails higher risks and uncertainties, making it a crucial aspect of logistics operations. Thus, for effective blockchain deployment in managing reverse logistics strategically, managers should participate in transformative strategy programmes which helps develop innovative ways of optimising transaction costs through a digital ledger system. Therefore, we theorise that:

Proposition 3. *To achieve circular economy goals, logistics companies implement blockchain in reverse logistics to enhance their ability to strategically manage associated transaction costs leveraging transformative programmes*.

5.1. *Theoretical contribution*

Utilising TCE and PVC theories, we propose a conceptual framework suggesting that logistics firms should consider the transaction costs from reverse logistics as key sources of competitiveness when implementing blockchain in reverse logistics. The literature has consistently highlighted the lack of research on digital technology adoption in logistics (Cichosz et al., 2020). This study addresses this gap, thus making contribution to the literature in three specific ways. First, it integrates two established theories from mainstream SCM literature (TCE and PVC) to explain the transactional cost economies of reverse logistics activities. While previous studies have recognised the relevance of TCE in governing transaction costs in a blockchain-based supply chain (Treiblmaier, 2018), this study advances theory by linking TCE with PVC to create an integrated framework. It suggests that firms should leverage blockchain technology to manage transactional costs in their reverse logistics operations to enhance efficiency. The theoretical foundation of this study posits that both reverse logistics activities and governance strategy are critical determinants of operational efficiency.

Existing studies have highlighted firm resources and practices as sources of competitive advantages (Khan et al., 2021). This study identifies the strategies for blockchain implementation in reverse logistics and the expected outcomes on supply chain circularity. Previous research has provided frameworks for blockchain in reverse logistics through

conceptual and single case studies analysis (Dasaklis et al., 2020). Finally, we teased out the consequences of blockchain application in reverse logistics as cost reduction, improved returns processing efficiency, elimination of invoice disputes, reduced waste, and prevention of black-market activities.

The three propositions made in this study have enriched the theoretical understanding of CSCM and demonstrated blockchain's potential in optimising reverse logistics as its overarching contribution to supply chain circularity.

5.2. *Practical implications*

Despite blockchain's potential for reverse logistics, many managers remain unaware of its relevance to logistics functions and the impact of its adoption on supply chain circularity. The study's identified enablers have offered managers new justifications for adopting blockchain in supply chain management. Furthermore, the study's findings keep managers updated about blockchain's potential for CSCM, helping them develop efficient strategies for digital transformation of reverse logistics processes.

The functional strategies for blockchain implementation in reverse logistics for supply chain circularity presented in this study could guide managers in selecting appropriate models for effective coordination. Managers can adopt the strategies proposed in this study by conducting critical returns analysis for efficient returns management; collaborating for fraud detection or sending their managers for TSP towards cost savings.

Our theoretical framework could influence managers' views on the necessity of a digitally enabled circular supply chain, effectively managed when blockchain technology governs transaction costs. Thus, we highlight the importance of managers focusing on reverse logistics as a key value chain activity, whose costs should be reduced via blockchain.

5.3. *Limitations and suggestions for future research*

A key limitation of this study is its small sample size of 24 firms, as few companies met the defined selection criteria. We anticipate that more logistics firms will adopt blockchain technology and that the circular economy will become a primary objective among supply chain stakeholders. Future research should therefore explore this question with a larger sample size.

Additionally, the understanding of blockchain deployment in circular supply chains is limited, as blockchain adoption in logistics is still emerging. Consequently, our study is exploratory and has generated three propositions, by focusing solely on reverse logistics. Future research should consider other segments of logistics services and employ quantitative techniques to test the propositions emerging from this study.

Using the integrated theoretical framework proposed in this research, studies can explore blockchain's impact on all logistics firms' value chain activities. This investigation can be deepened in three ways. First, considering blockchain's effect on specific transaction costs like information, communication, advertising, personnel, and insurance expenses. Second, categorising firms' different value chain activities can provide further insights, as blockchain's impact on each activity can be evaluated. Third, firms use various blockchain types – private, consortium, public, or hybrid – so future studies should examine which type is most efficient for reverse logistics. Additionally, this study focused solely on blockchain. Future research should consider other disruptive technologies such as Artificial Intelligence, big data, and the Internet of Things, given that companies often use a mix of these digital technologies in their operations.

6. Conclusion

This study examined the contribution of blockchain to the achievement of circular economy principles in reverse logistics. It investigated why logistics companies adopt blockchain, how they deploy it in reverse logistics, and its overall influence on logistics circularity. Using data from 24 logistics companies, we identified the enablers, operational strategies, and impacts of blockchain application in achieving circular economy goals in supply chains. Findings showed internal enablers as quality assessment, returns evaluation, visibility concerns, and the need to boost e-commerce; external enablers included supply chain optimisation, scalability demands, shared cognition, and information security requirements.

We identified three key strategies for firms to employ blockchain in reverse logistics: returns analysis, collaborations, and transformational strategy programmes. Our analysis shows that blockchain implementation in logistics leads to gains in circularity, including lower transaction costs, reduced resource wastage, improved returns processing efficiency, prevention of logistics fraud, and optimised reverse flows.

This paper intersects blockchain adoption, reverse logistics, and the circular economy, contributing to CSCM theory and practice. It extends PVC by integrating it with TCE theory to propose a framework recognising transaction costs and strategic operations as sources of competitive advantage in logistics. The study's propositions can be quantitatively tested using survey data, laying the groundwork for further empirical research in blockchain adoption in logistics.

Disclosure statement

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