ISSN 1611-1699 / eISSN 2029-4433

JOURNAL of BUSINESS ECONOMICS & MANAGEMENT

2025
Volume 26
Issue 6
Pages 1308–1328
https://doi.org/10.3846/jbem.2025.24903

BARRIERS TO BLOCKCHAIN IMPLEMENTATION IN SUPPLY CHAIN FINANCE – BASED ON PERSPECTIVES OF GREY TRANSACTION BEHAVIOUR

Wei GAO[1], Ping-Kuo A. CHEN[2]✉

[1]*Business School, Shantou University, Shantou, China*
[2]*College of International Management, Ritsumeikan Asia Pacific University, Beppu, Japan*

Article History:
- received 03 December 2024
- accepted 18 August 2025

Abstract. The purpose of this study is to identify grey transaction behaviours that function as barriers to blockchain implementation in supply chain finance, explore which obstructions arise from these grey transaction behaviours and subsequently hinder blockchain implementation, and further measure the influence levels of the corresponding implementation barriers. The Delphi method and DANP are the main analysis methods used in this study. According to the analysis, three grey transaction behaviours that function as implementation barriers are identified, namely, kickbacks, internal and external accounting, and informal transaction relationships with banks. In addition, seven obstructions arise from these three barriers, and these obstructions can be adopted to explain why the three barriers hinder blockchain implementation. Finally, although internal and external accounting represents the main barrier, informal transaction relationships with banks may function as a critical underlying barrier that enhances the other two barriers. This study contributes in that it fills the gap of existing studies related to the intersection of supply chain finance and blockchain and provides a new perspective enabling practitioners to rethink how blockchain can be successfully implemented in the context of supply chain finance.

Keywords: blockchain, implementation barriers, supply chain finance, Delphi method, grey transaction behaviour, DANP.

JEL Classification: M10.

✉Corresponding author. E-mail: ***pkchen@apu.ac.jp***

1. Introduction

Supply chain finance (SCF) is defined as a financing model in which banks connect core enterprises and enhance the capital flows of supply chain partners (Minaam, 2018). This enables supply chain members to optimize the capital flows among themselves (Hofmann, 2005; Du et al., 2020). According to Xu et al. (2018), SCF is an effective way to lower financing costs and improve financing efficiency and effectiveness. Because SCF has a marginally positive effect on supply chains' market value and operational efficiency, an increasing number of supply chain organizations are working to build SCF (Zhang et al., 2019).

However, it is still difficult to implement increased SCF. According to More and Basu (2013) and Du et al. (2020), the main reasons for this difficulty include credit risks, unpredictable cash flows resulting from delays in financial transactions, a lack of automation in payment processes, and core enterprises from traditional SCF playing an irreplaceable role in managing supply chain information and capital flows, which results in inequality and information asymmetry. Due to the abovementioned issues, studies such as Hofmann et al. (2017) and Du et al. (2020) have found that the implementation of blockchain is necessary.

Blockchain technology, which has emerged in recent years, has provided the ability to solve these problems, thereby optimizing SCF (Kucukaltan et al., 2024). Related studies, such as Chen et al. (2020), have indicated that blockchain smart contracts can be used to solve traditional SCF problems, including those related to credit checks and transaction processes. Du et al. (2020) and Kaur et al. (2024) indicated that the characteristics of blockchain, including its decentralization, stability, security, anonymity, and tamper resistance, can improve problems related to information, knowledge, cash flows, payments and transactions. Yan and Kim (2021) and Dong et al. (2023) indicated that blockchain can promote smooth information flows, the coordination of entities, risk mitigation, control, and process simplification between financial services. Therefore, well-known multinational corporations, such as Maersk and FOXCONN, and state-owned enterprises in China, such as the Bank of China, have successfully implemented blockchain to build SCF.

However, it is difficult to implement blockchain widely across supply chain organizations. Yan and Kim (2021) found that laws and regulations, technical issues, regulatory measures, and risk prevention problems are the main barriers to implementation. Yli-Huumo et al. (2016) believed that a lack of government guidance and policy support is the main barrier. However, as more developed countries have recognized the importance of SCF, these barriers have been reduced and nearly solved through legislation and technology development. However, it is still difficult to widely implement blockchain across all supply chain organizations to build SCF. The main reason for this is that blockchain may hinder relevant information from reaching under-the-table transaction operations between banks, core enterprises, and partners (Murphet, 2020).

These under-the-table transaction operations are called grey transaction behaviours, and they are generally necessary due to their positive effect on the promotion of supply chain transaction processes; indeed, they may even maintain relationships. Grey transaction behaviours refer to financial or operational practices that, while not explicitly illegal, operate outside formal institutional oversight and rely on implicit agreements between supply chain actors. These practices often serve to facilitate transactions and preserve relationships within ambiguous zones of compliance. However, such behaviours may involve legally acceptable but morally questionable proposals. If such information is exposed, it can trigger serious conflicts or disrupt established partnerships. Blockchain technology, by enforcing transparency and traceability (Monrat et al., 2019; Chod et al., 2020; Gelsomino et al., 2023), challenges the existence of these informal arrangements. Consequently, grey transaction behaviours emerge as a critical barrier to blockchain adoption in supply chains.

However, to strengthen supply chain efficiency through financial and capital flows, blockchain must be implemented to build an improved SCF system. Therefore, to successfully implement blockchain for SCF construction, we should identify which grey transaction behaviours that function as implementation barriers are adopted in the supply chain, explore which obstructions are produced through these behaviours and subsequently hinder blockchain implementation, and measure the impacts of these implementation barriers. Based on the above, it is possible to consider related strategies to deal with grey transaction behaviours and reduce blockchain implementation barriers in SCF construction. However, previous studies still lack explorations of these issues. For this reason, this study attempts to identify the grey transaction behaviours that function as implementation barriers in the context of SCF, explore which obstructions are produced from these grey transaction behaviours, and measure the impacts of the corresponding implementation barriers.

As SCF is currently an important issue, the results of our analysis contribute to the literature on SCF and blockchain and provide practical suggestions for manufacturers aiming to enhance their implementation of blockchain, enabling them to realize improved SCF. Rather than proposing new modelling techniques, this study contributes by identifying a set of behavioural barriers that have not been formally addressed in prior literature. By treating grey transaction behaviours as structural resistance mechanisms, this research opens a new perspective on blockchain implementation in supply chain finance that moves beyond technical or institutional concerns.

Based on the above, this study does not aim to develop a new evaluation method. Instead, it constructs and formalises a previously underexplored problem. In the field of evaluation research, some studies focus on modifying or improving methods to better analyse known issues. Others, such as this one, begin with an unstructured but practically relevant phenomenon and apply a suitable method to reveal its internal structure. The contribution of this study lies in clarifying and organising the behavioural barriers that obstruct blockchain implementation in supply chain finance, rather than in altering the evaluation technique itself.

This study is structured as follows. Section 2 introduces SCF, its connection with blockchain technology, and the concept of grey transaction behaviours. Section 3 presents the methodology. Sections 4 and 5 provide the analysis and discussion. The conclusion summarizes the findings, and the Appendix lists all equations used in the analysis.

2. Literature review

2.1. SCF

Supply chain finance (SCF) is an important model and strategy in the supply chain context, and it plays an important role in strengthening capital, cash, and information flows between supply chain members (Demica, 2007). According to Hofmann (2005), SCF is "an approach for two or more organizations in a supply chain, including external service providers, to jointly create value through means of planning, steering, and controlling the flow of financial resources on an interorganizational level". Gomm (2010) indicated that SCF is defined as a process of financial optimization within supply chains that requires a combination of financial services and information technology. Wuttke et al. (2016) indicated that the aim of SCF is to align financial flows with product and information flows within supply chains, improving cash-flow management from a supply chain perspective. It can facilitate longer payment terms for buyers and improved access to financing for suppliers.

Regarding SCF practices, one or a few core enterprises usually act as leaders in a supply chain, and these organizations have strong competitiveness and great influence. To increase their supply chain efficiency and competitiveness, these core enterprises usually require their upstream and downstream partners to cooperate with their strategies related to deliveries, prices, quality, flexibility, and other factors. However, this approach inflicts heavy pressures related to capital and cash flows on these partners (Gelsomino et al., 2019). Indeed, these upstream and downstream partners are mostly small and medium-sized enterprises (SMEs); thus, it is difficult for them to raise funds through bank loans to cooperate with core enterprises because the credit of SMEs is insufficient to persuade banks to provide funding (Sang, 2021). In addition, it is difficult to verify the credit of SMEs (Riikkinen et al., 2018).

According to Carnovale et al. (2019), in the context of SCF, core enterprises are used as the starting point in providing financial support within supply chains. The strong influence and credit of a core enterprise and its long history of cooperation with a partner, including invoices and commercial contracts (Dyckman, 2009), function as a credit guarantee for that partner. These factors not only reduce the difficulty of credit investigation but also reduce the bank loan limitations faced. Figure 1 is an example; it shows interactions between core enterprises and suppliers. We can see that the commercial contracts between a set of core enterprises and suppliers can replace the suppliers' credit. When core enterprises provide commercial contracts and transaction invoices with their suppliers to banks and suppliers provide invoices from core enterprises, banks will agree to provide loans to those suppliers. Therefore, the SCF model can strengthen the capital, cash, and information flows between supply chain members and increase supply chain efficiency.

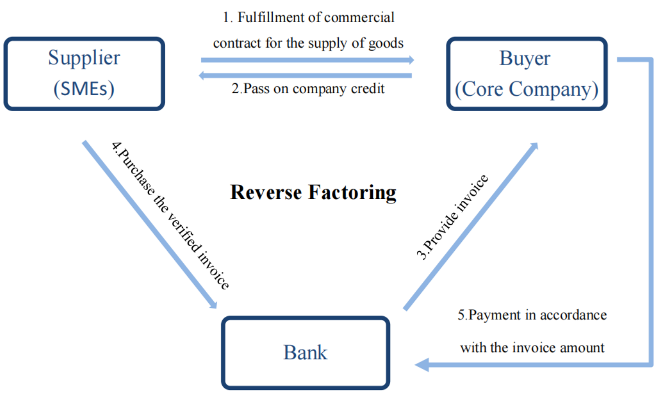

Figure 1. Common SCF models

2.2. Blockchain and SCF

With the publication of the article "Bitcoin: A Peer-to-Peer Electronic Cash System" in 2008 (Nakamoto, 2008), the blockchain became recognized by the public as the technology underlying Bitcoin. Essentially, blockchain technology is a decentralized database technology (Hammi et al., 2018) that uses its own distributed nodes to store, verify and transmit various data without relying on any central platform (Kotobi & Bilen, 2018). A blockchain stores complete transaction records (Wu & Liang, 2017). From a financial point of view, blockchain technology is regarded as a public distributed ledger, and any individual within the blockchain platform can contribute to the ledger (Lee Kuo Chuen, 2015; Sargent & Breese, 2024). The recorded ledger is broadcast and stored in the entire block network and is backed up and checked by each node. Because the operation is transparent and there is no central intervention, transaction records and other operations can be addressed immediately (Mohamed & Al-Jaroodi, 2019).

The block body consists of transactions and transaction counters, and the blocks contain information such as validation rule sets, hashes, and timestamps, which are permanently stored within the blocks and ordered according to timestamps; each block points to the hash value of the previous block (parent), forming a logical chain structure consisting of block data. Blockchain uses the mechanism of asymmetric encryption for transaction authentication within the network (Nomura Research Institute [NRI], 2015; Aune et al., 2018) and that of consensus algorithms to ensure consistency across different node ledgers in an untrusted environment (Nguyen & Kim, 2018). Based on the above, blockchain has the characteristic of immutability (Zheng et al., 2017). Based on blockchain's characteristics of immutability and decentralization and its distributed ledger, experts within many fields, such as the economic, market and financial sectors, believe that the implementation of blockchain can strengthen operations and information transparency, further promoting efficiency and competitiveness (Bindi, 2017; Jackson, 2017; Oh et al., 2023).

Due to the characteristics of blockchain, an increasing number of researchers and practitioners believe that the implementation of blockchain can positively affect the construction of SCF. However, although SCF can promote capital and cash flows within supply chains and increase supply chain efficiency, traditional SCF still has some problems. Du et al. (2020) indicated that the core enterprises of traditional SCF function as leaders in terms of managing supply chain information and capital flows, and this results in inequality and information asymmetry. It also imposes credit checking risk on partners. It is difficult for banks to ensure their partners' ability to repay loans, although core enterprises can provide evidence to support their partners' credit. More and Basu (2013) indicated that traditional SCF still faces the problems of unpredictable cash flows, delayed transactions that cause related risks, and a lack of automated payment processes. In addition, Wang et al. (2021) and Li (2021) indicated that it is still possible for stakeholders or third-party units to interfere with traditional SCF, and fake transactions and information can still arise and affect supply chain practices on the whole. However, Li et al. (2019) and Xie et al. (2020) indicated that the characteristics of blockchain can promote point-to-point communication, enabling digital encryption, distributed ledgers, multiparty collaboration, and increased information transparency. Thus, Li (2023) and Xiao et al. (2023) the implementation of blockchain can strengthen SCF and further enhance supply chain efficiency.

2.3. Grey transaction behaviours

In traditional supply chain finance (SCF), it is not uncommon to encounter transactions that diverge from formal financial procedures. Wang et al. (2021) observed that fabricated transactions are often employed within SCF systems. While these transactions may not be outright illegal, they tend to circumvent regulatory scrutiny and are often intended to support flexible financial coordination. Despite their deviation from transparency principles, such arrangements can play an important role in fostering cooperation and maintaining stability among supply chain partners.

These arrangements can be more precisely understood as grey transaction behaviours, a term referring to financial or operational practices which, although not clearly unlawful, fall outside the boundaries of formal institutional regulation. Mouzos (1999) described these behaviours as neither entirely legal nor entirely illegal. Moorehead (2019) noted their prevalence in sectors where regulatory enforcement is limited, and Gao and Chen (2021) suggested that certain grey practices may, in specific contexts, be necessary for maintaining long-term cooperation and relational stability.

Within SCF, such behaviours often arise from the pressures faced by firms seeking to sustain trust with financial institutions, and from the incentives banks may have to meet performance targets. These dynamics can lead to informal practices, including fabricated purchase orders, dual bookkeeping systems, or non-contractual financial arrangements between banks and core enterprises. While these practices remain unofficial, they serve to maintain liquidity and ensure operational continuity across the supply chain.

The introduction of blockchain technology presents a fundamental challenge to these arrangements. By enforcing transparency, traceability, and data immutability (Monrat et al., 2019; Chod et al., 2020; Gelsomino et al., 2023), blockchain limits the discretionary space in which grey transaction behaviours operate. Once transactions are recorded permanently and visibly, the flexibility and confidentiality that underpin many informal practices are undermined. Consequently, resistance may emerge from actors who have historically relied on such mechanisms to manage their financial relationships.

Although previous research has addressed regulatory, technical, and organisational challenges associated with blockchain implementation, there has been comparatively little attention to the behavioural and relational dimensions of resistance. This study seeks to address that gap by conceptualising grey transaction behaviours as structural features embedded within SCF operations. While these behaviours may offer certain relational benefits, they simultaneously present a fundamental obstacle to the adoption of technologies that prioritise transparency and accountability.

3. Methodology

Based on the purpose of research, this study adopts a two-stage methodological design that integrates qualitative expert judgment and quantitative multi-criteria analysis. The first stage employs the Delphi method to identify key gray transaction behaviours that function as barriers to blockchain implementation in supply chain finance and the specific obstructions that result from them. The second stage applies the DANP method, which combines the Decision-Making Trial and Evaluation Laboratory (DEMATEL) and the Analytic Network Process (ANP), to analyse the influence of structure among these barriers and determine their relative importance.

This combined approach is suitable for the research objective for two reasons. First, gray transaction behaviours are largely informal, underreported, and context-dependent, making relying on traditional data collection methods difficult. The Delphi method allows for systematically eliciting expert knowledge to reach consensus on these implicit practices. Second, the interactions among the identified barriers are expected to be interdependent rather than hierarchical. DANP provides a mechanism to analyse such complex feedback relationships and to compute influence weights by integrating causality (via DEMATEL) and interdependence (via ANP). This combination ensures both the conceptual discovery and structured evaluation of hidden resistance mechanisms to blockchain adoption in SCF environments.

3.1. Application of the Delphi method

The Delphi method is employed in the first stage of this study to identify critical gray transaction behaviours and the corresponding obstacles that hinder the implementation of blockchain technology in supply chain finance (SCF). Developed by the RAND Corporation (Dalkey & Helmer, 1963), the Delphi method is a structured process designed to obtain expert consensus through iterative consultation. It is particularly appropriate in contexts where the subject is underexplored, informally embedded, and not readily observable through conventional empirical methods.

The use of the Delphi method is well established in decision-making and supply chain research when investigating phenomena under uncertainty or lacking stable definitions (Bouzon et al., 2016; Schmidt et al., 2001; Seuring & Müller, 2008). It is especially effective in the early stages of theory construction or in fields where formalized knowledge is scattered across practical expertise. The present study follows a multi-stage Delphi procedure aligned with prior applications in supply chain and operational evaluation (Akkermans et al., 2003; MacCarthy & Atthirawong, 2003; Chen, 2011). The procedure includes expert selection, question formulation, individual consultation, and synthesis of inputs into an initial criteria system. The process followed in this study is illustrated in Figure 2.

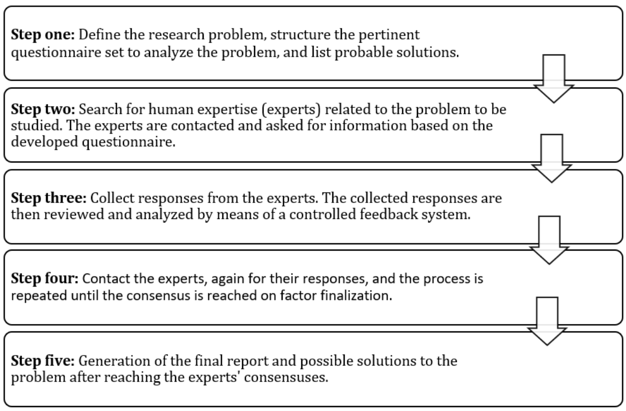

Figure 2. The steps of the Delphi method

A panel of four senior experts is invited to participate in the consultation process. These experts are selected based on their institutional roles, professional experience in SCF, and familiarity with both formal mechanisms and informal practices. The expert panel includes: (1) a supply chain finance manager from a guaranteed financial intermediary affiliated with a state-owned enterprise in China, (2) a project manager in the field of digital finance from Taishin Holdings in Taiwan, (3) a director of SCF operations at the Bank of China, and (4) a senior manager from China Supply Chain Cloud Financial Information Service Co., Ltd. (CSCC), which operates the largest SCF platform in China, connecting 153,503 banks and enterprises.

The consultation is guided by the following open-ended question: "What gray transaction behaviours produce obstacles that hinder the implementation of blockchain technology in the context of SCF?" Experts are asked to reflect on their institutional and industry experience to describe informal, semi-regulated behaviours that may not violate legal rules, yet actively resist transparency. Responses are individually collected and qualitatively consolidated. The synthesized insights form the foundation for the development of evaluation criteria. These criteria are subsequently used in the second-stage DANP analysis. The resulting categories and relationships are formally presented in the results section.

3.2. Application of the DANP methods

In the second stage of this study, the Decision-Making Trial and Evaluation Laboratory (DEMATEL) combined with the Analytic Network Process (ANP), referred to as the DANP method, is used to analyse the influence relationships and interdependencies among the implementation barriers identified through expert consultation. This hybrid method enables the modelling of feedback structures among criteria, which is essential when dealing with mutually reinforcing behavioural factors (Tzeng et al., 2007; Yang et al., 2008; Saaty, 2004).

DANP is considered appropriate for this study because grey transaction behaviours do not operate in isolation. Instead, they tend to form interlinked resistance mechanisms within supply chain finance, which cannot be effectively analysed using hierarchical or independent-assumption models. DANP enables a network-based analysis that reflects the actual decision dynamics among interrelated barriers.

Based on the evaluation framework developed through the Delphi method, a set of initial criteria is defined to reflect the behavioural and operational obstructions to blockchain implementation. These criteria are used to design a pairwise comparison questionnaire following DEMATEL logic, in which experts assess the degree of influence from one criterion to another on a five-point scale (0 to 4).

A total of 18 experts are selected from the same institutional background as the Delphi panel. These include bank executives, SCF platform managers, and digital finance specialists. Most participants had more than ten years of practical experience in SCF implementation or digital finance operations. The experts selected for this study are not hypothetical proxies, but practitioners with direct exposure to grey transaction behaviours in the SCF industry. Their daily work involves managing or responding to the very issues evaluated in this research, such as informal financing relationships and undisclosed fund flows. Although this study does not adopt a single-firm case format, it is grounded in field-informed judgment that reflects operational realities. Each expert independently completes the questionnaire. The collected responses are averaged to form the direct relation matrix, which is then normalized and used to calculate the total influence matrix as per DEMATEL procedures.

Using this matrix as input, the ANP supermatrix is constructed. The unweighted supermatrix is combined with the normalized influence values to generate a weighted supermatrix. Through a limiting process, the final global priority weights of each criterion are obtained. All computational steps, including matrix formulation, normalization, and convergence calculation, are detailed in the Appendix.

The results obtained through this method provide a structured understanding of how different behavioural and operational barriers interact and contribute to the resistance against blockchain adoption. By quantifying both the influence strength and direction among criteria, this approach offers a basis for explaining the systemic nature of grey transaction behaviours in SCF. The resulting prioritization supports the subsequent interpretation of which barriers exert dominant influence, and how these influences align with the broader challenges identified in literature. These findings are analysed in detail in the following results section.

4. Research results

4.1. Delphi-based identification of grey transaction behaviours

According to interviews with four senior managers based on the Delphi method, three grey transaction behaviours, including kickbacks, internal and external accounting, and informal transaction relationships with banks were identified as barriers to blockchain implementation. Based on the above, we further explain this phenomenon as follows.

First, kickbacks. It can be defined as “any remuneration (including any kickback, bribe, or rebate) directly or indirectly, overtly or covertly, in cash or in-kind” (Aussprung, 1998). The phenomenon of kickbacks in corporate transactions is widespread in supply chains (Withers & Ebrahimpour, 2018), and it objectively promotes transactions to a certain extent. According to the interview results, the participating experts believed that more transaction information involving kickbacks would be disclosed if blockchain is implemented. This disclosure produces three obstructions that hinder blockchain implementation. First, obstructions arise from individuals with vested interests. Specifically, kickbacks usually occur in various transactions within supply chains, even during cooperation with banks. However, different kickbacks also result in different benefits. Sometimes, individuals with vested interests may obtain benefits and promote transactions through low-cost kickback payments; however, other participants may only obtain benefits in transactions through expensive kickback payments. When all the kickbacks from different transactions are disclosed, some individuals with vested interests making low-cost kickback payments are also exposed. The second obstruction arises from internal conflict aversion. Many participants know of the existence of kickbacks. However, they usually adopt passive attitudes, and they are not willing to disclose these kickbacks. They know that disclosing kickbacks will lead to serious internal conflicts because certain transactional relationships between banks, core enterprises, and partners usually involve unequal agreements or "lining moguls' pockets", such agreements depend on kickbacks. These actions appear to be unethical business behaviour; however, they usually produce a force that maintains a stable business environment. However, these things cannot be openly discussed, as such discussion would lead to serious internal conflict. When kickbacks are disclosed, these unequal treaties or activities that line moguls' pockets are also disclosed, causing internal conflict and further leading to unstable supply chains. Third, an obstruction arises from external distrust. Specifically, the disclosure of kickbacks triggers distrust from other new participants. When transactions involving kickbacks are disclosed, new participants will question the quality of the products from the supply chain. Finally, many new participants will leave and cease cooperation, which decrease the supply chain's competitiveness.

Second, grey transaction behaviours also arise from internal and external accounting. According to Burritt et al. (2002), internal and external accounting involves such behaviours since the level of detail, aggregation of information, and extent of confidentiality applied to management needs differ from that applied to other stakeholder needs. Such grey behaviours are common in the supply chain (Hansen & Mowen, 2007). According to the interview results, internal accounting usually involves distorted information. The use of both internal and external accounting has two purposes: the first is tax savings, and the second is the maintenance of cooperative relationships with core enterprises, banks, and other partners. When taxes must be paid, external accounting maximizes tax savings. In addition, longer cooperative relationships usually depend on financial soundness. Internal accounting may involve more abnormal financial situations, although these situations do not entail a high financial risk. If a company implements blockchain, its real accounts (internal accounts) will inevitably be displayed on the SCF platform, affecting the maintenance of its cooperative relationships and increasing its tax costs. The motivation to obtain these tax savings and the need to maintain cooperative relationships obstruct blockchain implementation.

Third, regarding informal transaction relationships with banks, an informal relationship is defined as "a long-term cooperation and strategic partnership beyond simple business development such as contract and monitoring" (Ma et al., 2018). Many informal transaction relationships exist between banks and core enterprises, and banks are usually willing to develop informal relationships to maintain customer relationships (Tufa & Teshu, 2015). However, why do banks agree to develop informal transaction relationships? According to the interview results, the main reasons include bank industry competition and the maintenance of capital flows. Regarding bank industry competition, bank executives are quite concerned about competition. Therefore, when banks can build cooperative relationships with core enterprises, their competitive advantage in the banking industry is more clearly established. However, financing negotiations usually waste time, and banks may lose the chance to cooperate with core enterprises if they engage in such negotiations. Therefore, banks tend to establish cooperation quickly with powerful, creditworthy core enterprises through informal transaction relationships (Chen & Cheng, 2024). Specifically, these informal situations can facilitate flexible, quick adjustments to contract terms. They enhance convenience and attract more core enterprises to cooperate with banks. However, this approach also involves unfair competition and violates financial laws. Regarding the maintenance of capital flows, although supply chain partners can obtain bank loans through the credit and guarantees of core enterprises in the context of SCF, these partners still need flexible loan policies due to their capital needs related to seasonal deals. To maintain capital flows and reduce loan limitations, many banks routinely provide informal contracts to their partners when funding loans. Although this situation seems normal, the content of many informal contracts involves grey transactions, and this information cannot be disclosed. However, an SCF platform built with blockchain technology may disclose information about such informal transaction relationships with banks. Therefore, from the perspective of finance providers, this issue is also an obstacle to participation in blockchain implementation.

Through our analysis of the interview results, we classified the identified grey transaction behaviours and the corresponding obstructions as primary and subordinate criteria of barriers to blockchain implementation, as shown in Table 1.

Table 1. Criteria of barriers to blockchain implementation

Primary criteria	Subordinate criteria
D1. Kickbacks	C1. Obstructions from vested interests
	C2. Obstructions from internal conflict avoidance
	C3. Obstructions from external distrust
D2. Internal and external accounting	C4. Tax savings
	C5. Maintenance of cooperative relationships
D3. Informal transaction relationships with banks	C6. Bank competition
	C7. Maintenance of capital flows

4.2. DANP-based analysis of grey transaction behaviour

Based on Table 1, we designed an expert questionnaire for DANP data collection. This questionnaire was distributed to 18 experts from the companies of the 4 experts who participated in the Delphi interview. After collecting these experts' opinions, we further analysed the data using DANP. Table 2 shows the average matrix of the direct relationships generated based on the opinions of the 18 experts. The total impact matrix was calculated based on Equations (2)–(4), as shown in Table 3. Then, based on Equations (5) and (6), the sum ($r + d$) and difference ($r - d$) of the impacts received and caused could be obtained for each primary and subordinate criterion, as shown in Table 4. Table 4 shows that 'informal transaction relationships with banks (D_3), ($r - d$) has the highest positive value, indicating that this factor is the most important criterion. This indicates that the factor 'informal transaction relationships with banks' has a greater influence on the other criteria than they have on it. The participating experts believed that banks occupy relatively strong positions in SCF; therefore, their informal financing methods are a central consideration that affects barriers to introducing blockchain technology. 'Informal transaction relationships with banks (D_3)' also has the highest ($r + d$) value, which means this factor can strongly influence the other primary criteria and be influenced by them.

Table 2. The direct relation average matrix

D	C_1	C_2	C_3	C_4	C_5	C_6	C_7
C_1	0.00	0.17	0.18	0.16	0.17	0.16	0.16
C_2	0.12	0.00	0.14	0.14	0.14	0.14	0.13
C_3	0.13	0.13	0.00	0.15	0.17	0.16	0.15
C_4	0.14	0.14	0.16	0.00	0.14	0.14	0.14
C_5	0.14	0.12	0.15	0.14	0.00	0.17	0.14
C_6	0.13	0.15	0.14	0.13	0.17	0.00	0.14
C_7	0.13	0.14	0.13	0.14	0.15	0.15	0.00

Table 3. The total influence matrix

T	C_1	C_2	C_3	C_4	C_5	C_6	C_7
C_1	0.91	1.09	1.17	1.10	1.21	1.19	1.13
C_2	0.87	0.79	0.97	0.93	1.01	1.00	0.94
C_3	0.93	0.96	0.91	1.00	1.10	1.08	1.01
C_4	0.91	0.94	1.02	0.84	1.05	1.04	0.98
C_5	0.92	0.93	1.02	0.96	0.93	1.06	0.99
C_6	0.92	0.96	1.02	0.97	1.09	0.93	1.00
C_7	0.90	0.94	1.00	0.96	1.05	1.04	0.85

Table 4. The sum of the influences received and given on T_C and T

T_C	r	d	$r + d$	$r - d$	T	r	d	$r + d$	$r - d$
D_1	8.49	8.56	17.05	–0.07	C_1	7.79	6.36	14.15	1.44
					C_2	6.52	6.63	13.15	-0.10
					C_3	7.00	7.12	14.12	-0.13
D_2	9.21	9.71	18.92	–0.49	C_4	6.79	6.77	13.56	0.02
					C_5	6.81	7.43	14.25	-0.62
D_3	9.89	9.33	19.22	0.56	C_6	6.88	7.35	14.23	-0.46
					C_7	6.75	6.89	13.64	-0.14

Using Equations (8)–(10), the limit supermatrix can be obtained, and the weights of the various factors can be calculated, as shown in Table 5. The results show that "Internal and external accounting (D_2)" is the most important primary criterion, while "Banking competition (C_6)" and "Tax savings (C_4)" have the greatest weights overall. The influential relationships between the three primary criteria and their subcriteria can be visualized as plotted in Figure 3. As shown in Figure 3, we found that the obstructions from vested interests (C_1), tax savings (C_4), and the maintenance of capital flows (C_7) have the highest values $(r-d)$ within their respective subsystems.

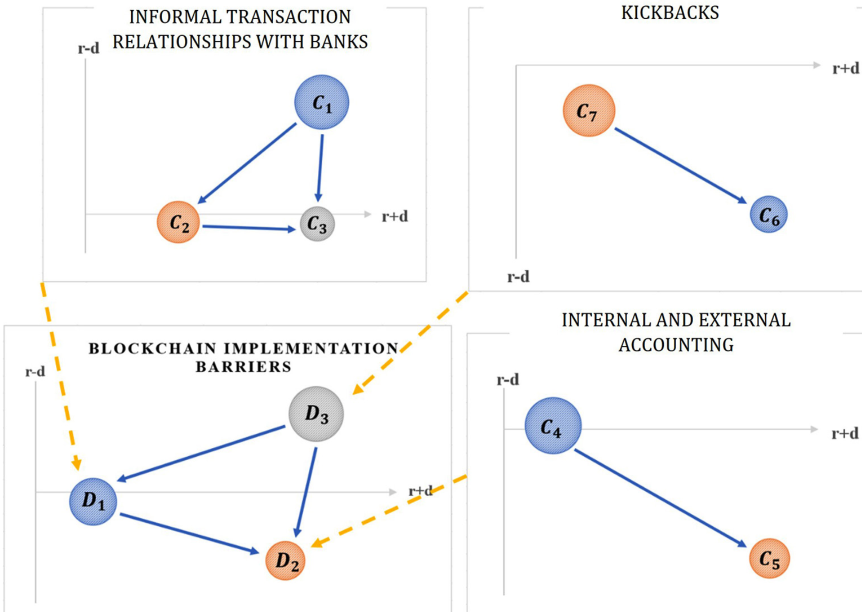

Figure 3. The steps of the Delphi method

Table 5. Influential weights of criteria

T_C	Local weight	Ranking	T	Local weight	Ranking	Global weight
D_1	0.31	3	C_1	0.48	1	0.15
			C_2	0.30	2	0.09
			C_3	0.22	3	0.07
D_2	0.35	1	C_4	0.53	1	0.19
			C_5	0.47	2	0.17
D_3	0.34	2	C_6	0.58	1	0.20
			C_7	0.42	2	0.14

5. Discussion

According to the analysis results, three implementation barriers of blockchain were identified, namely, kickbacks, internal and external accounting, and informal transaction relationships with banks. Based on the above, we further identify seven obstructions arising from these three barriers and explain why these three are the main barriers to blockchain implementation.

The analysis results reveal that internal and external accounting (D_2) has the highest weight, namely, 0.35. However, it does not impose the highest degree of influence ($r - d$). Internal and external accounting are still means for grey behaviour, and they are widely adopted. However, excessive distorted information is involved in internal accounting, while external accounting seems to involve negative reporting (Black, 2019). Internal and external accounting are employed to reduce taxes and maintain cooperative relationships, and they have an important function. However, it is impossible to disclose all internal accounting information. Sometimes internal accounting involves much information regarding real transactions with stakeholders, including banks, core enterprises, and other partners (Burritt et al., 2002). If internal and external accounting information is disclosed via blockchains, a domino effect may ensue and lead to a serious financial crisis. Many banks, core enterprises, and other partners may be implicated, which could even lead to related problems such as tax issues, financial risk, and social pressures. Based on the above, internal and external accounting certainly act as critical barriers that hinder blockchain implementation.

Regarding the cause-and-effect relationship between the three barriers, the ($r - d$) value of the primary criterion, "Informal transaction relationships with banks (D_3)", is the largest, and this factor influences kickbacks (D_1) and internal and external accounting (D_2). This analysis result is amazing because it means that informal relationships with banks may be a critical under-the-table barrier to blockchain implementation in SCF! Specifically, informal transaction relationships with banks increase banks' industry competition because they can facilitate convenient loan funding for core enterprises and attract more cooperation. They also enhance the loan flexibility of supply chain partners about seasonal needs and further maintain capital flows to these partner firms. However, ultimately, the above behaviours generate more revenue for banks. Therefore, to strengthen the cooperation relationships between banks, core enterprises, and partners, all supply chain participants, including banks, rely excessively on informal relationships to maintain capital flows because this approach can create a win–win situation. Thus, banks are the bridge connecting core enterprises, upstream and downstream partners, and major participants through financing activities; they are the central coordinators of supply chain capital flows, play a central controlling role (Fellenz et al., 2009), and must participate in a series of SCF activities. Banks cannot be unaware of the problems with kickbacks and internal and external accounting. Therefore, we can say that informal transactions with banks promote kickbacks and internal and external accounting. Therefore, the existence of barriers to blockchain implementation is made possible through the grey transaction behaviours of banks.

6. Conclusions

SCF is an important model and strategy, and it has a strong effect on enhancing the cash and capital flows of supply chains, thus strengthening supply chain efficiency. However, traditional SCF problems still must be solved. Against this background, the implementation of blockchain has been proven to have positive effects on improving the problems with traditional SCF. However, only large, multinational groups have successfully implemented blockchain to strengthen SCF. Other supply chain organizations still face difficulties in implementing blockchain for SCF, although existing studies have explored and identified related implementation barriers. Based on the above, this study attempted to identify barriers to blockchain implementation from the perspective of grey transaction behaviours. According to the analysis results, three grey transaction behaviours that function as barriers were identified, namely, kickbacks, internal and external accounting, and informal transaction relationships with banks. Based on these three barriers, seven obstructions were highlighted to further explain why these three barriers hinder blockchain implementation.

This study has valuable academic and practical implications. Academically, this study fills a research gap on the barriers to blockchain technology implementation in the context of SCF. The existing studies in this field generally explore implementation barriers in ideal situations and ignore the dark sides of such approaches. However, in the real world, many negative factors, such as grey transaction behaviours, are involved in financial and supply chain operational environments. In addition, many barriers certainly arise from such negative factors. However, the existing studies lack an exploration of these dark sides. Thus, this study tried to explore barriers to blockchain implementation in the context of SCF, focusing on grey transaction behaviours; thus, the analysis results certainly fill the abovementioned gap in the existing studies.

Regarding the practical implications, SCF plays a crucial role in supporting liquidity and operational continuity across a wide range of industries. While this study focuses on the context of China's SCF system, the types of behavioural barriers examined include informal financial practices and internal accounting irregularities. These are also common in other economies with similar institutional characteristics. Therefore, the findings presented in this study may offer meaningful reference points for practitioners and regulators involved in SCF reforms across different industrial and national settings. Strengthening SCF through blockchain implementation remains necessary but challenging. This study identified three implementation barriers through an analysis of grey transaction behaviours and further explained the subordinate obstructions derived from them. Managers can thus reconsider strategies to reduce these frictions by prioritising the most influential barriers and their causal relationships. In particular, internal and external accounting appear as a dominant constraint, while informal transaction relationships with banks act as a latent but powerful enabler of other obstructions. These findings suggest that policymakers and platform developers should go beyond traditional technical solutions by embedding institutional sensitivity and offering gradual compliance mechanisms. For managers, internal audit systems and phased integration strategies can help organisations shift away from grey transactional routines. Decision-makers in SCF institutions and regulatory agencies can use these findings to target informal resistance more effectively, sequence interventions, and develop governance models that align technical solutions with behavioural realities.

This study also has shortcomings. We identify the examined barriers by referring to data extracted via an unstructured questionnaire from experts in China, and this approach may have introduced limitations related to generalizability and the number of questionnaires used; thus, more expert interviews could be conducted globally in the future to ensure that the findings are informative throughout the broader field of SCF. Second, this research area is unique in that the relevant barriers are hidden within the industry processes and are confidential; therefore, there may still be more grey trade indicators that urgently need to be identified, and an alternative evaluation system could be considered to validate the findings further. Finally, empirical research and industry practice should verify whether the revelation of the relevant grey industry means provided by this study can substantially help with blockchain implementation.

Author contributions

Gao and Chen conceived the study and were responsible for the design and development of the data analysis. Gao was responsible for data collection and analysis. Chen was responsible for data interpretation. Gao wrote the first draft of the article.

Disclosure statement

This paper has not any competing financial, professional, or personal interests from other parties.

References

Akkermans, H. A., Bogerd, P., Yücesan, E., & Van Wassenhove, L. N. (2003). The impact of ERP on supply chain management: Exploratory findings from a European Delphi study. *European Journal of Operational Research*, *146*(2), 284–301. https://doi.org/10.1016/S0377-2217(02)00550-7

Aune, R. T., Krellenstein, A., O'Hara, M., & Slama, O. (2018). Footprints on a blockchain: Trading and information leakage in distributed ledgers. *The Journal of Trading*, *13*(4), 49–57. https://doi.org/10.3905/jot.2017.12.3.005

Aussprung, L. (1998). Fraud and abuse: Federal civil health care litigation and settlement. *Journal of Legal Medicine*, *19*(1), 1–62. https://doi.org/10.1080/01947649809511052

Bindi, T. (2017, May 23). *Alibaba and AusPost team up to tackle food fraud with blockchain*. https://www.zdnet.com/article/alibaba-and-auspost-team-up-to-tackle-food-fraud-with-blockchain/

Black, R. A. (2019). Accounting and the auditing function in economic history: Transaction costs, trust, and economic progress. *Journal of Markets & Morality*, *22*(1), 41–65. https://www.marketsandmorality.com/index.php/mandm/article/download/1388/1138

Bouzon, M., Govindan, K., Rodriguez, C. M. T., & Campos, L. M. (2016). Identification and analysis of reverse logistics barriers using fuzzy Delphi method and AHP. *Resources, Conservation and Recycling*, *108*, 182–197. https://doi.org/10.1016/j.resconrec.2015.05.021

Burritt, R. L., Hahn, T., & Schaltegger, S. (2002). Towards a comprehensive framework for environmental management accounting – Links between business actors and environmental management accounting tools. *Australian Accounting Review*, *12*(27), 39–50. https://doi.org/10.1111/j.1835-2561.2002.tb00202.x

Carnovale, S., Rogers, D. S., & Yeniyurt, S. (2019). Broadening the perspective of supply chain finance: The performance impacts of network power and cohesion. *Journal of Purchasing and Supply Management*, *25*(2), 134–145. https://doi.org/10.1016/j.pursup.2018.07.007

Chen, J., Cai, T., He, W., Chen, L., Zhao, G., Zou, W., & Guo, L. (2020). A blockchain-driven supply chain finance application for auto retail industry. *Entropy*, *22*(1), Article 95. https://doi.org/10.3390/e22010095

Chen, X., & Cheng, X. (2024). How does the digital economy affect corporate business credit supply?. *Journal of Business Economics and Management*, *25*(4), 685–708. https://doi.org/10.3846/jbem.2024.22027

Chen, Y. J. (2011). Structured methodology for supplier selection and evaluation in a supply chain. *Information Sciences*, *181*(9), 1651–1670. https://doi.org/10.1016/j.ins.2010.07.026

Chen, F. H., Hsu, T. S., & Tzeng, G. H. (2011). A balanced scorecard approach to establish a performance evaluation and relationship model for hot spring hotels based on a hybrid MCDM model combining DEMATEL and ANP. *International Journal of Hospitality Management*, *30*(4), 908–932. https://doi.org/10.1016/j.ijhm.2011.02.001

Chod, J., Trichakis, N., Tsoukalas, G., Aspegren, H., & Weber, M. (2020). On the financing benefits of supply chain transparency and blockchain adoption. *Management Science*, *66*(10), 4378–4396. https://doi.org/10.1287/mnsc.2019.3434

Dalkey, N., & Helmer, O. (1963). An experimental application of the Delphi method to the use of experts. *Management Science*, *9*(3), 458–467. https://doi.org/10.1287/mnsc.9.3.458

Demica, S. S. (2007). *The growing role of supply chain finance in a changing world*. Demica Report Series.

Dong, L., Qiu, Y., & Xu, F. (2023). Blockchain-enabled deep-tier supply chain finance. *Manufacturing & Service Operations Management*, *25*(6), 2021–2037. https://doi.org/10.1287/msom.2022.1123

Du, M., Chen, Q., Xiao, J., Yang, H., & Ma, X. (2020). Supply chain finance innovation using blockchain. *IEEE Transactions on Engineering Management*, *67*(4), 1045–1058. https://doi.org/10.1109/TEM.2020.2971858

Dyckman, B. (2009). Integrating supply chain finance into the payables process. *Journal of Payments Strategy & Systems*, *3*(4), 311–319. https://doi.org/10.69554/VDLX4343

Fellenz, M. R., Augustenborg, C., Brady, M., & Greene, J. (2009). Requirements for an evolving model of supply chain finance: A technology and service providers perspective. *Communications of the IBIMA*, *10*(29), 227–235.

Gelsomino, L. M., de Boer, R., Steeman, M., & Perego, A. (2019). An optimisation strategy for concurrent Supply Chain Finance schemes. *Journal of Purchasing and Supply Management*, *25*(2), 185–196. https://doi.org/10.1016/j.pursup.2018.07.004

Gao, W., & Chen, P. K. (2021, December). Analysis of barriers to implement blockchain in supply chain finance. In *Proceedings of the 2021 3rd International Conference on E-Business and E-commerce Engineering* (pp. 46–52). Association for Computing Machinery. https://doi.org/10.1145/3510249.3510258

Gelsomino, L. M., Sardesai, S., Pirttilä, M., & Henke, M. (2023). Addressing the relation between transparency and supply chain finance schemes. *International Journal of Production Research*, *61*(17), 5806–5821. https://doi.org/10.1080/00207543.2022.2115575

Gomm, M. L. (2010). Supply chain finance: Applying finance theory to supply chain management to enhance finance in supply chains. *International Journal of Logistics*: *Research and Applications*, *13*(2), 133–142. https://doi.org/10.1080/13675560903555167

Hammi, M. T., Hammi, B., Bellot, P., & Serhrouchni, A. (2018). Bubbles of trust: A decentralized blockchain-based authentication system for IoT. *Computers & Security*, *78*, 126–142. https://doi.org/10.1016/j.cose.2018.06.004

Hansen, D. R., & Mowen, M. M. (2007). *Managerial Accounting*. South-Western.

Hofmann, E. (2005). Supply chain finance: Some conceptual insights. In *Beiträge Zu Beschaffung Und Logistik* (pp. 203–214). Springer. https://doi.org/10.1007/978-3-658-03815-1

Hofmann, E., Strewe, U. M., & Bosia, N. (2017). *Supply chain finance and blockchain technology*: *The case of reverse securitisation*. Springer. https://doi.org/10.1007/978-3-319-62371-9

Jackson, B. (2017). Canada's first commercial blockchain service could become the 'Interac' for digital transactions. *IT World Canada News*, 1–5.

Kaur, J., Kumar, S., Narkhede, B. E., Dabić, M., Rathore, A. P. S., & Joshi, R. (2024). Barriers to blockchain adoption for supply chain finance: The case of Indian SMEs. *Electronic Commerce Research*, *24*(1), 303–340. https://doi.org/10.1007/s10660-022-09566-4

Kotobi, K., & Bilen, S. G. (2018). Secure blockchains for dynamic spectrum access: A decentralized database in moving cognitive radio networks enhances security and user access. *IEEE Vehicular Technology Magazine*, *13*(1), 32–39. https://doi.org/10.1109/MVT.2017.2740458

Kucukaltan, B., Kamasak, R., Yalcinkaya, B., & Irani, Z. (2024). Investigating the themes in supply chain finance: The emergence of blockchain as a disruptive technology. *International Journal of Production Research*, *62*(22), 8173–8192. https://doi.org/10.1080/00207543.2022.2118886

Lee Kuo Chuen, D. (2015). *Handbook of digital currency*. Elsevier.

Li, G. (2023). Application of blockchain in supply chain finance. *Information Systems and Economics*, *4*(10), 13–19. https://doi.org/10.23977/infse.2023.041003

Li, J., Wang, Y., Li, Y., & Li, Q. L. (2019, November). A simple survey for supply chain finance risk management with applications of blockchain. In *International conference of celebrating Professor Jinhua Cao's 80th birthday* (pp. 116–133). Springer, Singapore. https://doi.org/10.1007/978-981-15-0864-6_5

Li, Y. (2021, March). Optimization strategy of supply chain financial platform based on blockchain. In *The international conference on cyber security intelligence and analytics* (pp. 125–130). Springer, Cham. https://doi.org/10.1007/978-3-030-69999-4_17

Ma, J. H., Ahn, Y. H., & Choi, S. B. (2018). The impact of the buyer participation in CSR activities on a supply chain. *Journal of Distribution Science*, *16*(3), 23–32. https://doi.org/10.15722/jds.16.3.201803.23

MacCarthy, B. L., & Atthirawong, W. (2003). Factors affecting location decisions in international operations – a Delphi study. *International Journal of Operations & Production Management*, *23*(7), 794–818. https://doi.org/10.1108/01443570310481568

Minaam, D. S. A. (2018). Smart kitchen: Automated cooker technique using IoT. *International Journal of Electronics and Information Engineering*, *9*(1), 1–10.

Mohamed, N., & Al-Jaroodi, J. (2019, January). Applying blockchain in industry 4.0 applications. In *2019 IEEE 9th annual computing and communication workshop and conference* (*CCWC*) (pp. 0852–0858). IEEE. https://doi.org/10.1109/CCWC.2019.8666558

Monrat, A. A., Schelén, O., & Andersson, K. (2019). A survey of blockchain from the perspectives of applications, challenges, and opportunities. *IEEE Access*, *7*, 117134–117151. https://doi.org/10.1109/ACCESS.2019.2936094

Moorehead, C. (2019). Need to negotiate: The strategic ambiguity of dealing with kidnappers. *TLS*. *Times Literary Supplement*, (6063), 12–13.

More, D., & Basu, P. (2013). Challenges of supply chain finance: A detailed study and a hierarchical model based on the experiences of an Indian firm. *Business Process Management Journal*, *19*(4), 624–647. https://doi.org/10.1108/BPMJ-09-2012-0093

Mouzos, J. (1999). International traffic in small arms: an Australian perspective. *Trends & Issues in Crime & Criminal Justice*, (104), 1–6. https://read-me.org/s/International-small-Australia.pdf

Murphet, J. (2020). block/supply/chain. *Australian Humanities Review*, (66), 181–187. https://australianhumanitiesreview.org/wp-content/uploads/2020/05/AHR66_12_Murphet.pdf

Nakamoto, S. (2008). *Bitcoin: A peer-to-peer electronic cash system*. (Decentralized Business Review 21260). https://static.upbitcare.com/931b8bfc-f0e0-4588-be6e-b98a27991df1.pdf

Nguyen, G. T., & Kim, K. (2018). A survey about consensus algorithms used in blockchain. *Journal of Information Processing Systems*, *14*(1), 101–128. https://volunteerscience.com/media/research_teams/Luke's%20Sandbox/consent_forms/revised_proposal.2.pdf

Nomura Research Institute. (2015). *Survey on blockchain technologies and related services* (Technical Report).

Oh, K., Yoo, H., & Jeong, E. (2023). Research trends in digital transformation in supply chain based on bibliometric and network analysis. *Journal of Business Economics and Management*, *24*(6), 1042–1058. https://doi.org/10.3846/jbem.2023.20649

Riikkinen, M., Saarijärvi, H., Sarlin, P., & Lähteenmäki, I. (2018). Using artificial intelligence to create value in insurance. *International Journal of Bank Marketing*, *36*(6), 1145–1168. https://doi.org/10.1108/IJBM-01-2017-0015

Saaty, T. L. (2004, August). The analytic network process: Dependence and feedback in decision making (Part 1): Theory and validation examples, SESSION 4B: Theory and development of the analytic hierarchy process/analytic network process. In *The 17th International Conference on Multiple Criteria Decision Making* (pp. 6–11).

Sang, B. (2021). Application of genetic algorithm and BP neural network in supply chain finance under information sharing. *Journal of Computational and Applied Mathematics*, *384*, Article 113170. https://doi.org/10.1016/j.cam.2020.113170

Sargent, C. S., & Breese, J. L. (2024). Blockchain barriers in supply chain: A literature review. *Journal of Computer Information Systems*, *64*(1), 124–135. https://doi.org/10.1080/08874417.2023.2175338

Schmidt, R., Lyytinen, K., Keil, M., & Cule, P. (2001). Identifying software project risks: An international Delphi study. *Journal of Management Information Systems*, *17*(4), 5–36. https://doi.org/10.1080/07421222.2001.11045662

Seuring, S., & Müller, M. (2008). Core issues in sustainable supply chain management – a Delphi study. *Business Strategy and the Environment*, *17*(8), 455–466. https://doi.org/10.1002/bse.607

Shieh, J. I., Wu, H. H., & Huang, K. K. (2010). A DEMATEL method in identifying key success factors of hospital service quality. *Knowledge-Based Systems*, *23*(3), 277–282. https://doi.org/10.1016/j.knosys.2010.01.013

Tseng, M. L. (2009). Application of ANP and DEMATEL to evaluate the decision-making of municipal solid waste management in Metro Manila. *Environmental Monitoring and Assessment*, *156*(1), 181–197. https://doi.org/10.1007/s10661-008-0477-1

Tufa, A. G., & Teshu, M. M. (2015). The Impact of customer relationship marketing on customer satisfaction; A case study on selected commercial banks in Ethiopia. *ZENITH International Journal of Business Economics & Management Research*, *5*(6), 215–228.

Tzeng, G. H., Chiang, C. H., & Li, C. W. (2007). Evaluating intertwined effects in e-learning programs: A novel hybrid MCDM model based on factor analysis and DEMATEL. *Expert Systems with Applications*, *32*(4), 1028–1044. https://doi.org/10.1016/j.eswa.2006.02.004

Wang, S., Xiao, P., Chai, H., Tu, X., Sun, Q., Cai, H., & Wang, F. Y. (2021, July). Research on construction of supply chain financial platform based on blockchain technology. In *2021 IEEE 1st international conference on digital twins and parallel intelligence* (*DTPI*) (pp. 42–45). IEEE. https://doi.org/10.1109/DTPI52967.2021.9540119

Withers, B., & Ebrahimpour, M. (2018). The effects of codes of ethics on the supply chain: A comparison of LEs and SMEs. *Journal of Business and Economic Studies*, *19*(1), Article 3766. https://jbes.scholasticahq.com/article/3766.pdf

Wu, T., & Liang, X. (2017, August). Exploration and practice of inter-bank application based on blockchain. In *2017 12th international conference on computer science and education* (*ICCSE*) (pp. 219–224). IEEE. https://doi.org/10.1109/ICCSE.2017.8085492

Wuttke, D. A., Blome, C., Heese, H. S., & Protopappa-Sieke, M. (2016). Supply chain finance: Optimal introduction and adoption decisions. *International Journal of Production Economics*, *178*, 72–81. https://doi.org/10.1016/j.ijpe.2016.05.003

Xiao, P., Salleh, M. I., Zaidan, B. B., & Xuelan, Y. (2023). Research on risk assessment of blockchain-driven supply chain finance: A systematic review. *Computers & Industrial Engineering*, *176*, Article 108990. https://doi.org/10.1016/j.cie.2023.108990

Xie, P., Chen, Q., Qu, P., Fan, J., & Tang, Z. (2020). Research on financial platform of railway freight supply chain based on blockchain. *Smart and Resilient Transport*, *2*(2), 69–84. https://doi.org/10.1108/SRT-09-2020-0007

Xu, X., Chen, X., Jia, F., Brown, S., Gong, Y., & Xu, Y. (2018). Supply chain finance: A systematic literature review and bibliometric analysis. *International Journal of Production Economics*, *204*, 160–173. https://doi.org/10.1016/j.ijpe.2018.08.003

Yan, H. S., & Kim, H. H. (2021). Opportunities and risks faced by the combination of blockchain and supply chain finance. *Turkish Journal of Computer and Mathematics Education* (*TURCOMAT*), *12*(13), 6154–6161.

Yang, Y. P. O., Shieh, H. M., Leu, J. D., & Tzeng, G. H. (2008). A novel hybrid MCDM model combined with DEMATEL and ANP with applications. *International Journal of Operations Research*, *5*(3), 160–168. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=0c35c3655b8af88cba020d0a35ba727ea12b9a24

Yli-Huumo, J., Ko, D., Choi, S., Park, S., & Smolander, K. (2016). Where is current research on blockchain technology? – A systematic review. *PloS ONE*, *11*(10), Article e0163477. https://doi.org/10.1371/journal.pone.0163477

Zhang, T., Zhang, C. Y., & Pei, Q. (2019). Misconception of providing supply chain finance: Its stabilising role. *International Journal of Production Economics*, *213*, 175–184. https://doi.org/10.1016/j.ijpe.2019.03.008

Zheng, Z., Xie, S., Dai, H., Chen, X., & Wang, H. (2017, June). An overview of blockchain technology: Architecture, consensus, and future trends. In *2017 IEEE International Congress on Big Data* (*BigData congress*) (pp. 557–564). IEEE. https://doi.org/10.1109/BigDataCongress.2017.85

APPENDIX

Regarding the DANP analysis process, we explain the following.

The DEMATEL analysis proceeds as follows:

Step 1: Calculate the direct relation average matrix. This study uses a paired comparison expert questionnaire to collect expert opinions. In the questionnaire, we assume that the scales 0, 1, 2, 3, and 4 range from ''no influence'' to ''very high influence''. The respondents were asked to indicate the degree of direct influence that each criterion i exerts on each criterion j; this assumed level of influence is expressed by d_{ij}. A direct relation matrix is produced for each respondent, and an average matrix D can then be derived based on the means of the criteria within the various direct matrices of the respondents. This average matrix D is represented as follows:

$$D = \begin{bmatrix} d_{11} \cdots & d_{1j} \cdots & d_{1n} \\ \vdots & \vdots & \vdots \\ d_{i1} \cdots & d_{ij} \cdots & d_{in} \\ \vdots & \vdots & \vdots \\ d_{n1} \cdots & d_{nj} \cdots & d_{nn} \end{bmatrix}. \quad (1)$$

Step 2: Calculate the initial direct influence matrix. The initial direct influence matrix X ($X = \left[x_{ij}\right]_{n \times n}$) can be obtained by normalizing the average matrix D. Specifically, the matrix X can be obtained based on Eqs. (2) and (3), in which all principal diagonal elements are equal to 0.

$$X = s \cdot D; \quad (2)$$

$$s = \min\left[1 / \max_i \sum_{i=1}^{n} \left|d_{ij}\right|\right]. \quad (3)$$

Step 3: Derive the total influence matrix. This is realized through a sustained decrease in the indirect effects of the problems along the powers of X, e.g., X^2, X^3, ..., X^k and $\lim_{k \to \infty} X^k = \left[0\right]_{n \times n}$, where $X = \left[x_{ij}\right]_{n*n}$, $0 \le x_{ij} < 1$, $0 \le \sum_i x_{ij} < 1$, $0 \le \sum_j x_{ij} < 1$ and at least one column or one row sum equals 1. The total influence matrix can be expressed by the following equation:

$$T = X + X^2 + X^3 + \ldots + X^k = X\left(I - X^k\right)\left(I - X\right)^{-1} = X\left(I - X\right)^{-1},$$

when $$\lim_{k \to \infty} X^k = \left[0\right]_{n \times n}, \quad (4)$$

where $T = \left[t_{ij}\right]_{n \times n}$, $i, j = 1, 2, \ldots, n$ and $\left(I - X\right)\left(I - X\right)^{-1} = I$. Moreover, this method can be used to calculate the sum of each row and column of matrix T, which are calculated based on Eqs. (5) and (6):

$$r = \left(r_i\right)_{n \times 1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n \times 1}, \quad (5)$$

$$d = \left(c_j\right)_{n\times 1} = \left(c_j\right)'_{1\times n} = \left[\sum_{i=1}^{n} t_{ij}\right]'_{1\times n}, \tag{6}$$

where d_i denotes the sum of the ith row of matrix T and represents the sum of the direct and indirect influences of criterion i on the other criteria, likewise it denotes the sum of the j th column of matrix T and the sum of the direct and indirect effects on criterion j from other criteria. Moreover, when $i = j$ (i.e., the sum of the aggregate rows and columns), $r_i + d_i$ provides an index of the given and received influence intensities; that is, $r_i + d_i$ denotes the intensity of the central role played by criterion i in the problem. If $r_i - d_i$ is positive, criterion i affects criterion s; if $r_i - d_i$ is negative, criterion i is influenced by criteria (Tzeng et al., 2007; Yang et al., 2008).

Step 4: Set a threshold value and obtain the NRM. Each criterion *tij* of matrix *T* provides network information on how criterion *i* impacts criterion *j*. To isolate the relation structure of criterion *s*, it is necessary to set a threshold value α to filter the minor impacts denoted by criterion s of matrix *T*. In practice, if all the information from matrix *T* is converted to the NRM, the map would be too complicated to provide the necessary network information for decision-making. To reduce the complexity of the NRM, the decision-maker sets a threshold value α for the influence level to filter out minor effects: only criteria s whose influence values in matrix *T* are higher than the threshold value are chosen and converted. Specialists must set this threshold value. An NRM can be drawn when the threshold value and the relative NRM have been determined.

ANP is a mathematical theory that can systematically overcome dependence (Saaty, 2004). The steps of the method are as follows:

Step 5: Compare the criteria in the whole system to form an unweighted supermatrix. The first step of ANP is to use pairwise comparisons of criteria to set up an unweighted supermatrix by asking, "How important is the focal criterion compared to another criterion concerning the task?". These relative importance values can be expressed on a scale (1 to 9) ranging from equal to extremely important. The general form of this supermatrix is described as follows:

$$
\begin{array}{cc}
 & \begin{array}{ccccccccc} & C_1 & & & C_2 & & & C_n & \\ C_{11} & \cdots & C_{1m_1} & C_{21} & \cdots & C_{2m_2} & \cdots & C_{n1} \; \cdots & C_{nm_n} \end{array} \\
W = \begin{array}{cc} C_1 & \begin{array}{c} C_{11} \\ C_{12} \\ \vdots \\ C_{1m_1} \end{array} \\ C_2 & \begin{array}{c} C_{21} \\ C_{22} \\ \vdots \\ C_{2m_2} \end{array} \\ \vdots & \\ C_n & \begin{array}{c} C_{n1} \\ C_{n2} \\ \vdots \\ C_{nm_n} \end{array} \end{array} &
\begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1n} \\ W_{21} & W_{22} & \cdots & W_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ W_{n1} & W_{n2} & & W_{nn} \end{bmatrix}
\end{array} \tag{7}
$$

where C_n denotes the n th cluster, c_{nm} denotes the m th criterion in the n th cluster, and W_{ij} is the principal eigenvector of the influence of the criteria in the j th cluster with respect to the i th cluster. Moreover, if the j th cluster has no importance in relation to the i th cluster, $W_{ij} = [0]$.

Step 6: Obtain the weighted supermatrix by multiplying the normalized matrix based on the DEMATEL technique. Following tradition, we accurately convert the sum of each column to 1 to obtain the weighted supermatrix. To make the sum of each column equal to 1, each criterion in a column is divided by the corresponding number of clusters. This means that each cluster has the same weight when using this normalization method. However, each cluster may influence other clusters in different ways. Therefore, assuming that all the clusters' weights are equal to obtain the weighted supermatrix is unreasonable. A hybrid method based on the DEMATEL technique has been proposed to solve this problem (Yang et al., 2008). First, the DEMATEL technique is used to derive the total influence matrix T shown in step 3. The normalized total influence matrix is expressed as T_D.

$$T_p = \begin{bmatrix} t_{11}/d_1 & \dots & t_{1j}/d_1 & \dots & t_{1n}/d_1 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ t_{i1}/d_i & \dots & t_{ij}/d_i & \dots & t_{in}/di \\ \vdots & \vdots & \vdots & \vdots & \\ t_{n1}/d_n & \dots & t_{nj}/d_n & \dots & t_{nn}/d_n \end{bmatrix} = \begin{bmatrix} t_{11}^D & \dots & t_{1j}^D & \dots & t_{1n}^D \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ t_{i1}^D & \dots & t_{ij}^D & \dots & t_{in}^D \\ \vdots & \vdots & \vdots & \vdots & \\ t_{n1}^D & \dots & t_{nj}^D & \dots & t_{nn}^D \end{bmatrix}. \quad (8)$$

Then, Eq. (9) is used to combine T_D with the unweighted supermatrix W to obtain a weighted supermatrix, W_w.

$$W_w = \begin{bmatrix} t_{11}^D \times W_{11} & t_{21}^D \times W_{12} & \dots & \dots & t_{n1}^D \times W_{1n} \\ t_{12}^D \times W_{21} & t_{22}^D \times W_{22} & \vdots & \dots & \vdots \\ \vdots & \dots & t_{ji}^D \times W_{ij} & \dots & t_{ni}^D \times W_{in} \\ \vdots & \dots & \vdots & \dots & \vdots \\ t_{1n}^D \times W_{n1} & t_{2n}^D \times W_{n2} & \dots & \dots & t_{nn}^D \times W_{nn} \end{bmatrix}. \quad (9)$$

Step 7: Calculate the global priority vectors using the limiting process method. We can raise the weighted supermatrix by limiting it to a sufficiently large power k (as shown in Eq. (10)) until it converges and becomes a long-term stable supermatrix; in this way, we can obtain the overall priorities, which are called ANP weights.

$$\lim_{k \to \infty} W_w^k. \quad (10)$$

If there are multiple limiting supermatrices, for example, if there are N supermatrices, the average of the values is obtained by adding all N supermatrices and dividing by N.

This procedure provides the final global priority weights of all criteria. The use of this DANP procedure in this study ensures that the complex feedback and interdependencies among gray transaction behaviours and their related barriers are rigorously captured and quantitatively analysed, building on the frameworks proposed by Shieh et al. (2010), Tseng (2009), and Chen et al. (2011).