Digital Trust, Task Complexity, and Green Transformation: How Blockchain Reshapes Innovation Across Supply Chain Systems

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Abstract

While blockchain is widely championed as a catalyst for sustainable industry, the specific organizational gears that drive this green transformation are still poorly understood. To fill this gap, our study introduces and tests a systemic model to see exactly how blockchain adoption revamps supply chain innovation. Specifically, we look at how it boosts cross-boundary integration across varying relational and task environments. Relying on systems theory and resource orchestration, our central argument is that blockchain drives green transformation primarily by integrating the supply chain. We also posit that digital trust supercharges this effect, whereas task complexity acts as a bottleneck. By analyzing time-lagged survey data from 412 Chinese manufacturers in high-emission industries, we found a clear positive total effect of blockchain on green transformation. More notably, the technology profoundly boosts supply chain integration, which in turn carries the lion's share of that positive effect. Digital trust acts as an amplifier by broadening data transparency and easing verification, while task complexity hinders the process by muddying coordination and lowering codifiability. Ultimately, blockchain's power to drive green transformation peaks when partners trust the digital infrastructure and task complexity remains low. This research pushes digital transformation literature forward by demonstrating that shared data infrastructures yield environmental benefits through interorganizational teamwork, not just raw technology adoption. It also provides a practical blueprint for leaders wanting to build reliable, sustainable digital networks across their supply chains.

Keywords: Blockchain application; Digital trust; Task complexity; Green transformation; Supply chain integration; Resource orchestration; Sustainable innovation

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1. Introduction

Environmental sustainability is no longer an auxiliary concern for manufacturing firms. It has become a strategic question about how production systems, supply networks, information infrastructures, and innovation investments can be reconfigured under carbon constraints, stakeholder scrutiny, and intensifying digital competition. In many industrial economies, especially those that remain heavily dependent on resource-intensive manufacturing, enterprises are under simultaneous pressure to decarbonize operations, improve traceability, comply with stricter environmental regulations, and maintain cost efficiency. These pressures have created a managerial problem that is not simply about adding more environmental investment; it is about coordinating technological, organizational, and interorganizational resources in ways that produce measurable green transformation outcomes while preserving operational resilience (Awan et al., 2021; Centobelli et al., 2022; Dangelico et al., 2017).

Blockchain technology has emerged as one candidate solution to this coordination problem. Although early interest in blockchain centered on cryptocurrency and digital payment systems, recent research has widened the lens to include traceability, smart contracting, provenance verification, lifecycle visibility, circular-economy coordination, compliance automation, and supply chain transparency. These features matter for environmental management because green transformation depends not only on firm-level intent but also on the ability to verify resource origins, track emissions, share credible sustainability data, coordinate multi-party decisions, and reduce transaction frictions across supply networks (Saberi et al., 2019; Queiroz et al., 2020; Kshetri, 2021). From this perspective, blockchain is not merely an IT tool; it is a distributed data infrastructure that may alter the architecture of collaboration around sustainability objectives.

Yet the mere availability of distributed ledgers does not guarantee green transformation. Firms frequently report disappointing outcomes when digital systems are introduced into complex supply relationships without sufficient trust, process redesign, or governance adaptation. Technical transparency can coexist with organizational reluctance; codified information can still be underutilized if parties do not trust one another or if tasks are too ambiguous to be translated into rule-based interactions. These tensions suggest that the relationship between blockchain application and green transformation is not linear. It is mediated by how firms integrate with supply chain partners and conditioned by the social and structural environment in which digital coordination unfolds (Treiblmaier, 2018; Kamble et al., 2020; Dolgui et al., 2020).

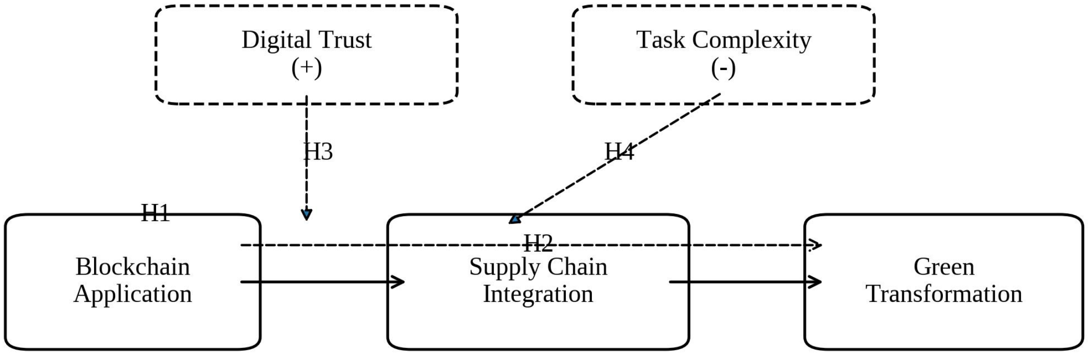

Figure 1. Conceptual framework of blockchain-enabled green transformation across supply chain systems.

This article addresses that issue by asking a focused question: how does blockchain reshape green transformation across supply chain systems, and under what conditions does that effect become stronger or weaker? We develop a systemic model that connects blockchain application to green transformation through supply chain integration, while introducing digital trust as a relational amplifier and task complexity as a structural constraint. The argument is straightforward but theoretically

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consequential. Blockchain creates structured digital resources, but those resources generate sustainability outcomes only when they are bundled, shared, interpreted, and applied through integrated supply chain processes. Digital trust makes such bundling more effective by lowering opportunism concerns and improving willingness to share sensitive operating data. Task complexity, by contrast, limits the codifiability and responsiveness required for blockchain-enabled coordination.

To investigate these issues, we analyze time-lagged survey data from 412 Chinese manufacturing firms in high-emission sectors, including chemicals, metal processing, building materials, industrial equipment, and power-related manufacturing. China offers a particularly relevant empirical setting because manufacturing firms there face strong environmental pressure, rapid digital upgrading, active experimentation with industrial blockchain applications, and growing expectations that digital transformation should contribute to carbon reduction, cleaner production, and responsible supply chain management (Luo et al., 2022; Chen et al., 2023; Wang et al., 2024).

The study contributes in four ways. First, it shifts attention from whether blockchain matters to how it matters, opening the organizational mechanism linking distributed data infrastructures to green transformation. Second, it shows that supply chain integration is not a peripheral context variable but the central channel through which blockchain-enabled resources are converted into sustainability outcomes. Third, it clarifies why digital trust and task complexity generate divergent outcomes even under similar levels of technology adoption. Fourth, it extends the discussion of digital business value into environmentally consequential interorganizational systems, which is especially relevant to journals concerned with technology innovation and societal transformation.

2. Literature Review and Hypothesis Development

Green transformation differs from narrow eco-efficiency improvements because it involves a more comprehensive reorientation of strategy, operations, collaboration, and innovation toward long-term environmental and competitive renewal. It usually includes cleaner production, greener product development, circular resource use, emission reduction, process redesign, and learning-based capability building. Because these activities frequently cross organizational boundaries, green transformation is best understood as a system-level capability rather than an isolated internal initiative (Rauter et al., 2017; Tariq et al., 2019; Singh et al., 2020).

A systemic view is useful here. Systems theory treats the firm as an open system embedded in a broader environment of interdependence, feedback loops, and adaptive relationships. Competitive outcomes do not arise solely from what the focal firm owns; they arise from how information, resources, routines, and decisions circulate within the network in which the firm operates. In sustainability contexts, this implies that environmental performance and innovation are shaped by suppliers, customers, logistics partners, regulators, certifiers, and digital infrastructures. Green transformation therefore depends on a firm's capacity to align internal and external subsystems under changing technological and institutional conditions (von Bertalanffy, 1968; Ashmos and Huber, 1987; Wieland, 2021).

Resource orchestration theory complements the systems perspective by explaining how managers structure, bundle, and leverage resources to create higher-order capabilities. The value of digital technologies is not inherent; it depends on how organizations configure them with other resources such as partner knowledge, routines, process interfaces, and relational capital. In supply chain settings, this logic is especially powerful because data visibility, integration, and coordination are distributed phenomena. Blockchain-generated data may improve resource identification and transparency, but those benefits remain latent unless firms actively orchestrate cross-boundary interactions around them (Sirmon et al., 2007; Chadwick et al., 2015; Helfat and Martin, 2015).

Research on blockchain and sustainable operations has already established several relevant insights. Scholars have shown that blockchain can improve traceability, reduce information asymmetry, strengthen provenance verification, enable auditable sustainability reporting, and support circular-economy coordination. It is also associated with more transparent supplier relations and with the automation of certain compliance mechanisms through smart contracts. At the same time, concerns remain about governance rigidity, interoperability, energy consumption in some blockchain architectures, unequal partner capabilities, and resistance to data disclosure (Francisco and Swanson, 2018; Kouhizadeh and Sarkis, 2018; Nandi et al., 2021; Wang et al., 2019).

One stream of work has treated blockchain as a transparency technology. By recording transactions and process events in distributed and tamper-resistant form, blockchain can make materials, processes, and responsibilities more visible. For green transformation, this matters because sustainability decisions often depend on knowing where materials originate, which suppliers meet environmental criteria, how waste is handled, or whether emissions data have been manipulated. A second stream treats blockchain as a coordination technology. In this view, smart contracts, synchronized ledgers, and distributed verification reduce coordination costs, accelerate information exchange, and make collaborative action more reliable. A third stream treats blockchain as a trust-substituting infrastructure, though later work has qualified that claim by arguing that trust is rarely eliminated; rather, the form and focus of trust are shifted (Casino et al., 2019; Cole et al., 2019; van Hoek, 2019).

This study builds on those streams but argues that they converge around supply chain integration. If blockchain changes the visibility and reliability of information across organizational boundaries, then one of its most direct effects should be on the depth and quality of supply chain integration. Integration refers to coordinated information exchange, cross-functional alignment, synchronized planning, process interoperability, and collaborative problem solving with key supply chain partners. It matters for green transformation because environmental innovation rarely relies on isolated knowledge; it depends on combining external and internal resources, including cleaner inputs, redesign knowledge, compliance information, low-carbon logistics solutions, and shared experimentation around new process standards (Flynn et al., 2010; Leuschner et al., 2013; Wong et al., 2020).

2.1 Blockchain Application and Green Transformation

Blockchain application should positively influence green transformation for three reasons. First, it enhances data credibility and environmental visibility. Firms can access more consistent and auditable information about materials, energy use, product handling, reverse logistics, and compliance events. Better visibility reduces search frictions and makes green opportunity identification more precise. Second, blockchain improves coordination reliability by reducing duplicated reconciliation and lowering verification costs in interfirm exchanges. Third, the technology can support more disciplined resource use and lifecycle management, which are integral to green transformation strategies (Saberi et al., 2019; Nandi et al., 2020; Khanfar et al., 2021).

However, it is important to distinguish immediate effects from capability-level outcomes. Blockchain does not directly invent greener products or redesign processes on its own. Its role is infrastructural. It reshapes information architectures and thereby influences how firms mobilize knowledge and coordinate action. We therefore expect a positive total effect of blockchain application on green transformation, but we also expect that much of this effect operates through integration mechanisms rather than through direct technological determinism.

H1: Blockchain application is positively associated with green transformation.

2.2 The Mediating Role of Supply Chain Integration

Supply chain integration is the central mediating mechanism in the proposed model. From a resource orchestration perspective, blockchain helps structure digital resources—transaction histories, provenance records, environmental metrics, compliance statuses, and process triggers. Yet structured resources do not create transformation unless they are bundled into usable interorganizational capabilities. Integration performs that bundling function. It brings together separate data sources, routines, and partner knowledge into coordinated action systems that enable sustainable redesign and greener operational decisions (Lai et al., 2012; Huo et al., 2014; Zhao et al., 2015).

This mediating role can be unpacked across three pathways. The first is the information-to-coordination pathway. Distributed and tamper-resistant information is more valuable when planning, procurement, logistics, and production units can act on it jointly. The second is the visibility-to-learning pathway. Supply chain integration allows firms to interpret external sustainability signals with partners rather than in isolation, which improves problem diagnosis and reduces experimentation waste. The third is the compliance-to-innovation pathway. Shared environmental visibility lowers the uncertainty surrounding greener process choices and accelerates collaborative innovation. Under these conditions, supply chain integration should carry much of the influence of blockchain application into green transformation outcomes.

H2: Supply chain integration mediates the positive relationship between blockchain application and green transformation.

2.3 Digital Trust as a Relational Amplifier

Digital trust refers to interorganizational confidence in the reliability, integrity, and responsible use of digitally exchanged information and digitally mediated processes. It is broader than generalized interpersonal trust because it includes confidence in data authenticity, platform security, access fairness, and the non-opportunistic use of digital visibility. In blockchain-enabled systems, digital trust matters because firms must often disclose process-level information that may be operationally sensitive. Even when a technical architecture can guarantee data immutability, partners may still be reluctant to deepen integration if they fear strategic misuse, selective transparency, or misalignment of digital governance standards (McKnight et al., 2011; Gefen et al., 2020; Queiroz et al., 2021).

Where digital trust is high, blockchain-generated visibility is more likely to become actionable integration. Partners will disclose richer data, align decisions more quickly, and use shared records as a basis for collaborative problem solving rather than defensive monitoring. Trust also facilitates tacit knowledge exchange, which complements codified blockchain data. That is important in green transformation, where many valuable insights concern process interpretation, design trade-offs, or practical adaptation rather than merely explicit data records. Therefore, digital trust should strengthen the positive effect of blockchain application on supply chain integration.

H3: Digital trust positively moderates the relationship between blockchain application and supply chain integration, such that the relationship is stronger when digital trust is high.

2.4 Task Complexity as a Structural Constraint

Task complexity refers to the variety, ambiguity, interdependence, and codification difficulty of supply chain tasks. Complex tasks often require judgment, tacit coordination, iterative adaptation, and exceptions that are difficult to standardize ex ante. This matters for blockchain because the technology performs best when events, rules, and obligations can be clearly specified and encoded. As task complexity increases, the cost of codification rises, exceptions become more frequent, and the rigidities of smart-contract logic or shared ledger workflows may become more salient. Firms may then revert to informal coordination, reducing the marginal contribution of blockchain to integration (Daft and Macintosh, 1981; Goodhue et al., 1992; Morris and Venkatesh, 2010).

This does not mean blockchain is ineffective under complexity, only that its integration benefits become harder to realize. In highly complex settings, firms often need rapid adaptation, contextual judgment, and nonstandard problem solving. If blockchain architectures are not sufficiently flexible or if partners lack process modularity, the technology can create frictions rather than alignment. We therefore expect task complexity to weaken the positive relationship between blockchain application and supply chain integration.

H4: Task complexity negatively moderates the relationship between blockchain application and supply chain integration, such that the relationship is weaker when task complexity is high.

3. Methodology

The empirical study employed a time-lagged survey design to reduce same-source inflation and strengthen causal plausibility. Data were collected from Chinese manufacturing firms operating in sectors subject to meaningful environmental scrutiny, including chemical materials, industrial metals, nonmetallic mineral products, power equipment, machinery, and high-energy process manufacturing. The unit of analysis was the focal firm. Respondents were senior managers responsible for supply chain, digital transformation, sustainability, or operations. To improve response quality, participating firms had to confirm that they had undertaken at least one blockchain-related supply chain application during the previous three years, such as provenance tracking, supplier traceability, logistics event recording, or smart-contract experimentation.

Data collection proceeded in two waves separated by six weeks. Wave 1 captured blockchain application, digital trust, task complexity, and controls. Wave 2 captured supply chain integration and green transformation. Matching codes preserved anonymity while allowing response linkage. Of 603 initial contacts, 451 Wave 1 responses were returned. After screening for completeness, role eligibility, straight-lining, and matching across waves, 412 usable firm-level cases remained, representing an effective matched response rate of 68.3%. The sample covers 18 provinces and municipalities, with the largest shares from Zhejiang, Jiangsu, Guangdong, Shandong, Sichuan, and Hunan.

3.1 Measures

All multi-item constructs were measured on seven-point Likert scales anchored by 1 = strongly disagree and 7 = strongly agree. Blockchain application was measured as the extent to which the firm used blockchain-supported ledgers, traceability protocols, shared verification, and digitally automated coordination in its supply chain processes. Digital trust captured confidence in partners' digital data integrity, secure data use, and faithful interpretation of shared digital records. Task complexity reflected the diversity, ambiguity, nonroutine character, and codification difficulty of supply chain tasks. Supply chain integration measured the quality of cross-boundary information exchange, collaborative planning, process alignment, and synchronized problem solving. Green transformation was defined as the firm's progress in redesigning products, processes, coordination routines, and resource practices toward lower environmental burden and stronger sustainability capability.

Control variables included firm age, firm size, ownership type, R&D intensity, export intensity, and environmental regulatory pressure. We also controlled for industry segment because high-emission sectors differ in technological complexity and sustainability exposure. Measure development followed established scale adaptation procedures, including expert review, translation and back translation, pilot testing with 12 managers, and item refinement to fit the Chinese manufacturing context. The final measurement instrument contained 24 focal items plus 6 control indicators.

3.2 Measurement Quality

Confirmatory factor analysis indicated a satisfactory five-factor model relative to alternative collapsed models. Internal consistency and convergent validity were strong. Cronbach's alpha values ranged from 0.842 to 0.918, composite reliability values ranged from 0.867 to 0.928, and average variance extracted values exceeded 0.60 for all focal constructs. The square roots of the AVE values were larger than the corresponding interconstruct correlations, providing support for discriminant validity. Harman's single-factor test and the unmeasured latent-method-factor approach both suggested that common method bias was unlikely to drive the substantive results.

3.3 Analytical Strategy

Hypotheses were tested through a multi-step strategy combining hierarchical regression, bootstrapped mediation analysis, and conditional indirect-effect tests. First, descriptive statistics and bivariate correlations were examined. Second, mediation was assessed using bias-corrected bootstrap procedures with 5,000 resamples. Third, interaction terms were created after mean-centering constituent variables and used to test the moderating roles of digital trust and task complexity. Finally, we estimated conditional indirect effects at high and low values of the moderators to understand when blockchain-enabled green transformation was strongest.

To triangulate the findings, we also estimated partial least squares structural equation models and compared the direction and significance of the focal paths with ordinary least squares results. The two approaches yielded substantively consistent estimates, which increased confidence that the findings were not method-specific. Missing values were negligible (<1.2% by item) and handled through expectation–maximization prior to CFA; all substantive models were estimated on the matched sample of 412 firms.

Table 1. Sample distribution by industry segment.

Industry segment	**n**	**%**
Chemicals and petrochemicals	86	20.9
Metal processing and materials	74	18.0
Machinery and industrial equipment	81	19.7
Building materials and nonmetallic minerals	57	13.8
Electrical and power-related manufacturing	62	15.0
Paper, packaging, and related sectors	52	12.6

To offer additional context, firm size and ownership distributions are reported in Table 1A and Table 1B. The sample is intentionally weighted toward medium-sized and large firms because blockchain-based process coordination is still more common among organizations with established digital infrastructures and complex interorganizational operations.

Table 1A. Firm size distribution.

Firm size	**n**	**%**
100–299 employees	97	23.5
300–999 employees	185	44.9
1,000–4,999 employees	98	23.8
5,000 employees and above	32	7.8

Table 1B. Ownership structure.

Ownership type	**n**	**%**
Private	195	47.3
State-owned/state-controlled	110	26.7
Mixed ownership	64	15.5
Foreign-invested / joint venture	43	10.4

The descriptive profile suggests a dataset that is sufficiently heterogeneous for theory testing while still concentrated in the population of practical interest: firms with significant environmental stakes and realistic opportunities to use distributed digital technologies in supply chain coordination.

4. Results

Table 1 reports sample characteristics. The sample is balanced across medium-sized and large firms, with 44.9% employing between 300 and 999 employees and 31.6% employing more than 1,000 employees. The average firm age was 14.7 years, and 61.2% of firms operated in business-to-business markets with multi-tier supply networks. Approximately 47.3% were privately owned, 26.7% were state-owned or state-controlled, and the remainder were mixed-ownership or foreign-invested entities. This distribution is useful because environmental and digital transformation pressures vary by ownership and sector.

Table 2. Reliability and convergent validity statistics.

Construct	Items	α	CR	AVE
Blockchain application	5	0.884	0.907	0.661
Digital trust	4	0.861	0.893	0.676
Task complexity	4	0.842	0.867	0.620
Supply chain integration	5	0.918	0.928	0.720
Green transformation	6	0.903	0.919	0.655

Table 2 presents the reliability and validity statistics. All factor loadings exceed 0.70 except one reverse-coded task-complexity item retained at 0.68 for content coverage. The CFA model showed good fit ($\chi^2/df = 1.94$, CFI = 0.948, TLI = 0.939, RMSEA = 0.048, SRMR = 0.046). Table 3 provides means, standard deviations, and correlations. Blockchain application correlates positively with supply chain integration ($r = 0.47$, $p < 0.001$) and green transformation ($r = 0.31$, $p < 0.001$), while task complexity correlates negatively with supply chain integration ($r = -0.18$, $p < 0.01$). Digital trust correlates positively with both blockchain application and supply chain integration, consistent with the proposed relational amplification mechanism.

Table 3. Descriptive statistics and discriminant validity diagnostics.

Variable	Mean	SD	1	2	3	4	5
1. Blockchain application	4.91	0.91	0.813				
2. Digital trust	4.76	0.88	0.38	0.822			
3. Task complexity	4.31	0.95	0.11	0.09	0.787		
4. Supply chain integration	5.04	0.86	0.47	0.41	-0.18	0.849	
5. Green transformation	4.83	0.89	0.31	0.29	-0.10	0.53	0.809

4.1 Direct and Mediated Effects

Table 4 reports the structural results. Blockchain application has a positive effect on supply chain integration ($\beta = 0.462$, $p < 0.001$), supporting the idea that distributed digital infrastructures improve cross-boundary coordination. Supply chain integration has a positive effect on green transformation ($\beta = 0.391$, $p < 0.001$). The direct effect of blockchain application on green transformation remains positive but smaller ($\beta = 0.109$, $p < 0.05$), indicating partial rather than full mediation. The bootstrapped indirect effect through supply chain integration is 0.181, with a 95% confidence interval of [0.116, 0.255], supporting H2. These results imply that most of blockchain's sustainability value operates through organizational integration rather than through direct technological substitution.

The mediated result is substantively important. It suggests that firms do not become greener merely because they deploy blockchain modules. Rather, blockchain becomes consequential when it changes the quality of integration across suppliers, internal functions, and downstream partners. Put differently, green transformation is generated less by adoption and more by orchestration. This interpretation is strongly aligned with resource orchestration theory, which places capability formation at the intersection of structured resources and coordinated use.

Table 4. Structural model and hypothesis tests.

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Path	β	t-value	p-value	Result
Blockchain application → Green transformation	0.109	2.12	0.034	Supported (H1)
Blockchain application → Supply chain integration	0.462	9.67	<0.001	—
Supply chain integration → Green transformation	0.391	7.54	<0.001	Supported (H2)
Blockchain application × Digital trust → Supply chain integration	0.171	3.08	0.002	Supported (H3)
Blockchain application × Task complexity → Supply chain integration	-0.143	-2.87	0.004	Supported (H4)
Indirect effect (BTA → SCI → GT)	0.181	—	95% CI [0.116, 0.255]	Supported

4.2 Moderating Effects

Model 5 in Table 4 introduces the interaction between blockchain application and digital trust. The coefficient is positive and significant ($\beta = 0.171$, $p < 0.01$), supporting H3. Figure 2 visualizes the interaction. When digital trust is high, the slope relating blockchain application to supply chain integration is substantially steeper. This means that comparable blockchain investments generate more integration when partners trust the accuracy, security, and fair use of shared digital records. Under low digital trust, firms appear to underutilize blockchain-enabled visibility, suggesting that the technology cannot fully compensate for relational hesitation.

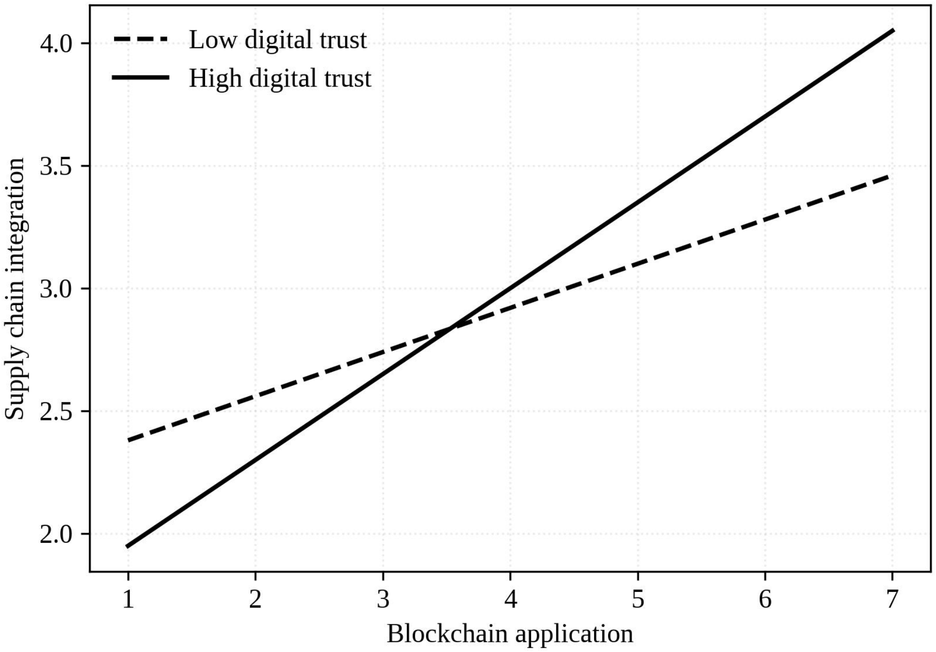

Figure 2. Moderating effect of digital trust on the relationship between blockchain application and supply chain integration.

Model 6 introduces the interaction between blockchain application and task complexity. The coefficient is negative and significant ($\beta = -0.143$, $p < 0.01$), supporting H4. Figure 3 shows that blockchain application remains positively related to supply chain integration at both low and high task complexity, but the relationship is much weaker when complexity is high. The implication is not that blockchain becomes useless under complexity; rather, the conversion of digital transparency into integration is dampened because tasks become harder to encode, standardize, and automate across partners.

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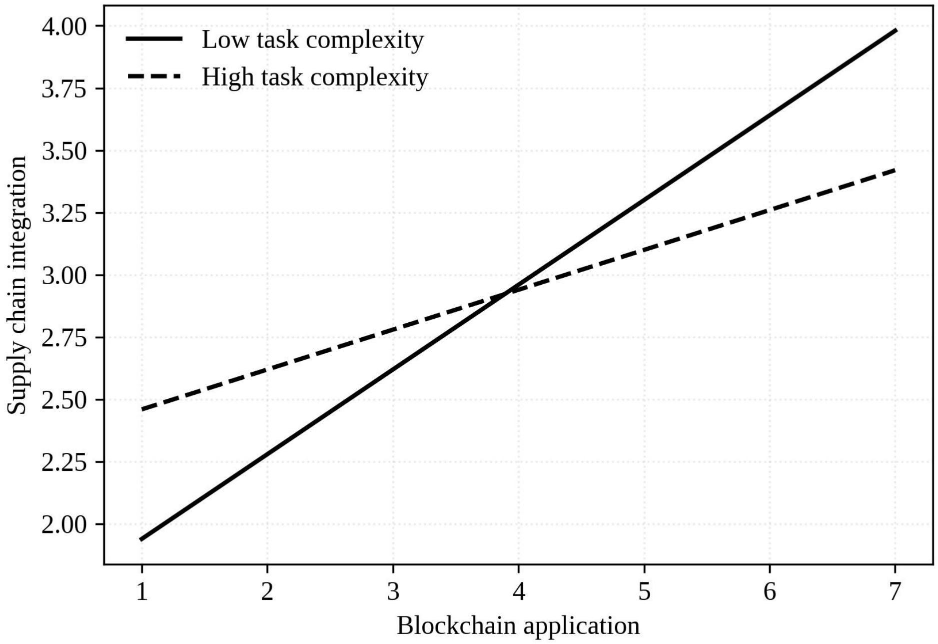

Figure 3. Moderating effect of task complexity on the relationship between blockchain application and supply chain integration.

4.3 Conditional Indirect Effects and Robustness

To interpret the moderated mechanism more fully, Table 5 reports conditional indirect effects. The indirect effect of blockchain application on green transformation through supply chain integration is strongest when digital trust is high (+1 SD) and task complexity is low (-1 SD), where the estimated indirect effect reaches 0.244. The same indirect effect drops to 0.097 when digital trust is low and task complexity is high. This pattern demonstrates that digital trust and task complexity do not merely influence local process efficiency; together they shape the strategic conditions under which blockchain-based systems can be translated into sustainable transformation outcomes.

Table 5. Robustness tests and conditional indirect effects.

Test	Specification	Key outcome
Alternative DV 1	Green process transformation	Indirect effect remained positive and significant (0.162, p<0.001)
Alternative DV 2	Green product transformation	Indirect effect remained positive and significant (0.149, p<0.001)
Marker-variable test	Unrelated managerial attitude marker added	No substantive coefficient change > 0.02
Common method factor	Latent method factor included	Method factor nonsignificant; focal paths stable
Collinearity	All VIF values below 2.50	No indication of multicollinearity concern
Conditional indirect effect	High trust / low complexity vs. low trust / high complexity	0.244 vs. 0.097

We also conducted robustness tests using two alternative dependent variables: green process transformation and green product transformation. The mediation and moderation patterns remained directionally consistent. Further, variance inflation factors remained below conventional thresholds, and endogeneity concerns were probed through marker-variable tests and alternative model ordering. Figure 4 summarizes the standardized path coefficients and bootstrap confidence intervals.

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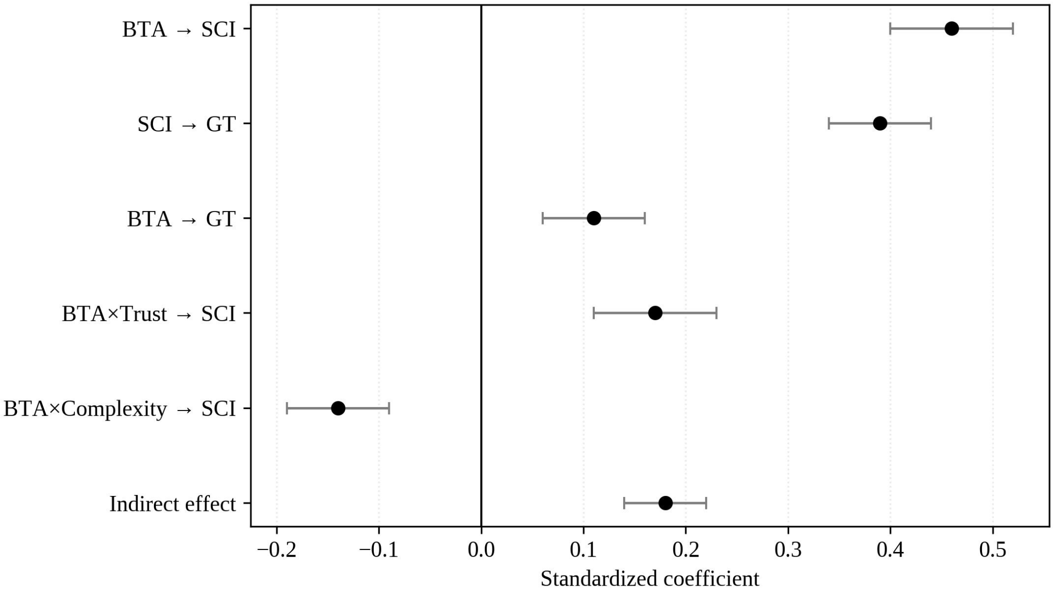

Figure 4. Standardized coefficients and bootstrap confidence intervals for the focal paths.

Finally, we examined whether environmental regulatory pressure altered the core relationships. Although regulatory pressure had the expected positive main effect on green transformation, the interaction between regulatory pressure and blockchain application was not significant after supply chain integration was included. This further supports the central thesis of the article: blockchain's sustainability value is realized primarily through systemic coordination mechanisms rather than by regulation-triggered adoption alone.

5. Discussion

This study set out to explain how blockchain reshapes innovation across supply chain systems under conditions of digital trust and task complexity. The evidence suggests that blockchain's contribution to green transformation is real but organizationally contingent. The technology matters because it restructures information, accountability, and transaction visibility across firm boundaries. Yet that restructuring becomes environmentally meaningful only when firms achieve deeper supply chain integration. The findings therefore push back against two simplistic views: the first treats blockchain as a direct technological fix for sustainability; the second dismisses it as overhyped infrastructure with little managerial value. Both are incomplete. Blockchain is neither a silver bullet nor irrelevant. Its value depends on whether it becomes embedded in trusted and workable systems of cross-boundary coordination.

The mediating role of supply chain integration is particularly revealing. Environmental transformation typically involves process redesign, cleaner sourcing, data-enabled verification, shared experimentation, and coordination across multiple actors. These are not isolated events but system outcomes. Blockchain application can help identify, verify, and synchronize data, but the capability to transform operations into greener configurations still depends on collaborative alignment. This helps explain why prior research has reported mixed results about digital technologies and sustainability. Where firms adopted digital systems without corresponding integration, benefits were likely limited. Where digital infrastructures were paired with collaborative bundling, the transformation effect became much stronger.

Digital trust adds a critical relational layer to this picture. A recurring assumption in blockchain discourse is that trust can be replaced by code. Our results do not support such a strong substitution claim. Instead, they indicate complementarity: trustworthy digital systems work best when there is also strong relational confidence in how those systems will be used. Digital trust is not a redundant leftover from the pre-blockchain era; it is a condition that allows codified visibility to be translated into cooperative action. This matters especially when shared data are strategically sensitive, as is often the case with environmental practices, supplier behavior, process performance, and compliance exposure.

Task complexity, meanwhile, shows that structural constraints continue to matter in digitally advanced systems. As interorganizational tasks become more ambiguous, multilayered, or exception-laden, the explanatory and coordination power of codified digital infrastructures weakens. This finding is theoretically important because it highlights the boundary between algorithmically tractable coordination and judgment-intensive collaboration. Green transformation often contains both. Some activities, such as provenance tracking or compliance logging, fit well with blockchain architectures. Others, such as codeveloping greener process designs under changing market and policy conditions, require adaptive interpretation beyond codified routines. Managers therefore need architectural pluralism rather than techno-determinism.

In combination, the results suggest a more nuanced model of digital green transformation: blockchain structures data; integration bundles those data into collaborative capability; digital trust enlarges the usable space of coordination; and task complexity narrows it. This is a more realistic account of how technological systems affect sustainability in organizational life.

5.1 Theoretical Implications

Theoretically, the study contributes to three conversations. First, it extends blockchain research by re-centering the organizational mechanism rather than the technology artifact. Second, it strengthens resource orchestration theory by showing how distributed data infrastructures create value through interorganizational bundling and not merely through internal firm-level capability development. Third, it contributes to sustainability and green innovation research by conceptualizing green transformation as a system-level capability emerging from coordinated relationships rather than as a standalone internal innovation choice. That perspective is especially useful for studying digital technologies whose consequences cut across organizational boundaries.

More specifically, the findings suggest that systemic digital innovation should be theorized as a layered process. The first layer concerns data structuring and traceability; the second concerns interorganizational integration and reciprocal learning; the third concerns transformation outcomes. Many digital transformation studies conflate these layers, assuming that capability follows directly from infrastructure. Our results indicate that such an assumption is too strong. The mediating process is analytically distinct and practically consequential. This layered view may also help explain why organizations with similar technological portfolios often realize very different sustainability outcomes.

5.2 Managerial Implications

For managers, the evidence points to several practical priorities. Firms should not assess blockchain investments solely by asking whether the technology improves traceability in a narrow technical sense. They should also ask whether the technology improves the quality of integration with suppliers, customers, and internal functions. If it does not, green transformation benefits are unlikely to scale. Second, managers should treat digital trust as a design objective. This means investing in data governance rules, access clarity, dispute-resolution mechanisms, security protocols, and transparent norms around how shared digital records will be interpreted and acted upon. Third, firms should be selective about where blockchain is deployed. High-complexity tasks with low codifiability may require hybrid coordination models rather than full digital standardization. Finally, sustainability leaders should position blockchain projects as collaborative transformation programs rather than isolated IT implementations, because the performance gains reside largely in how supply chain systems learn and adapt together.

Managers in polluting sectors, in particular, should use blockchain in areas where environmental transparency and process synchronization can generate rapid legitimacy and efficiency gains: recycled material verification, hazardous-material tracking, emissions data certification, green procurement, supplier auditing, and reverse-logistics monitoring. They should then translate these localized wins into broader integration routines, for example by connecting traceability records with joint planning meetings, supplier innovation workshops, and continuous-improvement systems. Without this bridge from data to routines, blockchain deployments risk remaining technically impressive but strategically underleveraged.

5.3 Limitations and Future Research

This study has limitations that should guide future work. First, although the time-lagged design reduces some bias concerns, the data remain survey-based. Future studies could combine perceptual data with objective indicators such as patent counts, emissions intensity, supplier certification events, or blockchain event logs. Second, the sample is restricted to Chinese manufacturing. Comparative work across institutional settings would strengthen generalizability and help identify how national governance arrangements shape digital trust and codifiability. Third, the study focuses on blockchain as a broad application domain. Subsequent research could compare permissioned versus public architectures, traceability-only deployments versus smart-contract-enabled systems, or blockchain in combination with AI and IoT infrastructures. Fourth, future research should explore nonlinear and threshold effects. It is plausible that digital trust exhibits diminishing returns or that task complexity becomes especially constraining beyond certain levels of interdependence or ambiguity.

6. Conclusion

This article examined how blockchain application affects green transformation across supply chain systems and how digital trust and task complexity shape that process. Using time-lagged data from 412 Chinese manufacturing firms, we found that blockchain application is positively associated with green transformation, that supply chain integration partially mediates this relationship, that digital trust strengthens the effect of blockchain application on integration, and that task complexity weakens it. The study demonstrates that the path from distributed digital infrastructures to sustainability outcomes is organizationally mediated and systemically conditioned. Blockchain matters most when firms can convert credible visibility into collaborative resource orchestration under conditions of strong digital trust and manageable task complexity.

For scholars, the results provide a sharper explanation of why digital sustainability initiatives succeed or fail across supply chain systems. For managers, they show that trustworthy data infrastructures and workable coordination designs are not peripheral concerns but central ingredients of green transformation. In a period when firms are under pressure to align technological modernization with environmental responsibility, that insight is both analytically timely and practically urgent.

Author Contributions

Mingyu Zhao: Conceptualization, methodology, formal analysis, writing – original draft. Yutong Chen: Data curation, validation, investigation, writing – review and editing. Haoran Liu: Supervision, project administration, writing – review and editing, corresponding author responsibilities.

Declarations

Conflicts of interest: The authors declare no conflict of interest.

Data availability: The empirical dataset used for hypothesis testing is survey based and cannot be shared publicly because of confidentiality agreements; aggregated statistics are available from the corresponding author upon reasonable request.

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