Blockchain-Enabled Environmental Accounting Transparency: Supply Chain Finance, Green Disclosure Quality, and Firm Heterogeneity

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Abstract

This study examines whether blockchain-enabled accounting and supply-chain records improve environmental accounting transparency. Using a panel framework designed around Chinese listed firms from 2015 to 2023, the paper links blockchain adoption, supply chain finance, green disclosure quality, and firm heterogeneity. The results indicate that blockchain adoption is positively associated with green disclosure quality after controlling for profitability, leverage, growth, cash flow, ownership concentration, inventories, board independence, audit quality, firm fixed effects, and year fixed effects. Supply chain finance partly transmits this association by turning verifiable invoices, receivables, and payment histories into credible financial signals. The effect is statistically clearer in technology-intensive firms and rises after firm-size thresholds, suggesting that digital capability and organizational scale condition blockchain governance benefits. The findings contribute to environmental accounting, digital finance, and disclosure research by showing how distributed ledgers can support credible green reporting without replacing conventional assurance and regulation. The paper also offers practical implications for firms, investors, lenders, and regulators seeking auditable environmental information in supply-chain ecosystems.

Keywords: Blockchain; environmental accounting; green disclosure quality; supply chain finance; firm heterogeneity; information transparency

Article History:

Received October 12, 2023
Revised December 18, 2023
Accepted February 04, 2024
Available Online March 30, 2024

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1. Introduction

Environmental accounting transparency has become a central governance issue because capital markets now evaluate firms not only through profitability, but also through the credibility of environmental impacts, climate-related commitments, pollution controls, resource efficiency, and supply-chain responsibility. Conventional reporting systems were built for periodic financial statements and often depend on managerial aggregation after transactions have already occurred. This creates a familiar disclosure problem: insiders observe production inputs, emissions-related costs, environmental liabilities, and supplier behavior earlier and in greater detail than investors, lenders, regulators, and communities. Information economics predicts that such asymmetry can lead to adverse selection, underpricing of credible firms, overpricing of weak disclosures, and strategic withholding of unfavorable information (Akerlof, 1970; Diamond and Verrecchia, 1991; Healy and Palepu, 2001; Verrecchia, 2001). In environmental accounting, the concern is amplified because green claims are hard to verify and because many environmental costs emerge through upstream suppliers rather than the focal firm alone.

Blockchain technology is increasingly discussed as an infrastructure for strengthening trust in this setting. A distributed ledger can attach time stamps to transactional events, record the sequence of supply-chain activities, reduce ex post alteration of documents, and enable programmable verification through smart contracts. These features do not automatically create truthful sustainability reporting; data can still be incomplete at the entry point. Yet blockchain can change the accountability environment by making accounting records more traceable, auditable, and shareable across firms, banks, auditors, and regulators. Prior blockchain research has emphasized information-system architecture, security, and industrial applications (Yli-Huumo et al., 2016; Lu, 2018; Lu, 2019; Lu, 2022; Zheng and Lu, 2022; Chen et al., 2024). More recent work connects blockchain with internal auditing, decentralized finance, Web 3.0, and large language models for supply chain finance, suggesting that distributed ledgers can become part of broader digital governance systems rather than isolated technologies (Xu et al., 2021; Xu et al., 2024; Wu et al., 2025; Yang et al., 2025; Zhang and Lu, 2025; Kou and Lu, 2025).

This paper extends that discussion to environmental accounting transparency. The underlying question is not whether blockchain should replace accounting standards, external assurance, or environmental regulation. It is whether blockchain-enabled data infrastructure can improve the quality of green disclosure when firms operate through complex supply chains and depend on external finance. Green disclosure quality is defined here as the authenticity, completeness, timeliness, and comparability of environmental and sustainability-related accounting information. The concept includes environmental cost recognition, disclosure of resource and emissions indicators, discussion of environmental risks, and the extent to which such disclosures can be reconciled with verifiable operational and financial records. The study is motivated by the view that credible green disclosure requires both information production and information discipline. Blockchain contributes mainly to the discipline side: it raises the expected cost of inconsistent reporting and lowers the cost of verification for outside stakeholders.

Supply chain finance provides the second pillar of the analysis. In many industries, environmental performance is inseparable from supplier contracts, receivables, inventory flows, logistics documents, and payment cycles. Supply chain finance converts such information into financing decisions through factoring, receivables pledging, reverse factoring, and platform-based credit assessment. When transaction documents are digitally traceable, financial institutions can price credit with less reliance on opaque collateral and more reliance on verified trade flows. This mechanism is relevant for environmental accounting because better financing channels reduce liquidity pressure, encourage formal documentation, and create third-party demand for clean records. Research on trade credit and supply chain finance shows that financing is deeply connected to information sharing, buyer-supplier trust, and operational coordination (Biais and Gollier, 1997; Klapper, 2006; Hofmann, 2009; Gomm, 2010; Kouvelis and Zhao, 2012; Gelsomino et al., 2016).

The paper draws on a panel design based on Chinese A-share listed firms from 2015 to 2023. The design follows the logic of the uploaded empirical manuscript but reframes the outcome as environmental accounting transparency and expands the discussion toward green disclosure quality. The empirical setting is valuable because the sample period captures the rapid diffusion of blockchain applications, the growth of digital supply-chain platforms, and the rising regulatory attention to corporate information disclosure. The analysis uses a binary indicator of blockchain-related application disclosed in annual reports or corporate announcements, a disclosure-quality score with values from 1 to 4, a supply chain finance ratio based on receivables financing relative to total assets, firm size measured by the natural logarithm of total assets, and a set of financial and governance controls. Firm and year fixed effects are included to absorb time-invariant firm characteristics and common macroeconomic shocks.

The study makes three contributions. First, it integrates environmental accounting with blockchain-enabled information governance. Earlier disclosure research has explained why transparency can reduce the cost of capital and improve monitoring (Bushman and Smith, 2001; Lambert et al., 2007; Francis et al., 2008; Leuz and Wysocki, 2016). This paper applies the same logic to green disclosure and adds a technology-based mechanism. Second, it links supply chain finance to environmental disclosure quality. The argument is that finance platforms and lenders act as information users who demand verifiable trade and environmental records. Third, it emphasizes firm heterogeneity. The value of blockchain depends on digital capability, organizational scale, and industry context; therefore, average effects may hide important differences across firms. Figure 1 summarizes the research framework and the expected channels.

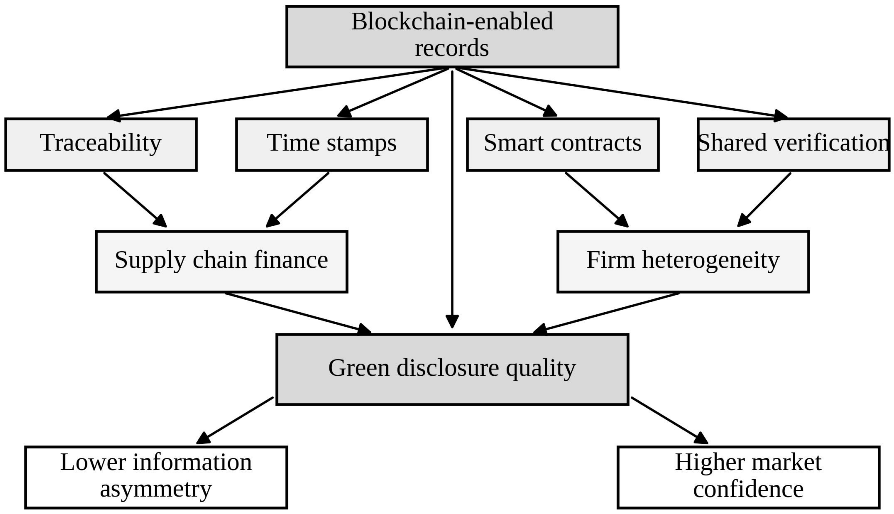

Figure 1. Research framework of blockchain-enabled environmental accounting transparency

The framework highlights that blockchain is not modeled as a single-purpose reporting tool. It is treated as a governance technology whose effects are transmitted through verifiable records, supply-chain finance, and heterogeneous firm capabilities. This structure also explains why the empirical analysis separates baseline effects from mediation and threshold tests.

A further motivation is that environmental accounting differs from ordinary financial reporting in the location of evidence. Many inputs that determine green performance are generated by suppliers, logistics providers, waste handlers, energy vendors, and financing intermediaries. A carbon-related procurement claim may require evidence about the supplier, the transport route, the production batch, and the payment document. A pollution-control claim may require evidence about equipment maintenance, permits, third-party inspection, and capitalized environmental expenditure. When such evidence is fragmented, the reporting firm can face high verification costs even if it intends to disclose honestly. Blockchain is attractive because it can create a common evidential layer that travels with the transaction instead of being reconstructed later from disconnected files.

The setting also matters because supply chains increasingly combine financial and environmental accountability. A core buyer may promise greener procurement, but the financing of smaller suppliers may still depend on paper invoices and delayed confirmation. A bank may fund receivables without observing whether the underlying transaction meets environmental conditions. A regulator may request environmental accounting data that are not reconciled with the cash-flow cycle. These gaps weaken both finance and disclosure. By connecting invoices, receivables, green certificates, and time-stamped operational records, a blockchain-enabled platform can help align the interests of firms, banks, auditors, and public authorities. The result is not perfect transparency, but a more disciplined path from operational events to accounting disclosure.

This paper therefore treats blockchain adoption as part of a broader shift from narrative reporting to evidence-based green disclosure. Narrative reporting remains important because firms must explain strategy, risks, and governance. Yet narrative disclosure becomes more useful when it is supported by records that outsiders can trace. The financial reporting literature has shown that information quality depends on both disclosure incentives and the reporting environment (Armstrong et al., 2010; Beyer et al., 2010). The environmental context adds the need to connect disclosure with physical and contractual evidence. This is why the paper examines supply chain finance and firm heterogeneity rather than estimating only a simple average blockchain coefficient.

The study is careful about causal language. The data structure supports a rich association analysis with controls, fixed effects, mediation, instrumental-variable diagnostics, and threshold tests, but it does not eliminate every source of endogeneity. Firms that adopt blockchain may already have stronger digital strategies, better governance, or more pressure from investors. The paper addresses these concerns by discussing the economic mechanism, by examining whether supply chain finance transmits part of the effect, and by showing that the effect varies across firms in theoretically expected ways. This design provides evidence that is useful for theory building and policy discussion while leaving room for future natural-experiment research.

2. Literature review and hypotheses

The theoretical foundation of the paper combines information asymmetry, agency theory, and signaling theory. Information asymmetry suggests that managers can possess private knowledge about environmental costs and supply-chain risks that outside investors cannot fully observe. Agency theory adds that managers may have incentives to delay bad news, overstate green achievements, or select disclosure formats that reduce accountability (Jensen and Meckling, 1976). Signaling theory explains why credible firms benefit from costly and verifiable signals: when disclosures are difficult to manipulate, they separate firms with substantive environmental practices from those relying on vague narratives (Spence, 1973). Blockchain can strengthen signaling because a traceable ledger makes the link between operational transactions and reported environmental outcomes more observable. However, credibility depends on complementary controls, including audits, internal governance, and standardized measurement.

Environmental disclosure research has long recognized the tension between accountability and impression management. Firms with stronger environmental performance may disclose more detailed information, while firms facing legitimacy pressure may disclose selectively or symbolically. Evidence from environmental accounting shows that disclosure informativeness depends on performance, governance, assurance, and capital-market incentives (Cho and Patten, 2007; Clarkson et al., 2008; Clarkson et al., 2011). Corporate social responsibility disclosure can influence analyst forecasts, the cost of equity, and investor assessments when users perceive the information as credible and decision useful (Dhaliwal et al., 2011; Dhaliwal et al., 2012; Matsumura et al., 2014; Plumlee et al., 2015). The implication for the present study is that blockchain should matter most when it improves the credibility of disclosed environmental information rather than merely increasing the volume of text.

Green finance literature offers a parallel argument. Investors and lenders increasingly price climate and environmental risks, and firms with credible sustainability policies may obtain financing advantages or valuation benefits. Studies of corporate social responsibility and capital structure link environmental performance with lower financing constraints, stronger stakeholder support, and positive market reactions under some conditions (El Ghoul et al., 2011; Cheng et al., 2014; Eccles et al., 2014; Flammer, 2015; Krueger, 2015). More recent evidence on green bonds and carbon risk shows that investors distinguish between credible commitments and exposure to transition risks (Flammer, 2021; Bolton and Kacperczyk, 2021; Krueger et al., 2020). The role of disclosure regulation remains important because markets need consistent information to compare firms across industries and over time (Christensen et al., 2021).

At the same time, green disclosure can become a channel for greenwashing. Symbolic claims may be attractive when stakeholders reward environmental language but cannot observe the underlying operational data. Greenwashing research warns that disclosure without verification can increase reputational risk and reduce trust, especially when broad claims are not connected to measurable actions (Lyon and Maxwell, 2011; Marquis et al., 2016). Blockchain is useful in this debate because it changes the audit trail. If environmental costs, supplier certificates, logistics events, and receivable-financing documents are linked to a tamper-resistant record, the firm has less room to rewrite the history of transactions after performance outcomes are known. This does not prevent all forms of misreporting, but it creates a stronger documentary basis for assurance and enforcement.

Blockchain studies in operations and accounting provide the technological basis for these claims. In supply chains, distributed ledgers can improve traceability, data sharing, provenance verification, and coordination between buyers, suppliers, logistics providers, and financial institutions (Treiblmaier, 2018; Saberi et al., 2019; Wang et al., 2019; Cole et al., 2019; Min, 2019; Bai and Sarkis, 2020; Dutta et al., 2020; Kouhizadeh et al., 2021). In accounting, blockchain has been connected to continuous auditing, triple-entry bookkeeping, smart contracts, and the redesign of evidence collection (Dai and Vasarhelyi, 2017; Coyne and McMickle, 2017; Kokina et al., 2017; Bonsón and Bednárová, 2019; Schmitz and Leoni, 2019). These studies indicate that blockchain can lower verification costs, but they also stress that organizational adoption, data standards, and governance are necessary for value creation.

The first hypothesis follows from the above logic. Blockchain-enabled records can reduce manipulation opportunities, accelerate disclosure, and increase the auditability of environmental accounting information. The mechanism is both technological and institutional. Technologically, distributed records preserve the sequence of invoices, payments, environmental certificates, and supply-chain events. Institutionally, the same records can be observed by lenders, auditors, platform operators, and regulators, which raises the reputational and legal cost of inconsistent reporting. Because green disclosure quality requires authenticity, timeliness, completeness, and comparability, blockchain adoption should be associated with a higher disclosure-quality score. H1: Blockchain adoption is positively associated with the quality of environmental accounting and green disclosure.

The second hypothesis focuses on supply chain finance. Supply chain finance depends on credible documents about real transactions. When invoices, receivables, contracts, and payment obligations are recorded on a blockchain-enabled platform, financial institutions can reduce due-diligence costs and monitor repayment risks more effectively. Improved financing then supports disclosure quality in two ways. First, it encourages firms to standardize transaction documentation because financing depends on data quality. Second, it reduces liquidity stress that might otherwise motivate delayed recognition of environmental obligations or selective disclosure. H2: Supply chain finance mediates the association between blockchain adoption and green disclosure quality.

The third hypothesis concerns industry heterogeneity. High-technology firms typically have stronger digital infrastructures, more skilled information-system staff, and greater experience with data-intensive reporting. They are therefore better positioned to integrate blockchain records with enterprise resource planning, supplier management, and environmental management systems. Digital transformation research shows that technology produces value only when it is combined with complementary organizational practices and managerial capability (Brynjolfsson and Hitt, 2003; Bloom et al., 2012; Goldfarb and Tucker, 2019; Vial, 2019). H3: The positive association between blockchain adoption and green disclosure quality is more statistically evident in technology-intensive firms than in traditional firms.

The fourth hypothesis concerns firm size. Large firms usually have more complex supply chains and stronger incentives to invest in credible reporting because they face greater attention from investors, banks, media, and regulators. They also possess more resources to implement blockchain infrastructure and to connect distributed records with internal control systems. Small firms may benefit from blockchain platforms, but adoption costs, limited technical personnel, and weak bargaining power can reduce early-stage benefits. This implies a nonlinear relationship in which the marginal disclosure benefit of blockchain rises after size thresholds. H4: Firm size has a threshold effect in the relationship between blockchain adoption and green disclosure quality.

A key insight from financial disclosure research is that transparency affects capital markets through multiple channels. More precise information reduces estimation risk, improves liquidity, supports monitoring, and allows investors to compare firms more fairly. Yet disclosure is also shaped by proprietary costs and by managerial incentives to present favorable information. Environmental accounting inherits these tensions and adds measurement uncertainty. Pollution, carbon emissions, waste handling, and supplier conduct are not always recorded in standard accounting systems. Blockchain can reduce the gap between operational measurement and external reporting if it is connected to the systems that create the underlying evidence. This is the reason the analysis emphasizes evidence quality rather than disclosure volume.

Blockchain research also warns against technological determinism. Systematic reviews show that blockchain applications differ by consensus mechanism, permission structure, governance rules, scalability, privacy protection, and interoperability (Casino et al., 2019). In a public chain, transparency may be high but business confidentiality can be difficult to protect. In a consortium chain, data access can be governed by participating firms and financial institutions, but the credibility of the system depends on the governance of the consortium. Supply-chain applications therefore require a design choice: the ledger must be transparent enough for assurance and financing, but controlled enough to protect commercially sensitive information. This design tension is central to environmental accounting because suppliers may resist disclosure if data access is not clearly governed.

Adoption barriers are especially important in supply chains. Firms must agree on data definitions, legal recognition of digital documents, identity management, error correction, and responsibility for inaccurate inputs. Empirical studies of blockchain adoption in supply chains show that organizational readiness, partner pressure, regulatory support, and perceived benefits all influence implementation decisions (Queiroz and Wamba, 2019). For environmental accounting, these barriers imply that a blockchain record is credible only when the participants agree on what counts as evidence. A time-stamped invoice is useful, but it does not verify environmental performance unless it is linked to environmental attributes such as certified materials, energy sources, recycling records, or emissions measurements.

Accounting and auditing studies provide a second caution. Blockchain may support continuous assurance, but auditors still need to assess access controls, data-entry reliability, smart-contract logic, and the completeness of off-chain information. A ledger can confirm that a record has not been altered after entry, but it cannot guarantee that the original measurement was accurate. This distinction is essential for environmental accounting. For example, a waste-transfer record can be immutable, yet the physical quantity of waste must still be measured and verified.

The most plausible future is therefore a hybrid assurance model in which blockchain provides an audit trail, auditors test the controls around the trail, and regulators define the disclosure standards.

Supply chain finance is more than a liquidity instrument in this framework. It creates a repeated demand for verified transaction information. When receivables are financed, the lender wants evidence that the buyer exists, the invoice is valid, the goods or services were delivered, and payment obligations are enforceable. If environmental attributes are attached to those transactions, the financing process can also reinforce green data quality. This is particularly relevant for smaller suppliers that might lack independent access to green financing. A blockchain-enabled platform can allow a core buyer's credit quality and environmental commitments to flow through the chain, but only if data standards are consistent and if the platform discourages false documentation.

Firm heterogeneity has both technological and economic dimensions. Technology-intensive firms may have better enterprise systems, stronger data governance, and more experience with digital platforms. Large firms may have more resources, but they also have more complex reporting needs and higher reputational exposure. Traditional firms can still benefit from blockchain, especially in traceability-intensive sectors, but the pathway may depend more heavily on external platforms and government-supported standards. These differences explain why the same technology can produce different disclosure outcomes. The empirical threshold design is therefore not a statistical add-on; it reflects the idea that digital infrastructure has fixed costs and complementarity with organizational capability.

The literature gap is thus clear. Prior studies have examined environmental disclosure, blockchain technology, and supply chain finance separately, but fewer studies integrate them into a single empirical disclosure framework. Environmental accounting studies often focus on what firms disclose; blockchain studies often focus on how data are stored; supply chain finance studies often focus on how transaction data support credit. The present paper connects these lines by asking whether blockchain-enabled transaction records improve green disclosure quality directly and through supply-chain-finance use. It also asks whether the benefits depend on industry and firm size. This integration is the main novelty of the article.

3. Research design

The empirical design uses a firm-year panel to evaluate the relationship among blockchain adoption, supply chain finance, green disclosure quality, and heterogeneity. The unit of analysis is the listed firm-year. The sample covers the years 2015 to 2023 because this period captures the emergence of blockchain applications in corporate finance and supply-chain management, while also reflecting stronger public attention to environmental disclosure and green finance. Observations with missing key variables are excluded, and continuous variables are interpreted together with standard financial controls. The final working sample contains 28,479 firm-year observations. Although the empirical results are reported in the language of association, the design reduces several obvious confounding concerns by using firm fixed effects, year fixed effects, financial controls, and additional mechanism tests.

The dependent variable, GreenQuality, is a disclosure-quality score ranging from 1 to 4, where higher values indicate better environmental accounting transparency. The measure is adapted from exchange-style disclosure evaluations and interpreted as capturing the credibility and usefulness of environmental and sustainability-related accounting information. The independent variable, Blockchain, equals 1 when a firm discloses blockchain-related application in supply-chain management, finance, accounting, traceability, or digital governance, and 0 otherwise. A binary proxy cannot capture adoption depth, but it provides a transparent classification for a large panel where detailed implementation intensity is not consistently observable. The interpretation is therefore conservative: the coefficient reflects the average difference between firms with disclosed blockchain-related application and firms without such disclosure.

Supply_Chain is the mediating variable and is measured by accounts receivable financing balance scaled by total assets. It represents the extent to which firms use supply chain finance mechanisms linked to receivables, bills, factoring, or platform-based financing. Scale is the threshold variable and equals the natural logarithm of total assets. Control variables include return on assets, leverage, revenue growth, operating cash flow, ownership concentration, inventory ratio, independent director ratio, and Big Four audit indicator. These controls capture profitability, financial risk, growth opportunities, liquidity, governance, operational structure, board oversight, and audit quality. Table 1 reports the variable definitions used in the study.

Table 1. Variable definitions and measurement

Variable	Notation	Measurement	Role
Green disclosure quality	GreenQuality	Score from 1 to 4; higher values indicate more authentic, complete, timely, and comparable environmental accounting disclosure.	Dependent variable
Blockchain adoption	Blockchain	Indicator equal to 1 if the firm discloses blockchain-related use in finance, accounting, supply chain, or traceability.	Core independent variable
Supply chain finance	Supply_Chain	Accounts receivable financing balance divided by total assets.	Mediating variable
Firm size	Scale	Natural logarithm of total assets.	Threshold variable
Controls	ROA, Lev, Growth, Cashflow, Top1, Inv, Indep, Big4	Profitability, leverage, growth, operating cash flow, ownership concentration, inventory ratio, independent directors, and audit quality.	Control variables

The variable system is intentionally close to financial statement data so that the model can be replicated. The main limitation is that the blockchain proxy does not distinguish between pilot use and mature integration. For this reason, the paper interprets coefficients as conservative evidence of association rather than as a direct measure of technological intensity.

The baseline model is specified as GreenQuality_it = alpha0 + alpha1 Blockchain_it + beta Controls_it + firm fixed effects + year fixed effects + error_it. The mediation model first regresses Supply_Chain on Blockchain and controls, and then regresses GreenQuality on both Blockchain and Supply_Chain. This structure separates the direct association from the supply-chain-finance channel. The threshold model estimates the marginal effect of Blockchain across firm-size intervals defined by estimated threshold values. The approach follows the logic of mediation and threshold analysis in applied empirical research, where indirect effects and nonlinear regimes are examined explicitly rather than absorbed into a single average coefficient (Baron and Kenny, 1986; Hansen, 1999; Hayes, 2009).

Blockchain adoption is identified from disclosed references to blockchain-related application rather than from vendor contracts or technical audits. The classification includes references to blockchain finance platforms, supply-chain traceability, digital certificates, smart-contract settlement, receivables verification, and accounting-data management. The advantage is coverage: public reports and announcements allow a broad panel to be constructed. The disadvantage is that disclosures may include projects at different maturity levels. To reduce overinterpretation, the paper uses the term adoption signal when discussing measurement and interprets coefficients as the average association between disclosed application and disclosure quality. Future research can improve this proxy by coding the intensity, scope, and operational maturity of blockchain systems.

The GreenQuality score is interpreted as a structured evaluation rather than a continuous environmental-performance metric. A score of 1 indicates weak disclosure discipline, limited detail, or low comparability. A score of 4 indicates strong disclosure discipline, timely information, and more complete documentation. The score does not mean that a firm is environmentally superior; it means that the disclosed environmental and accounting information is more useful to outsiders. This distinction is important because a firm with high emissions can still provide high-quality disclosure, while a firm with good environmental intentions can provide poor disclosure if evidence is fragmented or delayed.

The control variables are selected to match the main alternative explanations for disclosure quality. Return on assets captures profitability and potential slack resources. Leverage captures creditor monitoring and financial pressure. Growth captures expansion opportunities that may require external finance. Operating cash flow captures liquidity. Ownership concentration captures controlling-shareholder influence. Inventory ratio captures operational complexity and the importance of physical flows. Independent director ratio captures board monitoring. Big Four audit indicator captures audit-market quality. Including these controls helps isolate the blockchain association from differences in financial health, governance, and operational structure.

The fixed-effect structure is also important. Firm fixed effects compare each firm with itself over time, thereby controlling for stable characteristics such as industry culture, location-specific legacy, founding history, and long-run governance style. Year fixed effects control for economy-wide changes such as regulatory announcements, macroeconomic conditions, and general improvements in digital infrastructure. This design does not solve every endogeneity problem, but it reduces the risk that cross-sectional differences alone explain the results. The instrumental-variable diagnostic based on regional technological innovation environment is used as an additional check, because local innovation intensity may influence blockchain adoption through technology availability and digital-service ecosystems.

The threshold model estimates whether the marginal effect of blockchain changes at particular values of Scale. This is preferable to imposing a simple linear interaction because technology adoption may have discontinuous economics. A small firm might have enough resources for a pilot but not enough to integrate suppliers and accounting systems. A medium firm may begin to obtain benefits as financing partners demand standardized data. A large firm may realize stronger benefits because it has both the incentive and the capacity to embed blockchain records in internal controls. The threshold model is therefore aligned with the fixed-cost and complementarity interpretation of digital transformation.

Figure 2 describes the empirical workflow. Annual reports and firm announcements provide information on blockchain-related application. Exchange-style disclosure evaluations provide the score used to construct GreenQuality. Financial data are assembled from standard listed-company databases and then merged with governance controls. The analysis proceeds from descriptive statistics to fixed-effect regressions, instrumental-variable diagnostics, mediation tests, and threshold tests. The same workflow can be replicated in future research with more granular environmental data, such as carbon emissions, green patents, or supplier-level environmental certificates.

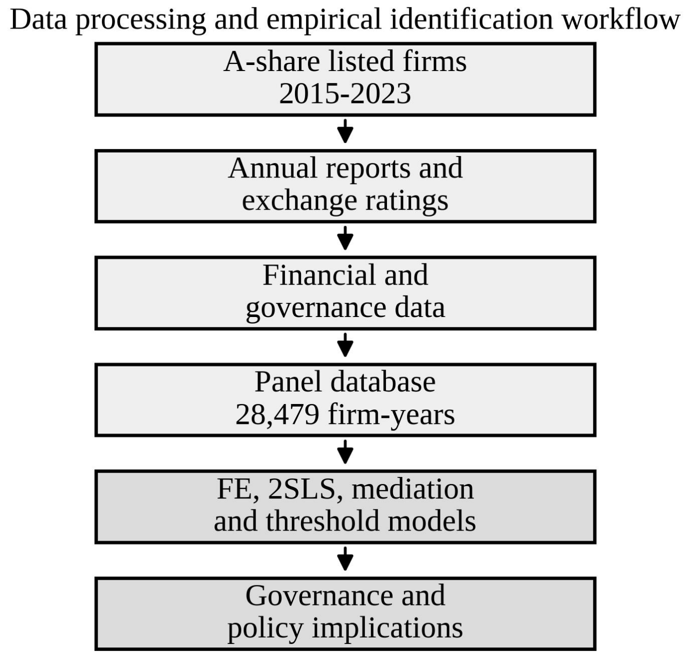

Figure 2. Data processing and empirical identification workflow

The workflow also clarifies the timing of analysis. Blockchain adoption, supply chain finance, firm characteristics, and disclosure-quality scores are aligned at the firm-year level. Fixed effects then compare changes within firms over time while controlling for economy-wide year shocks.

4. Empirical results

Table 2 presents the descriptive statistics. The mean value of GreenQuality is 2.0078, indicating that the average firm is near the middle of the 1-to-4 disclosure-quality scale. The standard deviation of 0.6614 shows meaningful variation across firms and years. Blockchain has a mean of 0.7814, which should be interpreted as the share of firm-year observations with blockchain-related disclosure or application signals rather than the share of firms with full enterprise-wide blockchain integration. Supply_Chain has a mean of 0.1310 and a wide range from 0 to 0.5060, confirming that the financing channel varies substantially across firms. Firm size also varies substantially, with Scale ranging from 19.7773 to 26.4403. The control variables show that the sample includes loss-making firms, highly profitable firms, low-leverage firms, and highly leveraged firms.

Table 2. Descriptive statistics for main variables

Variable	Obs	Mean	SD	Min	Median	Max
GreenQuality	28,479	2.0078	0.6614	1.0000	2.0000	4.0000
Blockchain	28,479	0.7814	0.4133	0.0000	1.0000	1.0000
Supply_Chain	28,479	0.1310	0.0946	0.0000	0.1297	0.5060
Scale	28,479	22.2976	1.2661	19.7773	22.1628	26.4403
ROA	28,479	0.0349	0.0638	-0.3730	0.0320	0.2473
Lev	28,479	0.4155	0.1973	0.0489	0.4060	0.9244
Growth	28,479	0.1395	0.3725	-0.6535	0.0866	4.0242
Cashflow	28,479	0.0497	0.0652	-0.1729	0.0479	0.2656
Top1	28,479	0.6383	3.2999	0.0760	0.3105	72.7869
Inv	28,479	0.1300	0.1123	0.0000	0.1096	0.7596
Indep	28,479	0.3797	0.0535	0.2857	0.3636	0.6000

Big4	28,479	0.0535	0.2251	0.0000	0.0000	1.0000

The large observation count and the dispersion in the variables provide enough cross-sectional and temporal variation for fixed-effect estimation. The low mean of Big4 indicates that most firms are audited by non-Big Four auditors, which is typical in a broad listed-company sample and motivates explicit control for audit quality.

The descriptive results already suggest why a heterogeneity design is necessary. Firms differ in size, profitability, liquidity, governance, and supply-chain-finance intensity. A single average relationship between blockchain and disclosure quality may hide different economic meanings across firm types. For example, a large firm with many suppliers may use blockchain to standardize documentation across procurement, inventory, and receivable-financing systems. A smaller firm may use a platform operated by a core buyer or bank, but may not have sufficient internal capacity to convert the ledger into comprehensive environmental accounting. These differences motivate the baseline, mediation, and threshold tests reported below.

The mean blockchain value deserves careful interpretation. A value of 0.7814 may appear high if one imagines blockchain as a fully deployed enterprise infrastructure. In this paper it is interpreted more narrowly as an adoption signal based on disclosed application. Many firms may mention blockchain in relation to platform participation, pilot projects, supplier traceability, or financial-data verification. The result should therefore not be read as evidence that most firms operate complete blockchain accounting systems. Instead, it shows that blockchain-related disclosure became common enough during the sample period to support panel analysis. This distinction prevents overstating the maturity of the technology.

The baseline coefficient can be interpreted using the dependent-variable scale. A 0.0200 increase on a 1-to-4 disclosure score is not a transformation by itself, but it is meaningful because disclosure scores tend to move slowly and because the coefficient is estimated after controlling for firm and year effects. In practice, improvements in disclosure quality may appear as faster release of environmental accounting information, more consistent reconciliation between financial and nonfinancial data, more complete discussion of environmental costs, or better documentation of supply-chain transactions. The coefficient is therefore best understood as evidence of incremental transparency rather than as evidence of a complete governance revolution.

The high-technology subsample result is also informative for adoption strategy. Technology-intensive firms may already have enterprise resource planning systems, data warehouses, digital procurement platforms, and internal audit routines. Blockchain can be layered onto these systems more easily than onto fragmented manual processes. Traditional firms may need to digitize basic records before blockchain can add value. This explains why the statistical signal is clearer for high-technology firms. It also suggests that policy support should focus not only on blockchain itself, but also on the complementary systems that allow blockchain data to become accounting evidence.

The mediation result gives the analysis a concrete economic channel. Without a channel, the positive blockchain coefficient could be interpreted as a broad indicator of digital sophistication. The supply-chain-finance test narrows the mechanism by showing that blockchain relates to the financing process and that financing process relates to disclosure quality. Receivables financing requires reliable transaction evidence; when that evidence is digitally traceable, it becomes easier for firms to maintain consistent records. The same information then supports environmental accounting if green attributes are attached to transactions. This channel is especially plausible for firms whose environmental claims are embedded in procurement and supplier relations.

The instrumental-variable evidence should be interpreted with caution but is still useful. Regional technological innovation environment is strongly associated with blockchain adoption, indicating that firms in innovation-rich regions are more likely to use or disclose blockchain applications. The second-stage coefficient is positive, which is consistent with the baseline result. However, regional innovation could also influence disclosure quality through other channels, such as better auditors, more active investors, or stronger local institutions. For that reason, the instrumental-variable result is used as a diagnostic rather than as definitive causal proof. The combined pattern across fixed effects, mediation, heterogeneity, and thresholds is more persuasive than any single test.

The threshold pattern has a practical implication for smaller firms. If the blockchain effect is weak below the first size threshold, simply encouraging small firms to adopt blockchain may not produce better green disclosure. Smaller firms may need shared digital infrastructure, simplified reporting templates, third-party platform services, and technical training. Core buyers and banks can also play a role by embedding environmental data requirements into supply-chain-finance platforms. In this sense, blockchain-enabled transparency is partly a network good: the value for one firm rises when counterparties, lenders, and auditors participate in compatible systems.

The results are consistent with a layered model of transparency. The first layer is the accounting record, which captures transactions and environmental costs. The second layer is the supply-chain record, which links the firm to suppliers, logistics providers, and financing partners. The third layer is the disclosure record, which communicates information to investors and regulators. Blockchain improves transparency most effectively when these layers are connected. If blockchain is used only at the disclosure layer, it risks becoming a symbolic technology. If it is used at the transaction and financing layers, it can change the quality of evidence available for environmental reporting.

Table 3 reports the main regression evidence. Across fixed-effect specifications, the coefficient on Blockchain is positive and statistically significant. In the full-control specification, the coefficient is 0.0200 with a t-statistic of 2.0653, suggesting that blockchain adoption is associated with higher green disclosure quality after controls and fixed effects. The magnitude appears modest on the 1-to-4 scale, but it is economically meaningful because disclosure quality is a coarse index and because the coefficient captures an average effect across many industries and firm types. The result supports H1 and is consistent with the view that traceable accounting records improve the credibility of environmental disclosure.

Table 3. Baseline, heterogeneity, and instrumental-variable evidence

Variables	(1) Baseline FE	(2) Full controls	(3) High-tech	(4) Traditional	(5) IV-2SLS
Blockchain	0.0205** (2.0939)	0.0200** (2.0653)	0.0047*** (3.3612)	0.0077 (0.4335)	2.1671*** (6.8041)
ROA	No	-1.1304*** (-16.5382)	-1.7441*** (-18.1554)	-1.4049*** (-10.4467)	-2.9178*** (-24.2823)
Lev	No	0.0987** (2.4683)	0.2103*** (3.4932)	0.1069 (1.4518)	0.0905** (2.5460)
Other controls	No	Yes	Yes	Yes	Yes
Firm FE / Year FE	Yes / Yes	Yes / Yes	Yes / Yes	Yes / Yes	Yes / Yes
N	28,479	28,479	14,149	14,330	28,479
R-squared	0.5893	0.5827	0.5533	0.6123	0.7550

Notes: t-statistics are reported in parentheses. The table condenses the reported fixed-effect specifications and the second-stage instrumental-variable diagnostic. Statistical significance is denoted by *, **, and *** at conventional levels. The environmental interpretation of the dependent variable is the green disclosure quality score used throughout this paper.

Industry heterogeneity in Table 3 indicates that the blockchain coefficient is statistically reliable among high-technology firms but not significant among traditional firms. This finding supports H3 in the sense that digital capability conditions the governance value of blockchain. The lack of significance in traditional firms does not imply that blockchain is useless; rather, it suggests that adoption may remain symbolic, partial, or operationally disconnected from accounting systems in firms with weaker digital infrastructure. The instrumental-variable diagnostic also reports a strong first-stage relationship between regional technological innovation environment and blockchain adoption, and a positive second-stage association with disclosure quality. This evidence reduces, but does not eliminate, concerns that the baseline association is driven only by omitted firm characteristics.

Several control variables are consistent with disclosure theory. Profitability has a negative coefficient in the reported specification, which may reflect that firms facing lower profitability disclose more environmental and accounting detail under pressure, or that the disclosure score captures regulatory scrutiny as well as voluntary transparency. Leverage is positive in the full model, suggesting that creditors may demand better information. Cash flow is positively associated with disclosure quality, consistent with the idea that better liquidity supports more complete reporting systems. Inventory intensity is negative, possibly because inventory-heavy firms face complex physical flows that are costly to document comprehensively. Audit quality has a negative coefficient in the table, which should be interpreted cautiously because Big Four audits are concentrated in particular firm types and may correlate with stricter evaluation standards.

Table 4 examines the mediating role of supply chain finance and the size-threshold structure. The first-stage mediation regression shows that Blockchain is positively associated with Supply_Chain. The second-stage regression shows that Supply_Chain is positively associated with GreenQuality while Blockchain remains positive. The bootstrap indirect effect is statistically significant, indicating that part of the blockchain-disclosure association operates through the financing channel. Economically, the result means that a blockchain-enabled firm is not merely adding a reporting tool; it is also improving the reliability of transaction data that banks and platform lenders use. Because financing documents require verification of invoices, receivables, and payment obligations, the same data infrastructure can strengthen environmental accounting records.

Table 4. Supply chain finance mediation and size-threshold evidence

Panel	Test item	Estimate	t/z or p-value	Interpretation
A. Mediation	Blockchain -> Supply_Chain	0.0018*	1.7469	Blockchain supports supply-chain-finance use.
A. Mediation	Supply_Chain -> GreenQuality	0.0752**	2.2463	Supply-chain finance is associated with higher disclosure quality.
A. Mediation	Bootstrap indirect effect	0.0478	p = 0.0000; CI [0.0304, 0.0653]	Indirect channel is statistically significant.
B. Threshold	First accepted threshold	21.8984	CI [21.5521, 22.2048]	Low-to-medium size boundary.
B. Threshold	Second accepted threshold	22.5842	CI [22.3048, 22.7643]	Medium-to-high size boundary.
B. Threshold	Blockchain effect below first threshold	0.0021*	1.7475	Limited marginal effect for small firms.
B. Threshold	Blockchain effect above second threshold	0.0103***	4.5986	Stronger marginal effect for larger firms.

The mediation and threshold evidence should be read together. The finance channel explains how blockchain affects disclosure processes, while the threshold analysis explains when the channel becomes more powerful. Larger firms usually have the internal capacity and external monitoring needed to turn verifiable supply-chain records into higher quality green disclosure.

The threshold results indicate that firm size changes the marginal effect of blockchain. The estimated thresholds are 21.8984 and 22.5842 in the accepted double-threshold specification. The blockchain coefficient is 0.0021 for firms below the first threshold, 0.0034 for firms between the thresholds, and 0.0103 for firms above the second threshold. Figure 3 presents these marginal effects. The pattern supports H4 and suggests that blockchain produces greater disclosure benefits after firms reach a scale at which internal systems, supplier networks, and external monitoring justify the fixed cost of implementation. This result is important for policy because it implies that small firms may need shared platforms, technical support, or standardized templates before they can realize the same transparency benefits.

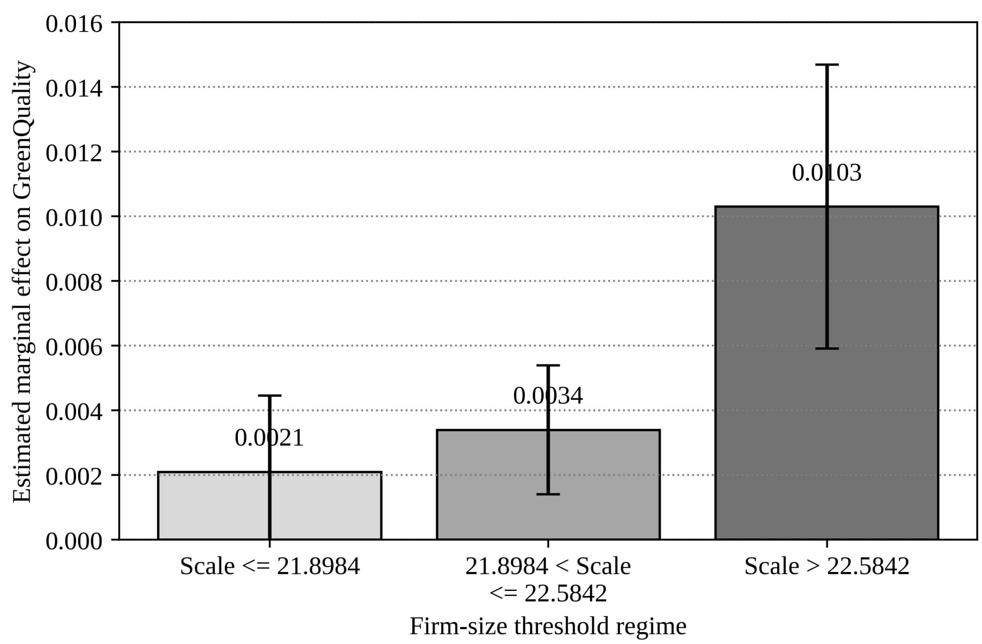

Figure 3. Marginal blockchain effects across firm-size threshold regimes

The figure shows a monotonic increase in the estimated marginal effect across size regimes. Error bars are based on reported t-statistics and illustrate why the large-firm regime is more precisely estimated. The pattern is consistent with a fixed-cost interpretation of blockchain adoption.

Table 5 translates the regression results into effect-size diagnostics. The baseline association of 0.0200 disclosure-quality points equals about 1.00 percent of the sample mean GreenQuality score. The high-size threshold coefficient is nearly 4.9 times the low-size coefficient, showing that scale is not a minor condition but a central part of blockchain's governance value. The mediation product using the reported coefficients is small in raw units, yet the bootstrap test is significant because the channel is consistently estimated across many observations. This pattern is common when the dependent variable is a bounded score: individual mechanisms may look numerically small, but they can still indicate systematic changes in the reporting process.

Table 5. Effect-size diagnostics based on reported estimates

Diagnostic item	Calculation	Value	Economic reading
Baseline association as share of mean quality	0.0200 / 2.0078	1.00%	Average blockchain association is modest but meaningful for a bounded score.
Supply-chain-finance product	0.0018 x 0.0752	0.00014	Raw product is small, but bootstrap evidence indicates consistency.
Low-size regime share of mean	0.0021 / 2.0078	0.10%	Small firms obtain limited disclosure benefit.
High-size regime share of mean	0.0103 / 2.0078	0.51%	Large firms obtain a stronger marginal benefit.
High-to-low threshold ratio	0.0103 / 0.0021	4.90x	Blockchain value rises substantially with firm scale.

The diagnostics are not separate regressions; they translate reported estimates into comparable economic quantities. This is useful because a one-point movement in the dependent variable represents a large change in disclosure evaluation, whereas many governance improvements occur incrementally.

The evidence also clarifies what blockchain can and cannot do. It can improve the traceability of documents, reduce the probability that conflicting versions of the same transaction circulate among stakeholders, and connect accounting disclosures with financing records. It cannot independently determine whether an environmental indicator was measured correctly at the source. For example, a ledger can record the time and identity of a supplier's emissions certificate, but external assurance is still needed to confirm measurement methods. The empirical results therefore support a complementary view: blockchain strengthens environmental accounting transparency when it is embedded in supply-chain-finance systems, governance controls, and disclosure standards.

The time dimension of the sample is also relevant. From 2015 to 2023, digital finance and green disclosure evolved simultaneously. Early blockchain references in annual reports may have represented exploratory projects, whereas later references were more likely to involve platforms, traceability systems, or finance applications. This diffusion path means that the binary adoption variable is necessarily imperfect. Nevertheless, its positive association with GreenQuality suggests that even disclosed adoption is informative about a firm's orientation toward verifiable data infrastructure. Future research can improve measurement by distinguishing pilot projects, fully integrated ledgers, smart-contract use, consortium platforms, and external third-party blockchain services.

5. Discussion

The findings have several implications for environmental accounting theory. First, they extend the disclosure-quality literature by showing that transparency depends not only on managerial incentives and regulatory rules, but also on the architecture of the information system that stores transactional evidence. Traditional disclosure theory often assumes that information exists inside the firm and that the central question is whether managers release it. In supply-chain settings, however, information is fragmented across many parties. Blockchain can help coordinate these fragments by giving stakeholders a shared reference point. This is why the direct effect and the supply-chain-finance channel appear together rather than as separate stories.

Second, the results refine the idea of green disclosure quality. High-quality green disclosure is not simply longer sustainability reporting or more favorable environmental language. It requires a chain of evidence connecting procurement, production, logistics, financing, environmental costs, and risk discussion. A firm may publish extensive sustainability narratives but still fail to provide auditable evidence. Conversely, a firm with a blockchain-enabled transaction record may disclose fewer slogans but provide more verifiable data. The empirical emphasis on authenticity, timeliness, completeness, and comparability is therefore consistent with a decision-usefulness approach to environmental accounting.

Third, the supply chain finance channel shows how lenders and platform operators can become indirect monitors of environmental accounting quality. When receivables and invoices are financed, the lender has an incentive to verify that the underlying transactions are real and enforceable. If environmental costs, supplier qualifications, or green procurement records are linked to the same transaction chain, financing verification can spill over into disclosure verification. This does not transform banks into environmental auditors, but it creates additional demand for accurate and standardized records. The result is especially relevant in economies where supply-chain platforms are expanding quickly and where small suppliers depend on core firms for credit access.

Fourth, the heterogeneity findings caution against universal policy claims. Regulators may be tempted to promote blockchain as a general solution to greenwashing, but the evidence suggests that firm capabilities matter. High-technology firms and larger firms are better positioned to integrate blockchain with accounting, audit, and supply-chain systems. Smaller and traditional firms may need industry-level consortia, interoperable data standards, cloud-based services, or public infrastructure to reduce implementation costs. Without such support, blockchain adoption can become a label rather than a functioning transparency mechanism.

For managers, the main lesson is that blockchain adoption should begin with the disclosure problem rather than with the technology itself. Firms should identify which environmental accounting records are most vulnerable to dispute: supplier certifications, emissions data, waste-transfer documents, renewable-energy purchases, carbon-credit transactions, or green receivables. They should then design blockchain processes that connect these records to internal controls and external assurance. For investors, blockchain-related disclosure should be evaluated carefully. A credible report should explain what data are recorded, who can write to the ledger, who verifies entries, how errors are corrected, and how the system links to financial statements and environmental indicators.

For regulators and exchanges, the results support a balanced policy approach. It is useful to encourage digital traceability and standardized data interfaces, especially for sectors with complex environmental impacts. However, regulation should avoid treating blockchain adoption as an automatic signal of superior transparency. Disclosure rules should require firms to explain the scope of blockchain use, governance rights, data standards, audit procedures, and limitations. Regulators can also promote interoperable reporting taxonomies so that blockchain records can be compared across firms. Such policies would enhance the public value of blockchain without weakening the importance of accounting standards and environmental verification.

The analysis has limitations. The blockchain variable is binary, so it cannot capture the intensity, maturity, or quality of implementation. The disclosure-quality score is also broad and may mix environmental accounting quality with general disclosure discipline. The empirical setting is one national capital market, which provides institutional consistency but limits cross-country generalization. Finally, even with fixed effects and instrumental-variable diagnostics, observational data cannot establish definitive causality. These limitations create useful paths for future research, including text-based measures of environmental disclosure, supplier-level data, carbon-emissions verification, natural experiments, and cross-country comparisons of blockchain-enabled reporting systems.

An additional theoretical implication concerns the boundary between voluntary disclosure and mandatory reporting. Voluntary environmental disclosure can signal superior governance, but it can also be selective. Mandatory reporting improves comparability, but it may become a compliance exercise if firms lack reliable internal data. Blockchain-enabled records can support both regimes by improving the evidence base. Under voluntary disclosure, they make signals more credible. Under mandatory disclosure, they reduce the cost of producing standardized information. This dual role is important as sustainability reporting standards become more formal and as investors ask for information that can be connected to financial statements.

The findings also suggest that environmental accounting transparency should be evaluated as an ecosystem outcome. A firm cannot create full transparency alone if suppliers, banks, auditors, and regulators use incompatible data systems. Blockchain can provide shared infrastructure, but governance rules determine who participates, who validates records, and who can access data. This means that technical design and institutional design must develop together. Consortium chains may be appropriate for industry-level supply chains; permissioned platforms may be appropriate for bank-led receivables financing; public verification layers may be appropriate for certificates or carbon credits. The best architecture depends on the disclosure risk and the required level of confidentiality.

For accounting educators and researchers, the study points to a changing skill set. Environmental accountants increasingly need to understand data provenance, platform governance, smart-contract logic, and digital assurance in addition to conventional measurement and reporting rules. Auditors need to evaluate whether blockchain records are complete, whether off-chain data are reliable, and whether smart contracts execute according to approved policies. Finance professionals need to understand how supply-chain data affect credit risk and green-finance claims. These interdisciplinary skills are consistent with the broader movement toward digital finance and analytics, but the environmental setting makes the accountability consequences especially visible.

The paper also highlights a measurement agenda. Future researchers can use textual analysis to distinguish blockchain hype from operational adoption, identify references to environmental traceability, and classify the maturity of digital systems. They can combine annual-report data with platform data, patent data, green bond issuance, and third-party environmental databases. They can also examine whether blockchain-enabled disclosure changes investor behavior around earnings announcements, bond issuance, bank loans, or regulatory penalties. Such studies would move the field from adoption indicators toward direct evidence on market outcomes and environmental behavior.

Finally, the evidence has implications for responsible innovation. Blockchain systems consume resources, require governance, and may create privacy risks. An environmental accounting application must therefore be evaluated against its own environmental and social costs.

Firms should avoid adopting complex ledger architectures when a simpler database would solve the problem. Blockchain is most justified when multiple parties need a shared, tamper-resistant record and when no single party is fully trusted to maintain the database. This principle helps prevent technological overinvestment while preserving blockchain's value for high-risk supply-chain and financing contexts.

6. Conclusion

This paper investigates blockchain-enabled environmental accounting transparency through the joint lenses of supply chain finance, green disclosure quality, and firm heterogeneity. Using a panel framework for Chinese listed firms from 2015 to 2023, the study finds that blockchain adoption is positively associated with green disclosure quality. The association remains visible after financial and governance controls and is supported by additional mediation and threshold evidence. Supply chain finance partly explains the relationship because blockchain improves the credibility of transaction data used in receivables financing and platform-based credit assessment. Firm size and industry context condition the effect, with stronger statistical evidence in technology-intensive firms and larger marginal effects above size thresholds.

The central conclusion is that blockchain should be understood as an environmental accounting infrastructure rather than as a stand-alone disclosure label. Its value arises when distributed records connect environmental accounting evidence with supplier transactions, financing documents, internal controls, and external assurance. The findings contribute to environmental accounting by identifying a data-governance mechanism for improving disclosure credibility. They contribute to supply chain finance research by showing that financing platforms can transmit transparency benefits. They contribute to digital finance research by highlighting the importance of firm heterogeneity and organizational scale.

Practical implications follow directly from the evidence. Firms should prioritize blockchain applications that support auditable environmental records and supply-chain-finance documentation. Lenders should use blockchain-based transaction histories as part of credit assessment while requiring reliable environmental data standards. Auditors should treat blockchain records as a source of evidence but not as a substitute for verification. Regulators should promote interoperable disclosure frameworks, encourage shared platforms for smaller firms, and require clear explanation of blockchain scope and governance. These steps can reduce greenwashing risk and improve market confidence in environmental accounting information.

Future research can deepen this analysis by replacing the binary adoption proxy with implementation-intensity measures, by separating environmental disclosure from broader accounting disclosure, and by matching firm-level disclosures with physical environmental data. Scholars can also examine whether blockchain-enabled green disclosure reduces the cost of capital, improves green bond pricing, or changes supplier behavior. As environmental reporting becomes more data intensive, the integration of blockchain, supply chain finance, and accounting assurance will remain a promising field for research and practice.

A broader message is that environmental accounting is entering a stage in which data governance and financial governance are inseparable. Green claims are increasingly tied to procurement contracts, supplier finance, emissions certificates, tax incentives, subsidies, and capital-market instruments. A firm that cannot trace these connections will struggle to convince stakeholders that its disclosures are reliable. Blockchain can help build the traceability layer, while supply chain finance provides an economic reason for counterparties to maintain accurate records. The combination offers a practical route to higher transparency, especially when supported by auditing and regulation.

The article also provides a caution for empirical interpretation. Positive associations between blockchain adoption and disclosure quality should not be read as proof that blockchain automatically improves environmental performance. Disclosure quality and environmental performance are related but distinct. A firm can disclose poor environmental outcomes transparently, and this may still benefit markets by reducing uncertainty. The normative goal is not to reward blockchain labels, but to reward credible, comparable, and decision-useful information. This distinction should guide future research, investor assessment, and regulatory design.

AKNOWLEDGEMENT

The authors acknowledge the editorial template of the Journal of Environmental Accounting Green Finance and the empirical inspiration provided by prior work on blockchain, supply chain finance, and accounting disclosure. Any remaining errors are the responsibility of the authors.

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