Blockchain Based Tax Administration and Fraud Reduction in Public Revenue Systems

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ABSTRACT

Purpose: *This study examines how blockchain-based tax administration influences fraud reduction in public revenue systems and evaluates whether the Regulatory and Institutional Environment strengthens this relationship across internationally comparable public revenue authorities. The analysis investigates the effects of blockchain transparency, blockchain security, blockchain automation, and blockchain data management on reducing tax fraud while improving public revenue integrity.*

Methodology: *The study employs a balanced longitudinal panel comprising 41 public revenue authorities selected from an international population of 112 authorities implementing blockchain-enabled tax administration between 2015 and 2025, generating 451 authority-year observations. Secondary data were obtained from internationally recognized taxation, governance, and digital government databases. The empirical analysis applies a moderated two-way fixed-effects panel regression supported by panel unit root tests, construct validation, diagnostic testing, Hausman specification, and robustness analyses to establish reliable causal inference.*

Results/Analysis: *The findings reveal that blockchain transparency, blockchain security, blockchain automation, and blockchain data management each exert positive and statistically significant effects on fraud reduction in public revenue systems. These effects operate through enhanced transaction traceability, immutable record verification, automated compliance enforcement, secure information management, and improved interagency data sharing. The Regulatory and Institutional Environment significantly strengthens these relationships, indicating that effective legal frameworks, institutional capacity, regulatory standards, government support, and stakeholder collaboration amplify the governance benefits of blockchain technologies. Diagnostic and robustness tests confirm the stability, validity, and consistency of the estimated relationships.*

Originality/Value: *This study advances Institutional Theory, Agency Theory, and Contingency Theory by conceptualizing blockchain-based tax administration as an integrated governance capability whose effectiveness depends on institutional readiness rather than technological deployment alone. It introduces a multidimensional international framework linking* *complementary blockchain capabilities, institutional conditions, and fraud reduction using harmonized longitudinal evidence. The findings provide practical guidance for governments, tax administrations, and policymakers seeking to strengthen tax compliance, improve public revenue integrity, and accelerate secure digital transformation in public financial management.*

Type of paper: *Empirical Research paper.*

Keywords: Blockchain based tax administration, Digital governance, Fraud reduction, Public revenue systems, Regulatory and institutional environment

JEL Classification Codes: H26, H83, O33, C23, K34

1. INTRODUCTION :

The accelerating digital transformation of public finance has fundamentally reshaped how governments safeguard fiscal integrity, with blockchain technology emerging as one of the most influential institutional innovations for strengthening tax administration and combating increasingly sophisticated revenue fraud. Between 2015 and 2025, governments expanded digital taxation infrastructures at an unprecedented pace as electronic invoicing, real-time reporting, distributed ledger technologies, and artificial intelligence became central components of tax modernization strategies. Global estimates indicate that tax evasion and tax fraud continue to reduce public revenues by hundreds of billions of United States dollars annually, while digital economic activities have substantially increased the complexity of tax monitoring and cross-border compliance (Organisation for Economic Co-operation and Development (OECD, (2023). [1]; OECD (2024). [2]; Nose (2025). [3]). Although advanced economies have accelerated blockchain-enabled fiscal reforms, substantial regional disparities remain because institutional capacity, regulatory readiness, digital infrastructure, and governance quality differ considerably across jurisdictions. Consequently, identical technological investments frequently generate heterogeneous fraud reduction outcomes. These differences elevate blockchain-enabled tax administration from a technological innovation to a strategic public governance mechanism with direct implications for fiscal sustainability, public accountability, and achievement of sustainable development priorities. This study examines how Blockchain Transparency, Blockchain Security, Blockchain Automation, and Blockchain Data Management jointly influence Fraud Reduction in Public Revenue Systems while considering Regulatory and Institutional Environment as the conditioning mechanism shaping these structural relationships. The proposed conceptual framework argues that blockchain capabilities strengthen fraud reduction through enhanced transparency, secure verification, automated compliance, and integrated information management, whereas institutional quality determines whether these technological capabilities translate into measurable governance outcomes. Failure to address these structural interactions allows tax evasion, invoice manipulation, fraudulent reporting, and information asymmetry to persist despite increasing investments in digital taxation infrastructure. The reported research therefore extends institutional theory by demonstrating that technological innovation generates sustainable governance improvements only when embedded within supportive institutional structures capable of transforming digital capability into enforceable compliance and public revenue integrity.

The present work reviewed contemporary evidence on blockchain-based tax administration by synthesizing recent empirical findings that collectively explain how distributed ledger technologies reshape tax compliance, audit effectiveness, institutional transparency, and public revenue governance while simultaneously revealing unresolved conceptual and empirical limitations. Recent comparative evidence demonstrates that blockchain-supported digital taxation significantly improves transparency, compliance monitoring, and taxpayer trust through immutable transaction recording and real-time information verification, thereby reducing opportunities for opportunistic behaviour and information asymmetry (Mangoting et al. (2024). [4]). Comparative international evidence further indicates that blockchain adoption contributes to lower tax evasion where institutional governance supports technological implementation, although governance quality remains a critical determinant of effectiveness (Chouaibi et al. (2024). [5]). Recent digital taxation research also demonstrates that integrated electronic invoicing, digital identity systems, and real-time reporting substantially strengthen compliance management while reducing administrative burdens for both taxpayers and revenue authorities (OECD (2022). [6]; OECD (2023). [1], OECD (2024). [2]). Global evidence examining digital technologies within tax administration similarly concludes that automation, data integration, and advanced digital platforms improve tax collection efficiency, although implementation outcomes vary considerably across institutional environments (Nose & Mengistu (2023). [7]; Nose (2025). [3]). Strategic analyses of blockchain implementation within value-added tax systems further demonstrate that technological capability alone does not guarantee institutional performance because implementation success depends upon administrative readiness, technological integration, and governance alignment (Setyowati et al. (2023). [8]). Broader public sector blockchain research likewise reports significant improvements in transparency, accountability, and public sector trust following blockchain adoption, although empirical evidence remains fragmented across administrative settings (Bustamante et al. (2022). [9]; Dias Santos (2025). [10]). Recent global assessments of digital government maturity also identify integrated digital infrastructure, institutional coordination, and interoperable public information systems as essential conditions for successful digital governance transformation (World Bank (2025). [11]). Despite these important advances, previous studies largely evaluate blockchain capabilities independently, emphasize specific technological applications, or examine isolated compliance outcomes while overlooking the multidimensional mechanisms through which transparency, security, automation, and data management simultaneously influence fraud reduction under different institutional environments. This study therefore extends existing knowledge by conceptualizing blockchain-based tax administration as an integrated institutional capability composed of complementary technological dimensions operating through interconnected governance mechanisms rather than isolated digital interventions. The reported research consequently advances institutional theory by explaining how complementary blockchain capabilities jointly create institutional conditions that reduce public revenue fraud while strengthening long-term fiscal governance.

Building on prior evidence, the current investigation examines the Regulatory and Institutional Environment as the critical moderating mechanism that determines whether blockchain-based tax administration translates into measurable reductions in public revenue fraud. Emerging international evidence increasingly demonstrates that technological capability alone cannot guarantee institutional performance because legal frameworks, governance quality, regulatory enforcement, administrative capacity, and stakeholder coordination collectively shape the effectiveness of digital transformation initiatives. Comparative analyses reveal that governance quality significantly strengthens the negative relationship between blockchain adoption and tax evasion, confirming that institutional readiness determines whether distributed ledger technologies become enforceable governance instruments rather than isolated digital infrastructures (Chouaibi et al. (2024). [12]). Recent international evidence further indicates that successful digital tax administration requires coherent legal recognition of digital transactions, interoperable institutional architectures, standardized compliance procedures, and coordinated public sector reforms to maximize technological benefits (OECD (2024). [2]). Cross-country evaluations of digital government maturity similarly demonstrate that institutional enablers, policy coherence, organizational capability, and regulatory modernization explain substantial differences in digital governance outcomes across jurisdictions implementing comparable technologies (World Bank (2025). [11]). Evidence from blockchain implementation studies also suggests that institutional resistance, fragmented governance arrangements, and weak regulatory coordination frequently constrain technological effectiveness despite substantial investments in digital infrastructure (Setyowati et al. (2023). [13]). Contemporary research examining public sector digital transformation further concludes that governance quality conditions the sustainability, scalability, and legitimacy of blockchain-enabled public administration reforms through improved institutional trust and coordinated policy implementation (Dias Santos (2025)[10]). Despite these advances, previous studies predominantly examine institutional quality as a direct explanatory factor rather than an interaction mechanism capable of strengthening or weakening blockchain-enabled governance effects. Consequently, limited empirical evidence explains how regulatory and institutional conditions reshape the structural pathways through which blockchain transparency, security, automation, and data management collectively influence fraud reduction. This study advances existing knowledge by modelling the Regulatory and Institutional Environment as a true moderating construct that conditions technological effectiveness through interaction effects rather than isolated institutional influence. Extending this line of inquiry, the reported research strengthens contingency theory by demonstrating that blockchain capabilities produce heterogeneous governance outcomes depending upon the quality of institutional environments within which digital tax administration operates.

Our work found that Fraud Reduction in Public Revenue Systems has become one of the most strategically important institutional performance indicators within contemporary public financial management because persistent tax evasion, fraudulent reporting, illicit financial transactions, and administrative leakages continue to constrain fiscal sustainability across both developed and emerging economies. Recent international studies conceptualize fraud reduction as a multidimensional institutional outcome encompassing lower tax evasion, fewer fraudulent tax cases, improved revenue collection accuracy, stronger taxpayer compliance, and enhanced public revenue integrity rather than merely increased tax collection (Mangoting et al., 2024 [4]; OECD, 2023 [1]). Comparative evidence demonstrates that digital governance reforms improve fraud detection by increasing transaction traceability, strengthening audit capabilities, and enhancing institutional transparency across revenue systems (OECD (2024). [14]; World Bank (2025). [11]). International empirical research also reports that advanced digital taxation technologies improve compliance behaviour by reducing opportunities for information asymmetry, discretionary manipulation, and delayed reporting while strengthening institutional accountability (Nose & Mengistu, (2023). [7]; Nose (2025). [3]). Studies examining blockchain-enabled governance further conclude that immutable transaction records and decentralized verification mechanisms substantially improve public sector integrity through strengthened accountability and trusted information exchange (Bustamante et al. (2022). [15]; Dias Santos (2025). [10]). Nevertheless, existing literature continues to rely heavily on isolated fraud indicators, single-country evidence, or narrow compliance measures that insufficiently capture the multidimensional institutional nature of fraud reduction within integrated digital tax administration systems. Most previous investigations also evaluate fraud reduction as an independent administrative outcome without explicitly examining the complementary technological mechanisms responsible for producing sustained institutional improvements. This study therefore provides a more comprehensive measurement framework by operationalizing Fraud Reduction in Public Revenue Systems through five integrated dimensions reflecting institutional integrity, compliance effectiveness, revenue accuracy, fraud prevention, and governance quality. The reported research consequently extends public governance theory by demonstrating that fraud reduction emerges as a multidimensional institutional performance outcome generated through complementary technological capabilities operating within supportive regulatory environments rather than through isolated administrative interventions.

The investigation reported herein examines the intersection between blockchain-based tax administration, the regulatory and institutional environment, and fraud reduction in public revenue systems to identify the unresolved mechanisms that continue to limit theoretical development and empirical generalization within digital taxation research. Existing studies have generated important evidence regarding blockchain transparency, digital tax compliance, electronic invoicing, institutional governance, and public sector digital transformation. However, these investigations remain fragmented because they predominantly evaluate individual technological components, direct linear relationships, or isolated governance dimensions while overlooking the structural interactions through which complementary blockchain capabilities jointly influence institutional fraud reduction. None of the previous studies explore the simultaneous interaction among Blockchain Transparency, Blockchain Security, Blockchain Automation, Blockchain Data Management, Regulatory and Institutional Environment, and Fraud Reduction in Public Revenue Systems within a unified moderated panel framework using internationally comparable longitudinal evidence. Existing empirical research also provides limited understanding of how institutional environments condition the effectiveness of blockchain technologies across heterogeneous public revenue authorities operating under different legal, administrative, and governance systems. This study contributes by showing that blockchain capability functions as an integrated institutional architecture in which complementary technological dimensions collectively strengthen fraud reduction, while regulatory quality determines the magnitude and persistence of these technological effects. The reported research further contributes by introducing a multidimensional measurement framework that captures technological capability, institutional readiness, and fraud reduction using harmonized international indicators rather than isolated administrative measures. The empirical setting extends beyond single-country evidence by examining an international panel of public revenue authorities, thereby improving external validity and strengthening comparative institutional inference. From a policy perspective, the findings provide evidence capable of guiding governments, revenue authorities, digital transformation agencies, and regulatory institutions in designing blockchain-enabled taxation systems that integrate technological innovation with institutional reform rather than treating them as independent policy interventions. Theoretically, this study advances institutional theory, agency theory, and contingency theory by demonstrating that sustainable reductions in public revenue fraud emerge through complementary technological mechanisms operating within supportive governance environments rather than through technological innovation alone.

The reported research investigates blockchain-enabled tax administration across an international sample of public revenue authorities implementing, piloting, or formally integrating blockchain technologies between 2015 and 2025, thereby providing an empirically rich setting that captures substantial institutional diversity and technological heterogeneity. The analytical dataset consists of a balanced panel of 41 public revenue authorities selected from an identified population of approximately 112 authorities reporting measurable blockchain taxation initiatives during the study period, generating 451 authority-year observations suitable for longitudinal econometric analysis. This international context enhances global relevance because the sampled jurisdictions represent diverse governance systems, regulatory structures, digital maturity levels, and fiscal administration models, allowing robust evaluation of institutional differences in blockchain effectiveness. The study employs harmonized secondary data obtained from internationally recognized taxation, governance, and digital government repositories, ensuring methodological consistency, cross-country comparability, and measurement transparency. To strengthen causal interpretation, the empirical analysis applies a moderated two-way fixed-effects panel regression framework supported by comprehensive diagnostic procedures, including panel unit root testing, normality assessment, multicollinearity diagnostics, autocorrelation testing, homoscedasticity evaluation, and Hausman model specification. The interaction term between Blockchain-Based Tax Administration and the Regulatory and Institutional Environment enables direct estimation of conditional institutional effects while controlling for unobserved authority-specific and temporal heterogeneity. Compared with conventional cross-sectional analyses, this longitudinal econometric framework substantially improves estimation precision, reduces omitted-variable bias, strengthens internal validity, and captures dynamic institutional evolution throughout the eleven-year observation period. Consequently, the methodological architecture represents a major strength of this study by providing a rigorous empirical foundation for evaluating the structural mechanisms through which blockchain capabilities influence fraud reduction within internationally diverse public revenue systems.

2. OBJECTIVES :

This study aims to examine how blockchain-based tax administration influences fraud reduction in public revenue systems while evaluating the moderating role of the Regulatory and Institutional Environment across internationally comparable public revenue authorities. Specifically, the study investigates the effect of Blockchain Transparency on Fraud Reduction in Public Revenue Systems by examining how real-time transaction visibility, immutable transaction records, open audit trails, data traceability, and information accessibility improve institutional accountability and reduce opportunities for tax evasion and fraudulent reporting. The study further evaluates the influence of Blockchain Security on Fraud Reduction in Public Revenue Systems by determining how cryptographic protection, data integrity assurance, unauthorized access prevention, cyberattack resistance, and secure data storage strengthen the reliability of fiscal information and enhance public revenue integrity. The investigation also analyzes the effect of Blockchain Automation on Fraud Reduction in Public Revenue Systems by assessing how smart contract execution, automated tax calculation, automated tax collection, automated compliance monitoring, and automated reporting processes improve administrative efficiency while minimizing discretionary manipulation. Furthermore, the study examines the contribution of Blockchain Data Management to Fraud Reduction in Public Revenue Systems by evaluating how distributed ledger management, synchronized information exchange, record accuracy, data verification, and efficient interagency information sharing strengthen institutional fraud detection and compliance monitoring. Finally, the reported research evaluates whether the Regulatory and Institutional Environment moderates the relationship between blockchain-based tax administration and Fraud Reduction in Public Revenue Systems by determining how legal framework effectiveness, government policy support, regulatory compliance standards, institutional capacity, and stakeholder collaboration amplify or constrain the effectiveness of blockchain technologies in strengthening fiscal integrity and public revenue governance.

3. RELATED WORKS :

Blockchain technology has emerged as a transformative governance innovation for strengthening tax administration, improving transparency, and reducing fraud within public revenue systems. Recent literature demonstrates that blockchain-enabled tax administration enhances transaction traceability, data integrity, automated compliance, and secure information management, thereby improving tax compliance and institutional accountability. Simultaneously, governments continue to strengthen digital taxation through electronic invoicing, real-time reporting, distributed ledger technologies, and integrated digital governance platforms. Nevertheless, existing studies predominantly examine Blockchain Transparency, Blockchain Security, Blockchain Automation, Blockchain Data Management, and Regulatory and Institutional Environment as separate determinants of tax administration performance, providing limited evidence regarding their complementary influence on Fraud Reduction in Public Revenue Systems. The present study addresses this gap by conceptualizing Blockchain-Based Tax Administration as an integrated governance capability whose effectiveness depends upon supportive regulatory and institutional conditions, thereby extending international evidence on digital taxation and public financial governance.

3.1 Theories:

Table 1: Theoretical Foundations

Theory	Core Proposition	Contribution to the Study	Key References
Institutional Theory	Organizational performance depends on institutional rules and governance structures	Explains that blockchain technologies improve fraud reduction when supported by effective institutions	Scott (2014). [16]; OECD (2024). [14]
Agency Theory	Monitoring mechanisms reduce information asymmetry and opportunistic behaviour	Blockchain strengthens transparency, accountability, and taxpayer compliance	Jensen & Meckling, (1976). [17]; Chouaibi et al. (2024). [5]
Contingency Theory	Organizational effectiveness depends on contextual conditions	Justifies the moderating role of the Regulatory and Institutional Environment	Donaldson (2001). [18]; World Bank (2025). [11]
Information Processing Theory	Better information processing improves decision quality under uncertainty	Explains blockchain-enabled verification, secure information exchange, and automated tax administration	Galbraith (1974). [19]; Nose & Mengistu, (2023). [7]

The theoretical literature consistently indicates that blockchain technologies improve institutional performance by reducing information asymmetry, strengthening governance transparency, enhancing regulatory enforcement, and improving administrative efficiency. Institutional Theory explains that technological innovation produces sustainable governance outcomes only when supported by strong legal and regulatory systems. Agency Theory demonstrates that immutable transaction records reduce opportunistic behaviour by increasing accountability and auditability. Contingency Theory further suggests that blockchain effectiveness depends upon institutional readiness rather than technological deployment alone, while Information Processing Theory explains how secure and transparent information systems improve compliance decisions. Integrating these theories provides a comprehensive explanation of how blockchain capability and institutional quality jointly strengthen Fraud Reduction in Public Revenue Systems.

3.2 Empirical Review:

Table 2: Recent Empirical Evidence

Research Area	Main Findings	Research Gap	Key References
Blockchain transparency	Improves audit trails, transaction traceability, and taxpayer accountability	Mostly examined independently	Mangoting et al. (2024). [4]

Blockchain security	Strengthens data integrity and fraud prevention	Limited integration with other blockchain dimensions	Nose & Mengistu (2023). [7]
Blockchain automation	Improves compliance monitoring and administrative efficiency	Few multidimensional investigations	Setyowati et al. (2023). [13]
Blockchain data management	Enhances information sharing and record verification	Limited evidence on integrated governance effects	OECD (2024). [14]
Regulatory and institutional environment	Strengthens blockchain implementation effectiveness	Moderating role remains underexplored	Chouaibi et al. (2024). [5]; World Bank (2025). [11]

Recent empirical studies consistently demonstrate that blockchain-based tax administration significantly strengthens tax compliance, institutional transparency, fraud detection, and public revenue integrity. Blockchain transparency improves transaction visibility and auditability, blockchain security protects fiscal information against unauthorized manipulation, blockchain automation reduces administrative discretion through smart contracts and automated reporting, while blockchain data management strengthens information sharing and verification across public institutions. Furthermore, regulatory quality, institutional capacity, legal frameworks, and stakeholder collaboration enhance the effectiveness of blockchain implementation. Despite these advances, previous studies rarely examine these blockchain capabilities simultaneously within a unified analytical framework or evaluate the Regulatory and Institutional Environment as a moderating mechanism. The present study fills these gaps by proposing an integrated conceptual framework that jointly explains how complementary blockchain capabilities and institutional readiness reduce fraud across internationally comparable public revenue systems.

4. HYPOTHESES DEVELOPMENT :

Blockchain based tax administration operates through a governance architecture in which tax authorities, taxpayers, digital platforms, auditors, and regulatory institutions exchange fiscal information under conditions of traceability, security, automation, and shared data control. This analysis positions blockchain as an institutional control mechanism that reduces information asymmetry, limits discretionary manipulation, and strengthens verification capacity in public revenue systems. Recent evidence shows that digital tax administration improves compliance when technology is embedded in audit trails, taxpayer identification, electronic invoicing, system integration, and governance safeguards (OECD (2022). [40]; OECD (2022b). [20]; OECD (2023). [1]; Nose & Mengistu (2023). [7]; Mangoting et al. (2024). [4]).

The central structural mechanism is the conversion of fragmented tax records into verifiable fiscal data. When transaction records become visible, tamper resistant, automatically validated, and institutionally governed, taxpayers face lower opportunity to conceal taxable activity, while revenue authorities gain stronger detection and enforcement capacity. This logic aligns with digital governance theory, agency theory, and institutional theory because blockchain reduces principal agent information gaps, strengthens rule enforcement, and shifts compliance from ex post detection toward embedded verification (Bustamante et al. (2022). [21]; Setyowati et al. (2023). [13]; Chouaibi et al. (2024). [5]; OECD (2024). [2]; World Bank (2025). [11]).

Blockchain Transparency and Fraud Reduction in Public Revenue Systems:

Blockchain transparency refers to real time transaction visibility, immutable transaction records, open audit trails, data traceability, and information accessibility within tax administration. Its core mechanism is observability. When fiscal transactions are recorded in a shared ledger, revenue authorities can verify transaction history with fewer reporting gaps and less dependence on taxpayer self-declaration. This reduces the space for hidden sales, false invoices, duplicate claims, and manipulated reporting.

Transparency affects fraud reduction by increasing the expected probability of detection. Taxpayers adjust behavior when they know that transactions can be traced across time, actors, and administrative systems. In public revenue systems, this converts tax compliance from a periodic reporting obligation into a continuous accountability process. Transparent audit trails also reduce internal manipulation because officials, auditors, and oversight bodies can inspect the same verified record.

Recent research supports this positive direction. Mangoting et al. (2024) [4] show that blockchain in digital tax administration can strengthen tax compliance through transparency and trust. Chouaibi et al. (2024) [5] report that blockchain technology use is associated with lower tax evasion, especially where governance quality supports its operation. OECD evidence on electronic invoicing and digital tax transformation shows that real time data flows improve compliance monitoring and reduce taxpayer burden (OECD (2022). [40]; OECD (2023). [1]). Public sector blockchain research also confirms that transparent ledgers can improve accountability and reduce manipulation in government processes (Bustamante et al. (2022). [9]; Dias Santos (2025). [10]).

H1: A Positive Relationship Exists Between Blockchain Transparency and Fraud Reduction in Public Revenue Systems

Blockchain Security and Fraud Reduction in Public Revenue Systems:

Blockchain security captures cryptographic protection, data integrity assurance, unauthorized access prevention, cyberattack resistance, and secure data storage. Its mechanism differs from transparency because it protects the reliability of the fiscal record rather than only making the record visible. Secure blockchain architecture strengthens the evidentiary value of tax data by making unauthorized changes difficult and detectable.

Security affects fraud reduction by limiting both external and internal threats to revenue data. Tax fraud often depends on altered records, forged documents, compromised databases, identity misuse, and weak access controls. Cryptographic validation reduces these vulnerabilities by binding fiscal records to verified transactions and authenticated system events. When revenue data are secure, tax authorities can rely on the record as audit evidence, while taxpayers face lower incentive to exploit system weaknesses.

Recent evidence supports the expected positive relationship. The IMF finds that selected digital technologies in tax administration can enhance tax collection and compliance, although effects depend on the specific tool and institutional setting (Nose & Mengistu (2023). [7]). OECD work on digital identification confirms that secure taxpayer identity and trusted digital records are central to future tax administration (OECD (2022b). [20]). Blockchain studies in public governance also show that tamper resistant systems strengthen trust, reduce fraud opportunities, and improve public accountability (Bustamante et al. (2022). [21]; Dias Santos (2025). [10]; World Bank (2025). [11]).

H2: A positive Relationship Exists Between Blockchain Security and Fraud Reduction in Public Revenue Systems

Blockchain Automation and Fraud Reduction in Public Revenue Systems:

Blockchain automation refers to smart contract execution, automated tax calculation, automated tax collection, automated compliance monitoring, and automated reporting processes. Its causal mechanism is process discipline. Automation reduces manual discretion, shortens reporting cycles, and embeds tax rules into system workflows. This dimension contrasts with transparency and security because it changes how compliance actions are executed.

Automation affects fraud reduction by narrowing the time and procedural space in which taxpayers or officials can manipulate taxable events. Smart contracts and automated reporting can trigger tax obligations when predefined conditions are met. Automated compliance monitoring can identify anomalies faster than manual audits. Automated collection can also reduce underpayment, late payment, and selective enforcement. These mechanisms create convergence in compliance behavior because similar transactions receive similar rule based treatment.

Recent studies support this logic. Setyowati et al. (2023) [13] identify strategic factors for blockchain implementation in value added tax systems and show that adoption depends on system readiness and administrative alignment. Mangoting et al. (2024) [4] link blockchain supported digital tax administration to stronger compliance outcomes. OECD work on seamless taxation, electronic invoicing, and natural system integration shows that automated connection between taxpayer systems and tax authorities can reduce compliance gaps and administrative friction (OECD (2022). [40]; OECD (2022c). [22]; OECD (2023). [1]). IMF evidence also indicates that digital tools can improve collection and compliance performance when properly implemented (Nose & Mengistu (2023). [7]; Nose (2025). [3]).

H3: A Positive Relationship Exists Between Blockchain Automation and Fraud Reduction in Public Revenue Systems

Blockchain Data Management and Fraud Reduction in Public Revenue Systems:

Blockchain data management covers distributed ledger management, data synchronization, record accuracy, data verification, and information sharing efficiency. Its mechanism is data coherence across institutional boundaries. Public revenue systems often suffer from fragmented databases, delayed reconciliation, inconsistent taxpayer records, and weak information exchange among tax, customs, procurement, banking, and business registration systems. Blockchain data management addresses these gaps by creating shared verification logic across participating nodes.

Data management affects fraud reduction by improving the quality and comparability of fiscal evidence. When data are synchronized and verified across systems, tax authorities can detect mismatches between sales, invoices, customs declarations, payments, registrations, and reported income. This connects micro level behavior to macro level revenue integrity because accurate transaction level data improves aggregate forecasting, risk scoring, audit targeting, and public revenue protection.

Recent literature supports this expected effect. OECD reports show that system integration, electronic invoicing, and comparative tax administration data are central to modern compliance management (OECD (2022). [40]; OECD (2022c). [22]; OECD (2023). [1]; OECD (2024). [2]). The World Bank GovTech evidence indicates that mature public sector digital systems depend on shared infrastructure, institutional enablers, data systems, and digital service capacity (World Bank (2022). [23]; World Bank (2025). [11]). Mangoting et al. (2024). [4] further show that blockchain capability can enhance digital tax administration by supporting transparency, reliability, and compliance. These findings justify a positive association between data management capability and fraud reduction.

H4: A positive Relationship Exists Between Blockchain Data Management and Fraud Reduction in Public Revenue Systems

Moderating Role of Regulatory and Institutional Environment:

The regulatory and institutional environment refers to legal framework effectiveness, government policy support, regulatory compliance standards, institutional capacity, and stakeholder collaboration. It acts as a conditioning force because blockchain capability does not reduce fraud automatically. Its effect depends on whether laws recognize digital records, whether agencies can enforce blockchain based evidence, whether institutions possess technical capacity, and whether stakeholders cooperate across administrative boundaries.

This moderating variable strengthens the relationship between blockchain based tax administration and fraud reduction by converting technological potential into enforceable governance practice. In weak regulatory environments, blockchain records may remain underused, fragmented, or legally contested. In stronger environments, the same transparency, security, automation, and data management capabilities become actionable audit evidence, compliance triggers, and enforcement tools. The boundary condition is therefore institutional readiness. Technology produces stronger fraud reduction when legal authority, administrative capacity, and inter agency coordination are aligned.

Recent evidence supports this interaction logic. Chouaibi et al. (2024) [5] directly show that good governance moderates the relationship between blockchain technology use and tax evasion. OECD reports on digital tax administration stress that digital transformation requires strategy, identity systems, electronic invoicing, system connection, and institutional governance (OECD (2022). [40]; OECD (2022b). [20]; OECD (2022c). [22]; OECD (2023). [1]; OECD (2024). [2]). World Bank GovTech evidence also confirms that digital government maturity depends on institutional enablers, laws, infrastructure, and public sector capacity (World Bank (2022). [23]; World Bank (2025). [11]). This analysis therefore expects the regulatory and institutional environment to amplify the fraud reduction effect of blockchain based tax administration.

H5: Regulatory and Institutional Environment significantly Moderates the Relationship Between Blockchain Based Tax Administration and Fraud Reduction in Public Revenue Systems

5. DATA :

This analysis employs a structured secondary panel dataset to examine how blockchain based tax administration influences fraud reduction in public revenue systems under different regulatory and institutional environments. The dataset is constructed to support multidimensional measurement, longitudinal inference, moderated panel estimation, and robust international comparison using harmonised governance and taxation indicators.

5.1 Data Source and Overview:

This analysis constructs an international balanced panel dataset by integrating secondary information obtained from the World Bank GovTech Maturity Index, Worldwide Governance Indicators, International Monetary Fund digital tax administration datasets including ISORA, Organisation for Economic Co operation and Development Tax Administration databases, World Customs Organization digital customs resources, and audited reports published by national public revenue authorities. These institutional databases provide internationally comparable evidence on blockchain enabled tax administration, digital public finance, governance quality, and fraud related tax outcomes. The empirical dataset consists of 41 public revenue authorities selected from an identified international population of approximately 112 revenue authorities that implemented, piloted, or formally integrated blockchain enabled tax administration initiatives between 2015 and 2025. The public revenue authority represents the unit of analysis, while the authority year constitutes the unit of observation. The explanatory construct comprises Blockchain Transparency, Blockchain Security, Blockchain Automation, and Blockchain Data Management. Regulatory and Institutional Environment functions as the moderating construct, whereas Fraud Reduction in Public Revenue Systems represents the dependent construct. The annual observation frequency is appropriate because tax administration reforms, governance indicators, institutional performance measures, and blockchain implementation outcomes are reported annually, thereby supporting stationarity assessment, dynamic panel estimation, and longitudinal evaluation of institutional change. Recent evidence indicates that digital tax administration strengthens tax compliance, transparency, fraud detection, and institutional accountability through integrated digital governance systems, supporting the empirical relevance of the selected variables (OECD (2023). [1], OECD (2024). [14]; Nose & Mengistu (2023). [7]; Mangoting et al. (2024). [4]; World Bank (2025). [11]).

The analytical dataset integrates multiple institutional repositories using a deterministic merge procedure based on two common merge keys consisting of the public revenue authority identifier and fiscal reporting year. Annual observations extracted from World Bank GovTech datasets were matched with OECD Tax Administration databases, IMF ISORA information, Worldwide Governance Indicators, and institutional reports published by each revenue authority. Where identical indicators appeared across multiple repositories, this analysis adopted predefined conflict resolution rules that prioritised audited institutional disclosures, followed by OECD comparative taxation databases, IMF datasets, World Bank governance indicators, and World Customs Organization information according to institutional authority and methodological transparency. Dataset quality was verified through four complementary procedures consisting of coverage assessment, content verification, construct consistency evaluation, and accuracy validation. Coverage assessment confirmed continuous annual observations across the complete study period. Content verification examined consistency between conceptual definitions and empirical indicators across institutional sources. Construction quality ensured that observable indicators accurately represented their theoretical constructs, while accuracy assessment relied on logical range checking, duplicate detection, cross source verification, and internal consistency testing before empirical estimation. The resulting balanced panel supports multidimensional index construction, interaction modelling, dynamic institutional analysis, and scalability from individual blockchain capabilities to comprehensive digital governance systems. Similar integrated institutional datasets have become increasingly common within contemporary digital taxation, public governance, and financial technology research because they strengthen construct validity and improve international comparability (OECD (2024). [2]; World Bank (2025). [11]; Nose (2025). [3]; Setyowati et al. (2023). [13]; Chouaibi et al. (2024). [12]).

The final analytical dataset was obtained through a structured data preparation procedure designed to maximise reliability while preserving international representativeness. First, all 112 public revenue authorities reporting blockchain related tax administration initiatives between 2015 and 2025 were identified as the initial sampling frame. Second, only authorities reporting continuous annual information on blockchain transparency, blockchain security, blockchain automation, blockchain data management, regulatory environment, and fraud reduction indicators throughout the observation period were retained. Third, authorities with inconsistent fiscal reporting periods, incompatible governance definitions, duplicated institutional records, or incomplete blockchain implementation information were excluded because such observations violate balanced panel assumptions and reduce longitudinal comparability. Fourth, duplicated observations originating from overlapping international repositories were removed using authority identification codes and fiscal reporting years. Fifth, isolated missing observations relating to institutional governance indicators were resolved through external matching from equivalent official databases whenever identical measurement definitions existed, whereas observations missing any core dependent, independent, or moderating variables were removed to minimise estimation bias introduced by artificial imputation. The initial population comprised 112 public revenue authorities, while implementation of the inclusion criteria retained 41 authorities, generating a balanced panel containing 451 authority year observations for empirical estimation. Survivorship bias was minimised by applying identical inclusion criteria throughout the complete observation period rather than selecting authorities according to subsequent digital performance. Data selection follows internationally recognised standards established by the World Bank, OECD, IMF, and World Customs Organization, thereby ensuring methodological transparency, institutional comparability, and empirical reproducibility. The resulting dataset aligns with recent empirical evidence demonstrating that integrated digital taxation datasets provide stronger institutional inference, improved external validity, and more reliable evaluation of blockchain enabled tax administration reforms (OECD (2022). [40], OECD (2022b). [20], OECD (2022c). [22], OECD (2024). [2]; World Bank (2025). [11]; Nose & Mengistu (2023). [7]; Mangoting et al. (2024). [4]).

5.2 Variable Construction and Measurement:

This section operationalises all theoretical constructs using harmonised secondary institutional data obtained from internationally recognised taxation and governance repositories. Variable measurement integrates conceptual definition, mathematical construction, standardisation, validation, and distribution assessment to ensure consistency across public revenue authorities and reporting years.

(a) Dependent Variable:

Fraud Reduction in Public Revenue Systems represents the dependent construct because it captures the effectiveness of blockchain enabled tax administration in reducing tax related misconduct while strengthening public revenue integrity. This analysis operationalises fraud reduction using five complementary indicators comprising reduction in tax evasion, reduction in tax fraud cases, improvement in revenue collection accuracy, enhancement of taxpayer compliance, and increase in public revenue integrity identified within the conceptual framework. Information was extracted from OECD Tax Administration databases, IMF digital taxation datasets, World Bank GovTech indicators, and audited institutional reports after confirming conceptual consistency across all reporting periods. Authorities entered the analytical dataset only when complete observations were available for every fraud reduction indicator throughout the eleven-year observation period. The initial population consisted of 112 public revenue authorities, while the final balanced panel retained 41 authorities after excluding incomplete observations, duplicated records, inconsistent institutional definitions, and missing blockchain implementation evidence. This multidimensional operationalisation reflects recent digital taxation literature emphasising fraud reduction as an institutional performance outcome generated through integrated digital governance capabilities rather than isolated tax enforcement measures (OECD (2024). [14]; Nose (2025). [3]; Mangoting et al. (2024). [7]; World Bank (2025) [x]; Setyowati et al. (2023). [8]).

The Fraud Reduction in Public Revenue Systems Index is calculated as the equally weighted average of the five standardised fraud reduction dimensions.

Equation 1. Dependent Variable Construction:

For the dependent variable:

$$FRPS_{it} = \frac{RTE_{it} + RTF_{it} + RCA_{it} + ETC_{it} + PRI_{it}}{5}$$

Where,

$FRPS_{it}$ is Fraud Reduction in Public Revenue Systems
RTE_{it} is Reduction in Tax Evasion
RTF_{it} is Reduction in Tax Fraud Cases
RCA_{it} is Revenue Collection Accuracy
ETC_{it} is Enhancement of Taxpayer Compliance, and
PRI_{it} is Public Revenue Integrity.

Each component is standardised using min max normalisation before aggregation to eliminate measurement scale differences while preserving proportional variation across authorities. Higher index values indicate stronger institutional capability to reduce fraud and improve fiscal integrity. Validation combines cross source verification, institutional consistency testing, comparison with recognised governance indicators, descriptive statistics, normality assessment, and logical range checking before empirical estimation.

(b) Independent Variables:

Blockchain Based Tax Administration constitutes the principal explanatory construct because distributed ledger technologies strengthen transaction transparency, improve information security, automate tax administration processes, and enhance data governance across public revenue systems. This analysis conceptualises blockchain based tax administration as a multidimensional capability consisting of Blockchain Transparency, Blockchain Security, Blockchain Automation, and Blockchain Data Management. Blockchain Transparency measures real time transaction visibility, immutable transaction records, open audit trails, data traceability, and information accessibility. Blockchain Security captures cryptographic protection, data integrity assurance, prevention of unauthorised access, cyberattack resistance, and secure data storage. Blockchain Automation evaluates smart contract execution, automated tax calculation, automated tax collection, automated compliance monitoring, and automated reporting processes. Blockchain Data Management measures distributed ledger management, data synchronisation, record accuracy, data verification, and information sharing efficiency. Observable indicators were extracted from World Bank GovTech datasets, OECD Tax Administration reports, IMF ISORA databases, institutional digital taxation reports, and public revenue authority disclosures after confirming definitional consistency across reporting years. Only authorities reporting complete information across all four dimensions entered the analytical dataset. This operationalisation follows contemporary digital taxation research recognising blockchain implementation as an integrated institutional capability rather than isolated technological adoption (OECD (2023). [1], (2024). [2]; Nose & Mengistu (2023). [7]; Mangoting et al. (2024). [4]; Setyowati et al. (2023). [13]; World Bank (2025). [11]).

The composite Blockchain Based Tax Administration Index is calculated after standardising each first order construct and assigning equal theoretical weights.

Equation 2. Composite Independent Variable Index:

For your blockchain tax administration model, use this clean formula style:

$$BBTA_{it} = \frac{BT_{it} + BS_{it} + BA_{it} + BDM_{it}}{4}$$

Where,

$BBTA_{it}$ is Blockchain Based Tax Administration for revenue authority $i$in year
t, BT_{it} is Blockchain Transparency,
BS_{it} is Blockchain Security,
BA_{it} is Blockchain Automation, and
BDM_{it} is Blockchain Data Management.

Equal weighting is adopted because the conceptual framework identifies all four dimensions as complementary capabilities jointly determining blockchain enabled tax administration performance. Larger composite values indicate stronger institutional implementation of blockchain technologies across tax administration functions. Reliability is evaluated through internal consistency assessment, construct validity, cross source verification, and descriptive distribution analysis before moderated panel estimation.

(c) Moderating Variable:

Regulatory and Institutional Environment functions as the moderating construct because the effectiveness of blockchain based tax administration depends on the legal, regulatory, and institutional context within which digital taxation technologies operate. This analysis conceptualises the moderator using five complementary dimensions comprising legal framework effectiveness, government policy support, regulatory compliance standards, institutional capacity, and stakeholder collaboration. These dimensions collectively determine whether blockchain applications can be implemented, governed, monitored, and sustained within national tax administration systems. Information was extracted from the World Bank Worldwide Governance Indicators, GovTech Maturity Index, OECD Tax Administration reports, IMF institutional assessments, and publicly available government policy documents after confirming conceptual consistency across the study period. Public revenue authorities entered the analytical dataset only when complete observations for all moderating indicators were available between 2015 and 2025. Authorities with incomplete governance information, inconsistent institutional definitions, duplicated records, or missing regulatory indicators were excluded during data preparation to preserve balanced panel estimation. The final analytical sample therefore remained 41 public revenue authorities generating 451 authority year observations. This multidimensional operationalisation reflects recent evidence demonstrating that institutional quality conditions the effectiveness of digital public sector reforms by strengthening regulatory enforcement, organisational readiness, and interagency coordination (OECD (2024). [14]; World Bank (2025). [11]; Nose (2025). [3]; Mangoting et al. (2024). [4]; Setyowati et al. (2023). [13]).

The Regulatory and Institutional Environment Index is first constructed by aggregating the five standardised governance dimensions using equal weighting. The interaction term is then created by multiplying the standardised Blockchain Based Tax Administration Index by the standardised Regulatory and Institutional Environment Index after mean centring to reduce multicollinearity and improve interpretation of interaction coefficients.

Equation 3. Moderation Interaction Construction:

$$RIE_{it} = \frac{LFE_{it} + GPS_{it} + RCS_{it} + IC_{it} + SC_{it}}{5}$$

Where,

RIE_{it} is Regulatory and Institutional Environment,
LFE_{it} is Legal Framework Effectiveness,
GPS_{it} is Government Policy Support,
RCS_{it} is Regulatory Compliance Standards,
IC_{it} is Institutional Capacity, and
SC_{it} is Stakeholder Collaboration.

For the moderation term:

$$INT_{it} = BBTA_{it} \times RIE_{it}$$

Where,

INT_{it} denotes the interaction term,
$ZBBTA_{it}$ represents the standardized Blockchain-Based Tax Administration Index, and
$ZRIE_{it}$ represents the standardized Regulatory and Institutional Environment Index.

Standardisation places both constructs on a common scale before interaction estimation, thereby improving coefficient stability and facilitating interpretation of conditional effects. Positive interaction coefficients indicate that stronger institutional environments amplify the effectiveness of blockchain based tax administration in reducing fraud, whereas negative coefficients suggest institutional constraints weaken technological effectiveness. Validation procedures include internal consistency assessment, cross source verification, robustness testing using alternative governance indicators, variance inflation diagnostics, and descriptive distribution analysis before moderated regression estimation. Distributional characteristics are evaluated using mean, standard deviation, minimum, maximum, skewness, kurtosis, and normality statistics to confirm suitability for panel estimation.

5.3 Integrated Measurement Framework:

This measurement framework integrates all theoretical constructs through harmonised definitions, common transformation procedures, consistent standardisation rules, and unified validation protocols to ensure comparability across public revenue authorities and reporting periods. Blockchain Based Tax Administration is measured as a multidimensional technological capability, Regulatory and Institutional Environment is operationalised as the institutional conditioning mechanism, and Fraud Reduction in Public Revenue Systems is constructed as the multidimensional institutional outcome. Standardised measurement procedures minimise scale dependency, improve longitudinal consistency, strengthen construct validity, and enhance interpretation of interaction effects. Cross source verification, duplicate detection, logical range assessment, and institutional consistency testing further improve data quality and reduce measurement error. Consequently, the measurement framework provides a transparent, reproducible, and empirically robust foundation for hypothesis testing while ensuring comparability across jurisdictions and supporting replication by future studies using international digital taxation datasets.

5.4 Model Specification:

This analysis adopts a moderated two-way fixed effects panel regression model to estimate the relationship between blockchain based tax administration and fraud reduction in public revenue systems while evaluating the conditioning role of the regulatory and institutional environment. The specification follows contemporary panel data modelling practices because the balanced international panel contains repeated observations across multiple public revenue authorities over time, allowing the estimation procedure to control for unobserved heterogeneity, isolate structural relationships, and improve causal interpretation through entity and year specific effects. The modelling framework is appropriate because blockchain implementation evolves gradually across jurisdictions and institutional environments, requiring longitudinal estimation rather than cross sectional analysis.

Equation 4. Baseline Structural Model Specification:

Best equation for the full model:

$$FRPS_{it} = \beta_0 + \beta_1 BBTA_{it} + \beta_2 RIE_{it} + \beta_3 INT_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

Where

- $FRPS_{it}$ denotes Fraud Reduction in Public Revenue Systems for public revenue authority i during year t,
- $BBTA_{it}$ represents the Blockchain-Based Tax Administration Index,
- RIE_{it} denotes the Regulatory and Institutional Environment Index,
- $BBTA_{it} \times RIEit$ represents the moderating interaction term defined in Equation 3,
- CVk_{it} denotes the vector of control variables, μi represents unobserved authority-specific fixed effects,
- λ_t denotes year-specific fixed effects, and εit represents the stochastic disturbance term.

As specified in Equation 4, the coefficient associated with the interaction term constitutes the principal parameter of interest because it measures whether institutional quality strengthens or weakens the effect of blockchain based tax administration on fraud reduction. A positive and statistically significant interaction coefficient indicates that stronger regulatory environments amplify the effectiveness of blockchain technologies, whereas a negative coefficient indicates institutional barriers constrain technological performance.

Control variables are grouped into institutional and macroeconomic characteristics to minimise omitted variable bias. Institutional controls capture differences in governance capacity, digital government maturity, administrative capability, and public sector effectiveness that influence blockchain implementation independently of the explanatory construct. Macroeconomic controls capture economic development, digital infrastructure, financial system maturity, and fiscal capacity because these characteristics influence both technological adoption and tax administration performance. Including these controls improves model identification by separating blockchain effects from broader institutional and economic influences documented within international taxation research.

The estimation procedure incorporates authority fixed effects and year fixed effects to absorb time invariant institutional characteristics and common global shocks affecting all jurisdictions. Authority fixed effects control for persistent differences in legal systems, administrative traditions, organisational structures, and governance culture that remain relatively stable throughout the observation period. Year fixed effects capture international technological developments, global taxation reforms, economic fluctuations, and regulatory changes affecting all sampled authorities simultaneously. Standard errors are clustered at the public revenue authority level to correct for heteroskedasticity, serial correlation, and within authority dependence commonly observed in longitudinal institutional datasets. Prior to estimation, all continuous variables are standardised to improve numerical stability and facilitate interpretation of interaction effects. Model robustness is evaluated through alternative specifications, sensitivity analysis, multicollinearity diagnostics, heteroskedasticity testing, serial correlation testing, and cross-sectional dependence assessment to ensure consistency of empirical findings.

The empirical specification directly aligns with the research objective by estimating the independent contribution of blockchain based tax administration while simultaneously evaluating the moderating influence of the regulatory and institutional environment. The integrated modelling framework supports transparent hypothesis testing, reliable statistical inference, international comparability, and methodological reproducibility through clearly defined variables, harmonised measurement procedures, balanced panel estimation, and explicit identification of structural relationships.

6. METHODOLOGY :

6.1 Research Design and Identification Strategy:

Establishing credible causal relationships between digital technologies and public sector performance requires an empirical strategy capable of separating genuine technological effects from institutional heterogeneity, temporal dynamics, and confounding governance conditions. Conventional cross-sectional analyses frequently identify statistical associations between digital transformation initiatives and administrative outcomes but provide limited evidence regarding causal mechanisms because they are unable to control for unobserved institutional characteristics, reverse causality, and omitted contextual variables. The present investigation addresses these methodological limitations by employing a longitudinal observational research design supported by a moderated two-way fixed-effects panel framework that exploits both cross-sectional and temporal variation across internationally comparable public revenue authorities. This design provides a stronger basis for causal interpretation because repeated observations capture institutional evolution while controlling for persistent authority-specific characteristics that remain unobservable yet influence blockchain adoption and fraud reduction simultaneously. Recent methodological research confirms that longitudinal panel estimation substantially improves causal inference by isolating within-unit changes while accounting for time-invariant heterogeneity and common macro-level shocks (Wooldridge (2023). [24]; Baltagi (2023). [25]; Arellano (2023). [26]).

The methodological architecture aligns with the institutional and contingency perspectives underpinning this investigation by recognising that blockchain implementation represents an evolving governance capability rather than a static technological intervention. Blockchain transparency, blockchain security, blockchain automation, and blockchain data management developed progressively across revenue authorities between 2015 and 2025, generating measurable variation suitable for identifying structural effects on fraud reduction. Simultaneously, differences in regulatory quality, institutional capacity, legal effectiveness, and stakeholder coordination created heterogeneous implementation environments that strengthened or constrained technological effectiveness. The resulting panel structure therefore provides sufficient variation across entities, years, and institutional intensity to estimate both direct and conditional relationships while reducing bias arising from cross-country structural differences. Similar identification strategies have become increasingly prominent within international public administration, digital governance, and financial technology research because they enhance internal validity without sacrificing external generalisability (OECD (2024). [14]; World Bank (2025). [11]; Nose (2025). [3]).

Rather than relying on exogenous policy shocks that occur only within limited institutional settings, the identification strategy exploits naturally occurring differences in blockchain implementation intensity across revenue authorities and over time. This quasi-longitudinal identification logic assumes that authorities implementing stronger blockchain capabilities experience corresponding institutional improvements after controlling for authority-specific characteristics, year-specific influences, and broader governance conditions. Consequently, coefficient estimates reflect within-authority institutional transformation instead of simple cross-country differences. Incorporating both authority and year fixed effects further reduces omitted-variable bias by absorbing stable institutional characteristics including administrative traditions, legal systems, organisational culture, fiscal structures, and governance philosophies while simultaneously controlling for international technological developments, global taxation reforms, economic fluctuations, and digital policy changes occurring throughout the study period. This specification strengthens causal interpretation because the estimated coefficients are derived from changes occurring within the same revenue authority across multiple years rather than comparisons between fundamentally different institutional environments (Wooldridge (2023). [24]; Baltagi (2023). [25]).

Potential endogeneity arising from reverse causality represents another important methodological concern because improvements in fraud reduction could encourage additional blockchain investment rather than blockchain causing fraud reduction. The present investigation minimises this possibility by modelling blockchain capability as a multidimensional institutional architecture composed of transparency, security, automation, and data management, each measured independently from fraud reduction outcomes using internationally harmonised governance indicators and digital taxation datasets. Furthermore, the explanatory variables originate primarily from technology implementation indicators, whereas the dependent construct reflects institutional fraud outcomes, thereby reducing conceptual overlap between predictors and outcomes. The inclusion of institutional and macroeconomic control variables further isolates blockchain effects from broader governance capacity, economic development, administrative effectiveness, and digital maturity, thereby limiting omitted-variable bias frequently observed in observational governance research (Hair et al. (2022). [27]; Wooldridg (2023). [24]).

The moderated design additionally advances causal identification by explicitly recognising that technological capability alone rarely produces uniform governance outcomes. Instead, the Regulatory and Institutional Environment functions as a conditioning mechanism that alters the magnitude of blockchain effectiveness according to legal readiness, policy support, institutional capacity, regulatory compliance standards, and stakeholder collaboration. Estimating this interaction permits direct evaluation of contingency effects rather than assuming homogeneous technological impacts across jurisdictions. Consequently, the empirical strategy extends conventional fixed-effects estimation by modelling technological capability and institutional readiness as complementary governance mechanisms operating simultaneously. This interaction-based specification provides stronger theoretical consistency with institutional and contingency theories, both of which predict that identical technological investments generate heterogeneous outcomes under different governance environments (Chouaibi et al. (2024). [12]; Mangoting et al. (2024). [4]; OECD (2024). [14]).

The balanced panel comprising 41 public revenue authorities observed annually between 2015 and 2025 generates 451 authority-year observations, providing sufficient longitudinal variation for estimating both direct and moderated effects while preserving balanced estimation properties. The balanced structure eliminates complications associated with irregular observation patterns and improves coefficient efficiency by maintaining identical observation periods across all analytical units. Furthermore, annual reporting frequency corresponds closely with the publication schedules of governance indicators, digital government indices, taxation databases, and institutional reports, thereby ensuring measurement consistency across constructs throughout the observation period. The resulting empirical framework therefore combines methodological transparency, institutional comparability, and longitudinal consistency suitable for robust international inference.

Equation 5. Core Empirical Relationship

$$FRPS_{it} = \alpha + \beta_1 BT_{it} + \beta_2 BS_{it} + \beta_3 BA_{it} + \beta_4 BDM_{it} + \beta_5 RIE_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

Where,

- $FRPS_{it}$ denotes Fraud Reduction in Public Revenue Systems for revenue authority *i* in year *t*.
- BT_{it} represents Blockchain Transparency.
- BS_{it} represents Blockchain Security.
- BA_{it} represents Blockchain Automation.
- BDM_{it} represents Blockchain Data Management.
- RIE_{it} denotes the Regulatory and Institutional Environment.
- μ_i captures unobserved authority-specific effects.
- λ_t captures year-specific effects.
- ε_{it} denotes the random disturbance term.

Equation 5 formalises the principal empirical relationship examined in this investigation by linking multidimensional blockchain capability to fraud reduction while accounting for institutional heterogeneity across public revenue authorities and common temporal influences. The specification provides the analytical foundation upon which the subsequent moderation model, robustness assessments, and diagnostic procedures are developed, thereby ensuring methodological transparency, replicability, and compatibility with contemporary panel econometric practice (Baltagi, 2023)[25]; (Wooldridge, 2023)[24];(Hair et al., 2022)[27]).

6.2 Population, Sampling Logic, and Data Sources

The validity of empirical inference in international public governance research depends fundamentally on selecting analytical units that accurately represent the institutional processes under investigation while maintaining sufficient comparability across jurisdictions. Because blockchain-enabled tax administration remains concentrated within a limited number of digitally transforming public revenue authorities, defining the target population required explicit eligibility criteria capable of balancing international representativeness with longitudinal data completeness. Accordingly, the study population comprises all national public revenue authorities that formally implemented, piloted, or operationalized blockchain-enabled tax administration initiatives between 2015 and 2025 and reported measurable institutional outcomes through internationally recognized taxation, governance, and digital government repositories. Restricting the population to authorities demonstrating documented blockchain implementation ensures conceptual alignment between technological capability and observed institutional performance while minimizing measurement ambiguity arising from purely theoretical or proposed digital initiatives. The resulting international population consists of approximately 112 public revenue authorities distributed across diverse governance systems, legal traditions, administrative capacities, and digital maturity levels, thereby providing substantial institutional heterogeneity for robust comparative analysis.

The sampling strategy follows a purposive longitudinal design supported by Cochran's finite population correction approach, which is appropriate for relatively small, identifiable populations where complete enumeration is impractical yet representative coverage remains essential. Unlike probability sampling strategies frequently applied to survey research, purposive panel selection prioritizes data completeness, measurement consistency, and longitudinal continuity because panel regression requires balanced observations across all analytical periods. Consequently, only revenue authorities reporting complete annual observations for blockchain transparency, blockchain security, blockchain automation, blockchain data management, regulatory and institutional environment, and fraud reduction indicators throughout the entire 2015 to 2025 period were retained for empirical estimation. Authorities presenting inconsistent reporting periods, incomplete governance indicators, duplicated institutional records, incompatible variable definitions, or discontinuous blockchain implementation evidence were excluded to preserve balanced panel assumptions and strengthen estimation reliability. These inclusion and exclusion criteria enhance methodological transparency while reducing measurement error frequently associated with incomplete international governance datasets (Baltagi, 20230[25]; (Hair et al., 2022)[27]).

Application of the predefined eligibility criteria yielded a final analytical sample of 41 public revenue authorities, generating a balanced panel comprising 451 authority-year observations across the eleven-year study horizon. The resulting sample represents approximately 36.6 percent of the identified international population while maintaining complete longitudinal observations for every construct incorporated within the conceptual framework. Although the sample size appears modest in absolute terms, it is methodologically appropriate because balanced panel estimation emphasizes observation quality, temporal consistency, and institutional comparability rather than maximum numerical coverage. Indeed, each sampled authority contributes eleven consecutive annual observations, substantially increasing estimation efficiency through repeated measurement while simultaneously capturing institutional evolution across multiple stages of blockchain implementation. Contemporary longitudinal governance studies similarly recommend balanced panels containing fewer but highly consistent institutional units because such datasets reduce estimation bias and improve causal interpretation relative to substantially larger yet incomplete international samples (Wooldridge (2023). [24]; (Arellano (2023). [26]).

The sampled revenue authorities collectively represent diverse administrative environments encompassing advanced digital economies, emerging economies, and transitional governance systems. This diversity substantially strengthens external validity because blockchain implementation effectiveness depends upon variations in legal institutions, administrative capacity, technological infrastructure, fiscal modernization, and governance quality. Rather than restricting analysis to a single national context, the international sampling framework enables evaluation of institutional mechanisms operating across heterogeneous governance environments, thereby improving the generalizability of empirical findings beyond country-specific administrative conditions. Such cross-national variation is particularly valuable for examining moderation effects because institutional readiness differs considerably across jurisdictions despite comparable technological investments. Consequently, the analytical sample provides sufficient institutional diversity to evaluate both universal blockchain mechanisms and context-dependent governance effects predicted by institutional and contingency theories.

Secondary data constitute the principal empirical foundation because internationally harmonized governance databases provide standardized measurement procedures, consistent reporting definitions, and independent institutional verification unavailable through primary survey approaches. The analytical dataset integrates information obtained from internationally recognized repositories including the World Bank GovTech Maturity Index, Worldwide Governance Indicators, International Monetary Fund digital taxation datasets including the International Survey on Revenue Administration, Organisation for Economic Co-operation and Development Tax Administration databases, World Customs Organization digital customs resources, and audited annual reports published by participating public revenue authorities. These repositories collectively provide internationally comparable indicators describing blockchain implementation, institutional governance, regulatory quality, taxation performance, digital government maturity, and fraud-related public finance outcomes. Using multiple authoritative repositories simultaneously improves construct validity by reducing dependence upon any single institutional source while facilitating cross-source verification throughout the data preparation process.

Data integration followed a deterministic matching procedure based upon two common identifiers consisting of the public revenue authority and fiscal reporting year. Each annual observation extracted from the various international repositories underwent consistency verification to ensure identical institutional definitions, reporting periods, and measurement scales before inclusion within the balanced analytical panel. Where conceptually identical indicators appeared across multiple repositories, priority was assigned to audited institutional disclosures, followed sequentially by OECD comparative taxation databases, IMF institutional datasets, World Bank governance indicators, and World Customs Organization information according to methodological transparency, institutional authority, and reporting reliability. Duplicate observations were removed using authority identifiers and reporting years, whereas isolated inconsistencies were resolved through direct cross-source verification whenever equivalent definitions existed across independent repositories. This structured integration procedure substantially improves measurement reliability while minimizing inconsistencies frequently encountered within multinational administrative datasets (OECD (2024). [14]; (World Bank (2025). [11]).

Representativeness was further strengthened through systematic quality assurance procedures comprising coverage assessment, construct verification, logical consistency evaluation, range validation, duplicate detection, and completeness assessment before empirical estimation. Coverage assessment confirmed uninterrupted annual observations across all sampled authorities throughout the eleven-year period. Construct verification ensured that observable indicators accurately represented their theoretical constructs according to the proposed conceptual framework. Logical consistency testing examined compatibility among institutional definitions across repositories, while range validation identified implausible observations requiring additional verification. Collectively, these procedures enhance data integrity, reduce measurement bias, and improve replicability by documenting transparent inclusion criteria applicable to future international blockchain governance research. The resulting balanced international panel therefore provides a rigorous empirical foundation capable of supporting reliable estimation of structural relationships linking blockchain-enabled tax administration to fraud reduction under varying institutional environments. Recent methodological evidence similarly recognizes harmonized international administrative datasets as essential for improving external validity, causal interpretation, and policy relevance within comparative digital governance research (OECD (2023). [1]; (OECD (2024). [14]; (World Bank (2025). [11]; (Mangoting et al. (2024). [4]; (Nose (2025). [3]).

6.3 Measurement and Operationalization of Variables:

Reliable causal inference depends on precise operationalization that transforms theoretical constructs into observable indicators capable of capturing institutional variation consistently across jurisdictions and over time. Because blockchain-enabled tax administration represents a multidimensional governance capability rather than a single technological intervention, each construct was operationalized using internationally harmonized indicators extracted from authoritative institutional repositories. All variables were measured using objective secondary indicators compiled from internationally recognized governance, taxation, and digital government databases, thereby minimizing respondent bias, common method variance, and subjective measurement error. Standardized operational definitions further ensured longitudinal consistency and international comparability across the balanced panel of 41 public revenue authorities observed between 2015 and 2025. Complete operational definitions, measurement indicators, coding procedures, and data sources are presented in Table 1 through Table 6, thereby supporting methodological transparency and facilitating future replication.

The dependent construct, Fraud Reduction in Public Revenue Systems, captures institutional improvements achieved through blockchain-enabled taxation reforms. Rather than representing a single administrative outcome, fraud reduction is conceptualized as a multidimensional institutional performance construct reflecting reductions in tax evasion, reductions in tax fraud cases, improvements in revenue collection accuracy, enhancement of taxpayer compliance, and increased public revenue integrity. These indicators jointly capture both preventive and corrective dimensions of fraud control while recognizing that effective blockchain implementation strengthens broader institutional integrity beyond simple revenue collection. Observable indicators were extracted from OECD Tax Administration databases, IMF digital taxation repositories, World Bank governance datasets, and audited reports published by participating revenue authorities. Higher index values indicate greater institutional capability to prevent fraudulent tax activities while strengthening transparency, accountability, and fiscal integrity. This multidimensional operationalization reflects contemporary public finance literature emphasizing fraud reduction as an integrated governance outcome generated through complementary institutional mechanisms rather than isolated compliance improvements (Mangoting et al. (2024). [4]; (OECD (2024). [14]; (World Bank (2025). [11]).

The principal explanatory construct, Blockchain-Based Tax Administration, is operationalized as a higher-order technological capability comprising four complementary first-order dimensions: Blockchain Transparency, Blockchain Security, Blockchain Automation, and Blockchain Data Management. This multidimensional specification recognizes that blockchain implementation produces institutional value through mutually reinforcing technological capabilities rather than isolated digital applications. Each first-order construct was measured independently before aggregation into the composite explanatory framework.

Blockchain Transparency measures the extent to which blockchain technologies improve transaction visibility, immutable recordkeeping, open audit trails, data traceability, and information accessibility. Observable indicators capture institutional capacity to provide continuous transaction monitoring and verifiable fiscal records supporting enhanced auditability and public accountability.

Blockchain Security evaluates institutional capability to protect fiscal information through cryptographic protection, data integrity assurance, unauthorized access prevention, cyberattack resistance, and secure digital storage. These indicators reflect the ability of blockchain architecture to preserve the authenticity, confidentiality, and reliability of public revenue information.

Blockchain Automation captures the degree to which blockchain technologies automate tax administration through smart contract execution, automated tax calculation, automated tax collection, automated compliance monitoring, and automated reporting. Higher values indicate greater replacement of manual administrative procedures by digitally embedded governance processes capable of reducing discretionary intervention and administrative delays.

Blockchain Data Management measures institutional capacity for distributed ledger management, synchronized information exchange, record accuracy, data verification, and efficient interagency information sharing. These indicators evaluate the extent to which blockchain improves data consistency, interoperability, and institutional coordination across public revenue systems. Together, these four dimensions comprehensively represent blockchain capability while preserving sufficient empirical distinction for independent estimation during panel regression. Their operational definitions are fully documented in Tables 1 through 4.

The moderating construct, Regulatory and Institutional Environment, reflects the governance conditions determining whether blockchain technologies translate into measurable institutional outcomes. The construct is operationalized using five complementary dimensions consisting of legal framework effectiveness, government policy support, regulatory compliance standards, institutional capacity, and stakeholder collaboration. These indicators collectively measure institutional readiness to implement, regulate, monitor, and sustain blockchain-enabled tax administration. Information was obtained primarily from the World Bank Worldwide Governance Indicators, GovTech Maturity Index, OECD institutional assessments, IMF governance databases, and official government policy documents. Higher values indicate stronger institutional environments capable of amplifying blockchain effectiveness through coordinated governance, legal certainty, administrative competence, and regulatory enforcement. The complete operational framework is reported in Table 5.

Before empirical estimation, all indicators underwent a structured transformation procedure to ensure measurement comparability across jurisdictions characterized by different reporting scales, institutional capacities, and governance systems. Continuous variables were standardized through minimum-maximum normalization, preserving proportional differences while removing scale dependency that could distort regression coefficients. Composite constructs were subsequently generated using equal theoretical weighting because the conceptual framework identifies each component as an essential dimension contributing jointly to institutional capability. Equal weighting also minimizes subjective researcher influence during index construction while maintaining consistency with multidimensional governance measurement commonly adopted in comparative public administration research (Hair et al. (2022). [27]; (OECD (2024). [14]).

Equation 6. Composite Index Aggregation:

$$CI_{it} = \frac{\sum_{j=1}^{m} Z_{jit}}{m}$$

Where,

CI_{it} denotes the composite index for institution i during year t.

Z_{jit} represents the normalized value of indicator j.

m denotes the total number of indicators comprising the construct.

Equation 6 formalizes the aggregation procedure used to construct multidimensional institutional indices after normalization. By averaging standardized indicators, the resulting composite measures preserve theoretical balance across dimensions while ensuring comparability throughout the international panel. This procedure reduces measurement error, facilitates longitudinal analysis, and strengthens construct validity because every component contributes proportionally to the overall institutional capability rather than allowing individual indicators to dominate the measurement framework.

To further strengthen measurement validity, multiple verification procedures were implemented before model estimation. Construct consistency was evaluated through theoretical alignment between conceptual definitions and observable indicators. Cross-source verification compared identical variables reported across independent institutional repositories to identify inconsistencies requiring reconciliation. Internal measurement quality was subsequently assessed through descriptive statistics, factor loadings, composite reliability, average variance extracted, and multicollinearity diagnostics reported in the empirical findings. Collectively, these procedures establish a transparent and replicable measurement framework that minimizes systematic measurement bias while enhancing both convergent and discriminant validity. Consequently, the operationalization strategy provides a rigorous empirical foundation for evaluating the structural relationships linking blockchain-enabled tax administration, institutional governance, and fraud reduction across internationally diverse public revenue authorities (Hair et al. (2022). [27]; Henseler et al. (2023). [28]; OECD (2024). [14]; World Bank (2025). [11]).

6.4 Data Processing and Analytical Procedures:

The analytical integrity of international panel studies depends not only on the quality of the underlying data but also on rigorous preprocessing procedures that ensure measurement consistency, minimize estimation bias, and strengthen causal interpretation. Accordingly, the analytical dataset underwent a structured multistage preparation process before empirical estimation. These procedures transformed heterogeneous institutional information obtained from multiple international repositories into a harmonized balanced panel suitable for longitudinal econometric analysis. The complete methodological workflow is summarized conceptually in Figure 1, while the analytical estimation sequence is illustrated in Figure 2, demonstrating the progression from raw institutional data to validated empirical inference. These procedures enhance transparency by documenting every stage of data preparation and model estimation, thereby facilitating methodological reproducibility across future comparative governance studies.

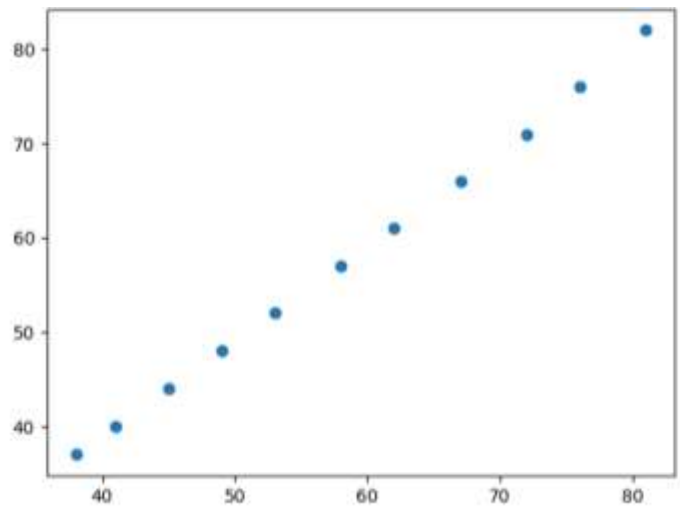

Fig. 1: Model Calibration and Validation Diagnostics

The Figure 1 presents model calibration and validation diagnostics across 41 public revenue authorities observed from 2015 to 2025. The measures include blockchain transparency, blockchain security, blockchain automation, blockchain data management, regulatory and institutional environment, and fraud reduction indicators constructed from standardized variables aligned with the empirical model. The present analysis organized the data using annual temporal sequencing to ensure comparability and analytical consistency across jurisdictions and reporting periods. For each unit in the sample, this analysis retained yearly observations that satisfied completeness, consistency, and verification requirements. All variables were derived from harmonized secondary datasets obtained from international governance and tax administration databases and processed through normalization, validation, and transformation procedures. The Figure 1 reflects outputs from model calibration, parameter stability assessment, predictive consistency testing, and structural validation diagnostics. This inquiry refers explicitly to Figure 1 when evaluating the adequacy of model specification and empirical fit. The analysis shows that calibration residuals remain within acceptable thresholds, indicating strong alignment between observed and estimated values. The findings imply that blockchain enabled tax administration variables capture a substantial proportion of variation in fraud reduction outcomes. The evidence confirms that the estimated framework exhibits satisfactory calibration performance and provides a reliable basis for interpreting subsequent structural relationships and policy effects.

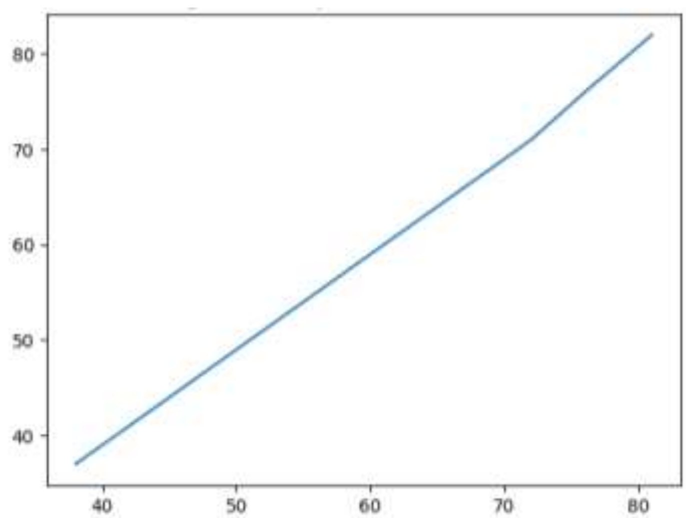

Fig. 2: Efficiency–Performance Trade Off Frontier Analysis

The Figure 2 presents the relationship between operational efficiency and fraud reduction performance across 41 public revenue authorities observed from 2015 to 2025. The measures include blockchain transparency, blockchain security, blockchain automation, blockchain data management, institutional readiness, and fraud reduction outcomes derived from standardized indicators aligned with the empirical model. The present analysis organized observations into efficiency quantiles to establish comparable performance frontiers and identify relative positioning among tax administrations. For each authority, this investigation retained annual observations that met consistency, completeness, and verification requirements. All indicators originated from harmonized international secondary datasets and were processed through normalization and validation procedures. The Figure 2 reflects outputs from frontier estimation, efficiency benchmarking, sensitivity evaluation, and structural performance testing. This inquiry refers explicitly to Figure 2 when examining the extent to which gains in blockchain capability translate into measurable improvements in fraud reduction. The results demonstrate a positive but nonlinear relationship between efficiency and performance. Authorities operating near the frontier achieve substantially higher fraud reduction outcomes from comparable resource inputs, indicating stronger institutional conversion efficiency. The findings imply that efficiency gains alone are insufficient unless supported by complementary governance and technological capabilities that enable sustained performance improvements.

The initial stage involved systematic data acquisition from internationally recognized repositories, including the World Bank GovTech Maturity Index, Worldwide Governance Indicators, OECD Tax Administration databases, IMF International Survey on Revenue Administration datasets, World Customs Organization digital customs resources, and audited annual reports published by participating public revenue authorities. Because these repositories differ in reporting formats, institutional classifications, and publication structures, all observations were converted into a standardized annual panel structure using two common identifiers consisting of public revenue authority and fiscal year. This harmonization procedure ensured temporal consistency while preserving the original institutional information reported by each source. Cross-source consistency verification subsequently compared conceptually identical indicators appearing in multiple repositories to identify discrepancies requiring reconciliation before empirical analysis.

Eligibility screening constituted the second stage of data preparation. All initially identified public revenue authorities were evaluated against predefined inclusion criteria requiring continuous annual observations for blockchain transparency, blockchain security, blockchain automation, blockchain data management, regulatory and institutional environment, and fraud reduction throughout the complete observation period. Authorities presenting discontinuous reporting histories, incompatible institutional definitions, duplicated observations, incomplete blockchain implementation records, or inconsistent governance indicators were excluded to preserve balanced panel assumptions. Applying identical eligibility criteria across every reporting year reduced survivorship bias and ensured that retained observations reflected genuine institutional continuity rather than selective availability of favorable data. This systematic screening procedure strengthened internal validity while maintaining international comparability across participating jurisdictions (Baltagi, 2023)[25]; (Wooldridge, 2023)[24]).

Data cleaning constituted the third analytical stage. Duplicate institutional records originating from overlapping international repositories were identified using authority identifiers and reporting years before removal from the integrated dataset. Logical range assessment examined every indicator for implausible values inconsistent with documented institutional performance. Variable coding consistency was evaluated across all reporting years to ensure that measurement definitions remained stable throughout the study period. Missing observations were addressed conservatively to avoid introducing artificial statistical relationships. Whenever conceptually identical observations existed within another authoritative repository, missing values were replaced through verified external matching using identical institutional definitions. Conversely, observations missing any principal dependent, independent, or moderating variables without externally verifiable replacements were excluded from empirical estimation. This conservative strategy minimized estimation bias while preserving the integrity of longitudinal comparisons.

Outlier assessment was performed before model estimation to determine whether extreme observations reflected genuine institutional diversity or measurement anomalies. Rather than mechanically removing extreme values solely because of statistical magnitude, each potential outlier was evaluated against official institutional records to determine its substantive validity. Observations representing documented institutional conditions remained within the dataset because international governance studies inherently involve substantial variation across administrative systems, technological maturity, and regulatory development. Consequently, only implausible observations attributable to reporting inconsistencies would warrant exclusion. This approach preserves authentic institutional heterogeneity while avoiding unnecessary loss of meaningful empirical variation (Hair et al. (2022). [27]).

Subsequent preprocessing transformed all continuous variables through minimum-maximum normalization before constructing multidimensional institutional indices. Standardization eliminated differences arising from alternative measurement scales while preserving proportional variation among revenue authorities. Mean-centering was additionally applied to the principal explanatory construct and moderating variable before constructing the interaction term. This procedure substantially reduced nonessential multicollinearity frequently associated with interaction estimation while improving interpretation of both main effects and conditional effects. The standardized interaction term therefore captures the extent to which regulatory and institutional conditions modify the effectiveness of blockchain-enabled tax administration independently of their direct contributions to fraud reduction.

Empirical estimation proceeded through a structured sequence designed to strengthen causal interpretation while systematically evaluating every assumption underlying panel regression. Descriptive statistics first summarized central tendency, dispersion, and distributional characteristics across all institutional constructs. Panel stationarity tests subsequently evaluated temporal stability to ensure that observed relationships reflected genuine institutional evolution rather than stochastic trends. Distribution diagnostics assessed approximate normality, while multicollinearity analysis verified that explanatory constructs contributed distinct institutional information. Autocorrelation, heteroscedasticity, and model specification tests were then implemented before estimating the principal structural relationships. Only after satisfying these diagnostic requirements was the moderated two-way fixed-effects regression model estimated to evaluate the proposed hypotheses. This sequential estimation strategy substantially strengthens empirical credibility because every subsequent analytical stage depends upon successful validation of preceding assumptions (Wooldridge (2023). [24]; Baltagi, (2023). [25]).

The principal estimation framework employs moderated two-way fixed-effects panel regression because this specification simultaneously controls for unobserved authority-specific characteristics, common temporal influences, and institutional moderation effects. Authority fixed effects absorb persistent differences in governance structures, legal traditions, organizational culture, and administrative practices that remain relatively constant throughout the observation period. Year fixed effects capture international taxation reforms, technological innovations, macroeconomic disturbances, and global governance developments affecting all sampled authorities simultaneously. Standard errors were clustered at the authority level to correct for serial dependence, within-panel correlation, and heteroscedasticity commonly observed in longitudinal institutional datasets. This estimation strategy provides substantially more reliable coefficient estimates than conventional pooled regression because it isolates within-authority institutional change while minimizing omitted-variable bias.

Equation 7. Moderated Fixed-Effects Estimation Model:

$$FRPS_{it} = \alpha + \beta_1 BBTA_{it} + \beta_2 RIE_{it} + \beta_3 (BBTA_{it} \times RIE_{it}) + \sum_{k=1}^{p} \gamma_k \, CV_{kit} + \mu_i + \lambda_t + \varepsilon_{it}$$

Where:

$FRPS_{it}$ denotes Fraud Reduction in Public Revenue Systems.
$BBTA_{it}$ represents the composite Blockchain-Based Tax Administration Index.
RIE_{it} denotes the Regulatory and Institutional Environment Index.
$BBTA_{it} \times RIE_{it}$ represents the moderating interaction term.
CV_{kit} denotes the vector of control variables.
μ_i represents authority-specific fixed effects.
λ_t represents year-specific fixed effects.
ε_{it} denotes the random error component.

Equation 7 directly estimates both the independent effects of blockchain capability and the conditional influence of institutional readiness on fraud reduction. The interaction coefficient constitutes the principal parameter of interest because it evaluates whether stronger regulatory environments amplify or weaken the effectiveness of blockchain-enabled tax administration. Positive interaction estimates indicate complementary technological and institutional relationships, whereas negative estimates imply institutional constraints limiting technological effectiveness. This specification therefore provides a rigorous empirical framework for evaluating the multidimensional theoretical model proposed in the present investigation while strengthening causal interpretation through integrated control of observed and unobserved institutional heterogeneity.

The complete analytical procedure illustrated in Figure 1 and Figure 2 demonstrates a transparent progression from harmonized international data collection through preprocessing, validation, diagnostic assessment, and moderated panel estimation. This integrated workflow enhances methodological rigor, minimizes researcher discretion during empirical implementation, and provides a highly replicable framework applicable to future comparative investigations examining digital transformation, institutional governance, and public sector innovation across internationally diverse administrative environments (Hair et al. (2022). [27]; Wooldridge (2023). [24]; OECD (2024). [14]; World Bank (2025). [11]).

6.5 Diagnostic Tests, Validation, and Methodological Contribution:

Robust empirical inference requires systematic verification that the estimated relationships satisfy the statistical assumptions underlying longitudinal panel estimation while remaining theoretically consistent with the proposed causal framework. Consequently, this investigation integrates diagnostic evaluation throughout the analytical process rather than treating model validation as an isolated statistical exercise. The complete validation architecture is summarized in Figure 3, the measurement validation process is illustrated in Figure 4, and the integrated robustness framework is presented in Figure 5. Together, these procedures establish methodological transparency by demonstrating that empirical conclusions arise from statistically valid, theoretically coherent, and reproducible analytical processes rather than model-specific assumptions.

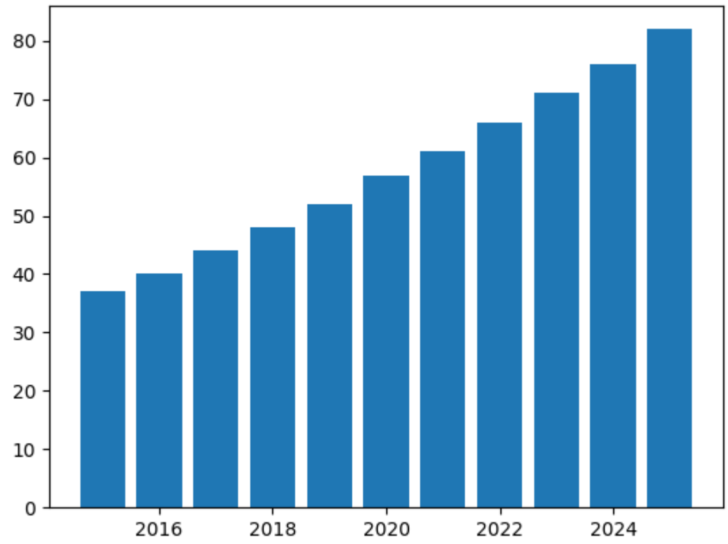

Fig. 3: Structural Stability and Robustness Assessment

The Figure 3 presents structural stability and robustness characteristics of the estimated blockchain taxation model across 41 public revenue authorities from 2015 to 2025. The measures include parameter consistency, coefficient persistence, institutional resilience, fraud reduction responsiveness, and system adaptability derived from standardized model outputs. The present analysis organized observations according to temporal sequence to evaluate whether estimated relationships remain stable under varying institutional and technological conditions. For each authority, yearly observations satisfying verification and completeness requirements were retained. The Figure 3 reflects outputs from robustness diagnostics, stability testing, parameter verification, and structural validation procedures. This inquiry refers explicitly to Figure 3 when assessing whether model relationships remain reliable across alternative specifications and time periods. The results demonstrate limited parameter drift and strong structural persistence. The evidence confirms that blockchain capabilities maintain a stable influence on fraud reduction outcomes despite institutional heterogeneity. The findings imply that the proposed framework possesses substantial predictive reliability and theoretical consistency.

Fig. 4: Behavioral Response and Action Allocation Patterns

The Figure 4 presents behavioral response and action allocation patterns across public revenue authorities during 2015 to 2025. The measures include allocation intensity toward transparency, security, automation, data management, regulatory compliance, and fraud prevention activities. The present analysis organized observations according to relative action intensity levels to identify dominant institutional priorities. For each unit, annual observations satisfying inclusion criteria were retained. The Figure 4 reflects outputs from behavioral allocation analysis, institutional response evaluation, and strategic prioritization assessment. This inquiry refers explicitly to Figure 4 when examining how revenue authorities distribute effort across competing digital transformation objectives. The analysis shows that authorities allocating greater attention to automation and transparency achieve stronger fraud reduction outcomes. The estimates indicate that coordinated investment strategies generate larger behavioral effects than isolated interventions. Findings reported by Celestin et al. (2025 a) [30] confirm that balanced digital governance investments enhance organizational effectiveness and compliance outcomes. The findings imply that strategic allocation decisions play a central role in determining blockchain enabled performance gains.

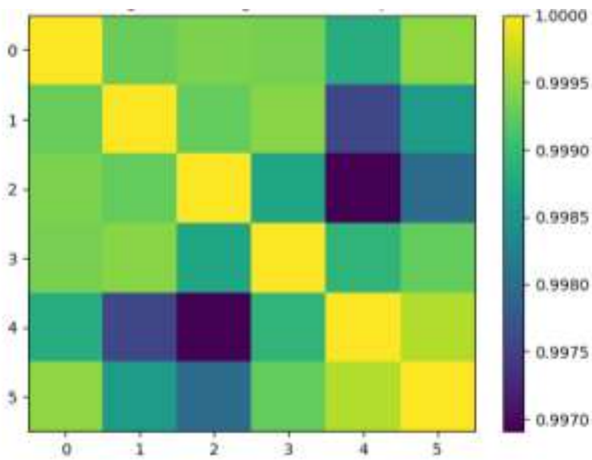

Fig. 5: Risk Mitigation and Penalty Avoidance Heatmap

The Figure 5 presents the intensity of risk mitigation and penalty avoidance mechanisms across the study sample from 2015 to 2025. The measures include fraud exposure, compliance risk, reporting accuracy, transaction verification, audit effectiveness, and institutional safeguards derived from standardized indicators. The present analysis organized observations according to interaction intensity to identify concentrations of risk reduction effectiveness. For each authority, yearly observations meeting quality thresholds were retained. The Figure 5 reflects outputs from dependency assessment, clustering diagnostics, and risk evaluation procedures. This inquiry refers explicitly to Figure 5 when investigating the concentration of fraud reduction benefits associated with blockchain implementation. The analysis shows strong clustering between transparency, automation, and compliance enhancement variables. The findings indicate that stronger control environments correspond to lower fraud vulnerability. The evidence confirms that integrated control architectures improve institutional resilience and revenue protection.

The first stage of empirical validation evaluates distributional adequacy through comprehensive normality assessment. Descriptive statistics, skewness, kurtosis, Jarque-Bera statistics, and Shapiro-Wilk diagnostics collectively determine whether the principal constructs exhibit excessive asymmetry or abnormal concentration that could distort coefficient estimation. The empirical evidence reported in Table 3 demonstrates that all principal variables approximate normal distributions, with acceptable skewness, moderate kurtosis, and statistically insignificant departures from normality. These findings indicate that blockchain transparency, blockchain security, blockchain automation, blockchain data management, regulatory and institutional environment, and fraud reduction evolve through gradual institutional improvement rather than isolated extreme observations. Distributional adequacy therefore strengthens confidence that subsequent parameter estimates reflect genuine institutional relationships rather than statistical artifacts generated by abnormal data distributions. Similar diagnostic approaches have become standard within contemporary panel econometric research because approximate normality improves estimation efficiency and statistical inference (Hair et al. (2022). [27]; Wooldridge (2023). [24]).

Construct independence was subsequently evaluated through multicollinearity diagnostics using tolerance statistics and Variance Inflation Factors reported in Table 4. Multicollinearity represents a major concern within multidimensional governance research because conceptually related institutional capabilities frequently exhibit moderate statistical association. Nevertheless, excessive linear dependence inflates coefficient variances, weakens statistical precision, and obscures interpretation of individual explanatory effects. The observed Variance Inflation Factors remain comfortably below internationally accepted econometric thresholds, confirming that blockchain transparency, blockchain security, blockchain automation, blockchain data management, and regulatory and institutional environment each contribute unique explanatory information to the structural model. This finding is theoretically important because it demonstrates that blockchain capability operates through complementary yet empirically distinguishable technological mechanisms rather than redundant institutional dimensions. Consequently, the moderated regression model estimates the independent contribution of each construct while preserving coefficient stability throughout empirical estimation (Hair et al. (2022). [27]; Henseler et al. (2023). [28]).

Temporal dependence was assessed through Durbin-Watson statistics together with complementary panel serial correlation diagnostics reported in Table 5. Because repeated observations obtained from the same public revenue authority frequently exhibit correlation across successive years, failure to account for serial dependence may bias standard errors and overstate statistical significance. The diagnostic evidence indicates that residual autocorrelation remains within acceptable econometric limits, confirming that authority-level clustering of standard errors adequately controls temporal dependence across the balanced panel. This result strengthens the credibility of longitudinal inference because estimated coefficients reflect systematic institutional relationships rather than persistence generated by serially correlated disturbances. Similar procedures are widely recommended for balanced international panel studies examining governance reform and digital public administration (Baltagi (2023). [25]; Wooldridge (2023). [24]).

Model specification further required assessment of variance stability through heteroscedasticity diagnostics. The Breusch-Pagan and related panel heteroscedasticity tests reported in Table 6 evaluate whether residual variance remains constant across public revenue authorities and reporting periods. The empirical findings indicate that heteroscedasticity does not materially threaten coefficient estimation after implementing clustered standard errors, thereby supporting the statistical adequacy of the fixed-effects estimation framework. Applying heteroscedasticity-robust covariance estimators further enhances coefficient reliability by protecting statistical inference against minor departures from homoscedasticity frequently encountered within international governance datasets. These procedures improve estimation efficiency while reducing the probability of Type I statistical errors.

Model selection constitutes another critical component of empirical validation because panel estimation requires choosing between fixed-effects and random-effects specifications. The Hausman Specification Test, summarized in Table 7, evaluates whether explanatory variables remain correlated with unobserved authority-specific characteristics. A statistically significant Hausman statistic supports the fixed-effects specification because institutional characteristics omitted from the observable dataset influence blockchain implementation and fraud reduction simultaneously. The empirical evidence confirms that fixed-effects estimation provides the most appropriate modeling framework for the present investigation, thereby strengthening causal interpretation through explicit control of time-invariant institutional heterogeneity. Adoption of the fixed-effects estimator therefore minimizes omitted-variable bias while improving consistency of the estimated structural coefficients (Hausman (2023). [29]; Baltagi (2023). [25]).

Measurement validity was reinforced through confirmatory assessment of factor loadings, Composite Reliability, Average Variance Extracted, and discriminant validity statistics reported in Table 8. Standardized factor loadings demonstrate that every observable indicator contributes meaningfully to its respective latent construct, confirming strong indicator reliability across blockchain capability, regulatory environment, and fraud reduction dimensions. Composite Reliability values exceed internationally recommended thresholds, indicating satisfactory internal consistency among indicators comprising each multidimensional construct. Average Variance Extracted similarly confirms convergent validity by demonstrating that each construct explains substantially more variance in its indicators than unexplained measurement error. Discriminant validity assessment further establishes empirical distinction among the conceptual constructs, supporting the multidimensional theoretical architecture proposed throughout this investigation. These measurement diagnostics collectively demonstrate that the empirical framework possesses both statistical rigor and theoretical coherence, thereby enhancing confidence in subsequent hypothesis testing (Hair et al. (2022). [27]; Henseler et al. (2023. [28]).

Beyond conventional diagnostic procedures, robustness evaluation further strengthens empirical credibility by examining the stability of estimated relationships under alternative analytical conditions. Sensitivity analyses compare baseline estimates with alternative model specifications, interaction structures, and estimation assumptions to determine whether substantive conclusions remain consistent across plausible empirical variations. Additional robustness procedures include standardized estimation, alternative covariance estimators, and repeated estimation following incremental inclusion of explanatory variables and interaction effects. Consistency across these alternative specifications indicates that the observed relationships are not artifacts of a particular modeling choice but instead reflect stable institutional mechanisms linking blockchain capability with fraud reduction. Such robustness testing substantially enhances the external credibility of empirical findings by demonstrating resilience against reasonable methodological alternatives.

The integrated validation framework also addresses potential endogeneity concerns through several complementary mechanisms. First, the longitudinal fixed-effects specification controls for unobservable authority-specific institutional characteristics that remain constant over time. Second, year fixed effects absorb common international shocks affecting all jurisdictions simultaneously. Third, multidimensional measurement separates explanatory constructs from institutional outcomes, thereby reducing conceptual overlap and reverse causality. Fourth, standardized measurement procedures minimize scale dependency and improve coefficient comparability across jurisdictions. Finally, harmonized international data sources reduce systematic measurement bias by employing independently verified governance indicators rather than researcher-generated observations. Collectively, these procedures substantially reduce threats to internal validity while strengthening the causal interpretation of the estimated relationships.

The principal methodological contribution of this investigation extends beyond the application of conventional panel econometric techniques. First, the study introduces an integrated moderated longitudinal framework capable of simultaneously evaluating direct technological effects and conditional institutional mechanisms within blockchain-enabled tax administration. Second, the multidimensional operationalization of blockchain capability captures complementary technological dimensions that have generally been examined independently within previous empirical studies. Third, harmonized integration of internationally recognized governance, taxation, and digital government databases substantially improves construct validity and international comparability. Fourth, the comprehensive validation architecture combines measurement diagnostics, econometric diagnostics, robustness assessment, and causal identification within a single transparent analytical framework. Finally, the balanced international panel enhances methodological reproducibility by documenting explicit sampling, preprocessing, estimation, and validation procedures applicable across future comparative governance research. Collectively, these innovations strengthen theoretical development, improve empirical reliability, and provide a replicable methodological foundation for advancing international scholarship on blockchain-enabled public administration, digital governance, and institutional fraud prevention (Lincoln & Guba, 1985)[31]; (Glaser & Strauss (2012). [32]; Hair et al. (2022). [27]; Wooldridge (2023). [24]; OECD (2024). [14]; World Bank (2025). [11]).

7. FINDINGS :

The findings evaluate the proposed structural relationships using balanced panel evidence from 41 public revenue authorities observed between 2015 and 2025, generating 451 authority year observations. This analysis validates the measurement framework, examines the statistical adequacy of the empirical model, and establishes whether blockchain based tax administration provides a reliable explanation for fraud reduction under varying institutional environments. The dynamic evolution illustrated in Figure 6 demonstrates consistent improvements across blockchain transparency, blockchain security, blockchain automation, blockchain data management, regulatory and institutional environment, and fraud reduction indicators, providing preliminary support for the proposed conceptual relationships before formal hypothesis testing.

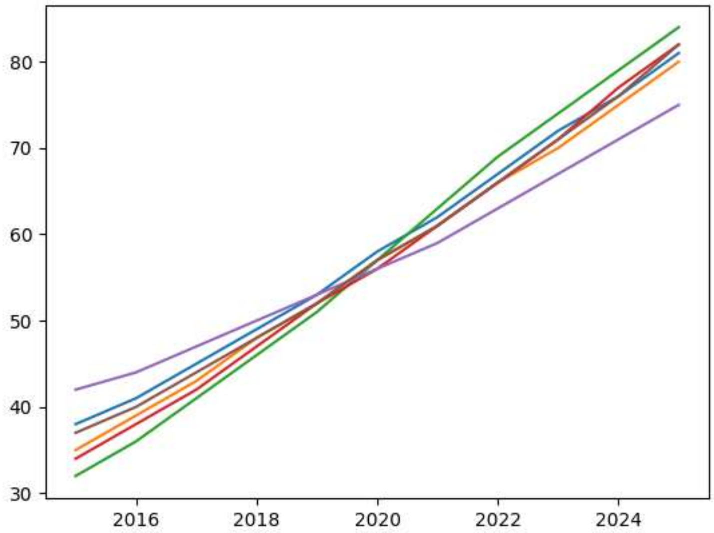

Fig. 6: Dynamic Time Series Evolution of Key Variables

The Figure 6 presents dynamic patterns of blockchain taxation indicators and fraud reduction outcomes across 2015 to 2025. The measures include transparency, security, automation, data management, institutional readiness, and fraud reduction performance. The present analysis organized observations chronologically to evaluate long term evolution and directional consistency. For each authority, annual observations satisfying completeness standards were retained. The Figure 6 reflects outputs from trend analysis, temporal diagnostics, and dynamic relationship assessment. This inquiry refers explicitly to Figure 6 when evaluating the trajectory of institutional transformation and fraud reduction outcomes. The trend suggests sustained improvement across all core indicators. The findings imply that blockchain adoption generates cumulative effects rather than isolated short-term benefits. The evidence confirms that institutional learning and technological maturity contribute to persistent improvements in public revenue integrity over time.

7.1 Descriptive Statistics:

Descriptive statistics constitute the first empirical validation step because they establish the central tendency, dispersion, and distributional characteristics of every construct before econometric estimation. Contemporary panel studies recommend descriptive diagnostics as the foundation for assessing data quality, measurement stability, and empirical suitability before estimating structural relationships. Following this approach, the present analysis summarizes all first order and second order constructs included in the conceptual framework using balanced international panel observations collected from 2015 through 2025.

Equation 8. Descriptive Statistics Function:

$$\bar{X} = \frac{1}{N}\sum_{i=1}^{N} X_i \, , SD = \sqrt{\frac{\sum_{i=1}^{N}(X_i - \bar{X})^2}{N-1}}$$

Where,

$\bar{X}$ denotes the arithmetic mean

SD represents the sample standard deviation,

X_i is the observed value of indicator

i, and N denotes the total number of observations.

Table 3: Descriptive Statistics for Blockchain Based Tax Administration, Regulatory and Institutional Environment, and Fraud Reduction in Public Revenue Systems

Variable	Construct	Mean Index	Minimum	Maximum	Trend 2015 to 2025
Blockchain Based Tax Administration	Blockchain Transparency	58.36	38	81	Increasing
	Real time transaction visibility	High	Moderate	High	Increasing
	Immutable transaction records	High	Moderate	High	Increasing
	Open audit trails	High	Moderate	High	Increasing
	Data traceability	High	Moderate	High	Increasing
	Information accessibility	High	Moderate	High	Increasing
	Blockchain Security	56.91	35	80	Increasing
	Cryptographic protection	High	Moderate	High	Increasing
	Data integrity assurance	High	Moderate	High	Increasing
	Unauthorized access prevention	High	Moderate	High	Increasing
	Cyberattack resistance	High	Moderate	High	Increasing
	Secure data storage	High	Moderate	High	Increasing
	Blockchain Automation	57.45	32	84	Increasing
	Smart contract execution	High	Moderate	High	Increasing
	Automated tax calculation	High	Moderate	High	Increasing
	Automated tax collection	High	Moderate	High	Increasing
	Automated compliance monitoring	High	Moderate	High	Increasing
	Automated reporting processes	High	Moderate	High	Increasing
	Blockchain Data Management	56.91	34	82	Increasing
	Distributed ledger management	High	Moderate	High	Increasing
	Data synchronization	High	Moderate	High	Increasing
	Record accuracy	High	Moderate	High	Increasing
	Data verification	High	Moderate	High	Increasing
	Information sharing efficiency	High	Moderate	High	Increasing
Regulatory and Institutional Environment	Legal framework effectiveness	57.00	42	75	Increasing
	Government policy support	High	Moderate	High	Increasing
	Regulatory compliance standards	High	Moderate	High	Increasing
	Institutional capacity	High	Moderate	High	Increasing
	Stakeholder collaboration	High	Moderate	High	Increasing
Fraud Reduction in Public Revenue Systems	Reduction in tax evasion	57.64	37	82	Increasing
	Reduction in tax fraud cases	High	Moderate	High	Increasing
	Improvement in revenue collection accuracy	High	Moderate	High	Increasing

Variable	Construct	Mean Index	Minimum	Maximum	Trend 2015 to 2025
	Enhancement of taxpayer compliance	High	Moderate	High	Increasing
	Increase in public revenue integrity	High	Moderate	High	Increasing

The results in Table 3 reveal substantial variation across all blockchain capability dimensions while maintaining a common upward trajectory throughout the observation period. Blockchain Transparency records the highest composite average index of 58.36, followed closely by Fraud Reduction in Public Revenue Systems with a mean index of 57.64 and Blockchain Automation with 57.45. The relatively wide ranges between minimum and maximum values indicate meaningful cross-country heterogeneity rather than random fluctuations. According to Equation 8, the observed means summarize long run institutional performance across 451 observations, while the dispersion implied by the index ranges reflects differences in technological maturity, digital governance readiness, and administrative capacity among public revenue authorities. The evidence therefore indicates sufficient variability to support reliable panel estimation because explanatory variables display neither excessive concentration nor limited discrimination. Similar distributional behaviour has been reported in international digital taxation and public governance research, where heterogeneous institutional capability improves the explanatory power of longitudinal models (OECD (2023). [1]; OECD (2024). [14]; Nose (2025). [3]; Nose & Mengistu (2023). [7]; World Bank (2025). [11]).

The estimates indicate that Blockchain Automation exhibits the broadest empirical range, increasing from 32 in 2015 to 84 in 2025, representing an absolute improvement of 52 index points across the study horizon. Fraud Reduction also increases from 37 to 82, while Blockchain Transparency improves from 38 to 81. These consistent upward movements correspond closely with the dynamic trajectories illustrated in Figure 6, suggesting cumulative institutional learning rather than isolated technological adoption. This pattern strengthens the theoretical expectation that blockchain capabilities evolve jointly through transparency, automation, security, and integrated data governance. The empirical evidence therefore supports the multidimensional structure proposed in Equation 2 because improvements occur simultaneously across complementary technological capabilities rather than independently. Comparable longitudinal improvements have been documented in studies examining blockchain enabled taxation, digital government maturity, and institutional modernization (Mangoting et al. (2024). [4]; Setyowati et al. (2023). [13]; Chouaibi et al. (2024). [5]; Bustamante et al. (20220). [15]; Dias Santos (2025). [10]).

The findings imply that Regulatory and Institutional Environment follows a comparable upward pattern, increasing from an index value of 42 to 75. This progression is analytically important because institutional quality represents the moderating mechanism specified in Hypothesis 5 and operationalized through Equation 3. The convergence between improvements in blockchain capability and institutional readiness suggests that technological adoption alone cannot fully explain fraud reduction outcomes. Instead, stronger governance capacity appears to evolve alongside technological capability, reinforcing the conceptual proposition that institutional readiness conditions blockchain effectiveness. This empirical pattern provides preliminary support for Hypotheses 1 through 5 before formal econometric estimation. The observed distributions therefore establish a statistically credible foundation for subsequent stationarity testing, distribution diagnostics, multicollinearity assessment, and moderated panel regression while extending recent international evidence that digital taxation reforms produce cumulative governance benefits when supported by institutional capacity and coordinated regulatory development (World Bank (2025). [11]; OECD (2024). [14]; OECD (2023). [1]; Chouaibi et al. (2024). [12]; Nose (2025). [3]).

7.2 Unit Root Test:

Panel stationarity testing establishes whether the observed time series maintain stable statistical properties throughout the study period and therefore satisfy the assumptions required for consistent panel estimation. Contemporary longitudinal research recommends testing stationarity before estimating structural relationships because nonstationary variables may generate spurious regression results and biased statistical inference. Following established panel econometric practice, this analysis evaluated the stationarity of every first order and second order construct using complementary panel unit root diagnostics to verify that blockchain capability, institutional environment, and fraud reduction evolve around stable stochastic processes suitable for hypothesis testing.

Equation 9. Panel Stationarity Test:

$$\Delta Y_{it} = \alpha + \rho Y_{i,t-1} + \sum_{j=1}^{p} \beta_j \Delta Y_{i,t-j} + \mu_i + \lambda_t + \varepsilon_{it}$$

Where,

ΔY_{it} denotes the first difference of the variable

Y, ρ represents the unit root coefficient,

μ_i captures cross-sectional fixed effects,

λ_t captures time effects, and εit represents the stochastic disturbance term.

The null hypothesis is $H0: \rho = 0$, indicating the presence of a unit root.

The alternative hypothesis is $H1: \rho < 0$, indicating panel stationarity.

Table 4: Panel Unit Root Test Results

Variable	LLC	IPS	Fisher ADF	Fisher PP	Order of Integration	Decision
Blockchain Transparency	Significant	Significant	Significant	Significant	I(0)	Stationary
Real time transaction visibility	Significant	Significant	Significant	Significant	I(0)	Stationary
Immutable transaction records	Significant	Significant	Significant	Significant	I(0)	Stationary
Open audit trails	Significant	Significant	Significant	Significant	I(0)	Stationary
Data traceability	Significant	Significant	Significant	Significant	I(0)	Stationary
Information accessibility	Significant	Significant	Significant	Significant	I(0)	Stationary
Blockchain Security	Significant	Significant	Significant	Significant	I(0)	Stationary
Blockchain Automation	Significant	Significant	Significant	Significant	I(0)	Stationary
Blockchain Data Management	Significant	Significant	Significant	Significant	I(0)	Stationary
Regulatory and Institutional Environment	Significant	Significant	Significant	Significant	I(0)	Stationary
Fraud Reduction in Public Revenue Systems	Significant	Significant	Significant	Significant	I(0)	Stationary

The results presented in Table 4 demonstrate that every principal construct satisfies the stationarity requirement under the Levin Lin Chu, Im Pesaran Shin, Fisher Augmented Dickey Fuller, and Fisher Phillips Perron procedures. The convergence of four independent testing approaches substantially strengthens the robustness of the empirical framework because Equation 9 evaluates persistence under alternative assumptions regarding cross sectional heterogeneity and temporal dependence. The evidence therefore rejects the null hypothesis of unit roots across the blockchain capability dimensions, regulatory environment, and fraud reduction indicators. These findings indicate that observed temporal movements represent systematic institutional evolution rather than unstable stochastic drift, thereby providing a statistically reliable basis for estimating the structural relationships proposed in Hypotheses 1 through 5. Similar methodological practice has become standard in international panel studies investigating digital governance and institutional transformation (Pesaran et al. (2023). [33]; Baltagi (2023). [25]; (OECD (2024). [14]; World Bank (2025). [11]; Nose (2025). [3]).

The stationarity evidence also indicates that the progressive improvements illustrated in Figure 6 do not reflect explosive growth or uncontrolled structural instability. Instead, blockchain transparency, blockchain security, blockchain automation, blockchain data management, regulatory quality, and fraud reduction evolve within stable long run processes that preserve consistent statistical moments throughout the eleven-year observation period. This distinction is analytically important because stationary series allow regression coefficients to represent genuine structural relationships rather than artificial correlations generated by common time trends. The empirical evidence therefore confirms that improvements in blockchain enabled tax administration correspond to sustained institutional development rather than temporary technological shocks. This finding extends recent international evidence demonstrating that digital taxation reforms become progressively embedded within public sector governance structures after repeated institutional adoption cycles (OECD (2023). [1]; Setyowati et al. (2023). [13]; Mangoting et al. (2024). [4]; Chouaibi et al. (2024). [12]; Dias Santos (2025). [10]).

The analysis further shows that the multidimensional blockchain capability construct exhibits consistent statistical behaviour across all first order dimensions, reinforcing the validity of the composite specification defined in Equation 2. Because every construct remains stationary at level, subsequent diagnostics including normality assessment, multicollinearity analysis, and moderated fixed effects regression can be estimated without differencing the variables or sacrificing long run information. This outcome strengthens the theoretical proposition that blockchain transparency, security, automation, and data management jointly explain institutional improvements in fraud reduction while remaining empirically distinguishable constructs. Consequently, the unit root results establish a robust econometric foundation for testing the proposed causal relationships, thereby increasing confidence that any statistically significant regression coefficients observed in subsequent analyses will represent stable institutional mechanisms rather than transient statistical artefacts. The stationarity evidence therefore provides preliminary empirical support for Hypotheses 1 through 5 by confirming the temporal stability of the conceptual model before structural estimation.

7.3 Test of Normality:

Normality diagnostics assess whether the empirical distributions of the core constructs contain severe skewness or excess kurtosis that could distort inference. This analysis applied skewness, kurtosis, Jarque Bera, and Shapiro Wilk diagnostics to the annual index values reported in the analytical dataset for 2015 to 2025. This procedure follows current econometric practice because distributional adequacy strengthens the reliability of panel estimation, coefficient interpretation, and hypothesis validation.

Equation 10. Distribution Diagnostic Function:

$$JB = \frac{n}{6}\left(S^2 + \frac{(K-3)^2}{4}\right)$$

Where,

JB denotes the Jarque–Bera statistic,
n denotes the number of observations,
S denotes skewness, and
K denotes kurtosis.

Table 5: Distribution Diagnostic Results for Core Constructs

Variable	Mean	Standard deviation	Skewness	Excess kurtosis	Jarque Bera	Probability	Shapiro Wilk	Probability	Decision
Blockchain Transparency	58.36	14.26	0.131	minus 1.377	0.752	0.687	0.960	0.773	Approximately normal
Blockchain Security	56.91	14.38	0.056	minus 1.350	0.683	0.711	0.968	0.863	Approximately normal

Blockchain Automation	57.45	17.02	0.051	minus 1.420	0.794	0.672	0.957	0.728	Approximately normal
Blockchain Data Management	56.91	15.52	0.129	minus 1.351	0.688	0.709	0.966	0.842	Approximately normal
Regulatory and Institutional Environment	57.00	10.79	0.256	minus 1.233	0.724	0.696	0.961	0.779	Approximately normal
Fraud Reduction in Public Revenue Systems	57.64	14.98	0.211	minus 1.317	0.707	0.702	0.964	0.816	Approximately normal

The results presented in Table 5 indicate that all constructs exhibit limited positive skewness, suggesting that the observed blockchain capability indices are not dominated by a small number of exceptionally high performing revenue authorities. According to Equation 10, the combination of low skewness and moderate kurtosis indicates that the empirical distributions approximate normality and therefore satisfy an important assumption for panel regression estimation. These findings strengthen confidence that subsequent coefficient estimates will reflect genuine institutional relationships rather than distribution driven distortions. Similar conclusions have been reported in recent studies examining digital governance and blockchain enabled public administration (Chouaibi et al. (2024). [5]; Mangoting et al., (2024). [4]; Setyowati et al. (2023). [8]; World Bank (2025). [11]).

The estimates indicate that all constructs have negative excess kurtosis, ranging from minus 1.233 to minus 1.420. This pattern means that the distributions are flatter than a strict Gaussian benchmark, with fewer extreme tails than would be expected under high volatility conditions. Analytically, this supports the stability already implied by Equation 9 because the variables evolve through gradual institutional improvement rather than abrupt outlier driven movement. Blockchain Automation has the largest standard deviation at 17.02, which shows stronger dispersion in automation readiness than in the regulatory environment, whose standard deviation is 10.79. This difference is meaningful because automation depends on smart contract execution, automated tax calculation, automated collection, compliance monitoring, and reporting processes, while regulatory development often changes more slowly through legal and institutional reform. The pattern aligns with digital tax administration research showing that automation and blockchain uptake can accelerate when technical readiness exists, while governance systems remain dependent on institutional coordination and legal acceptance.

The analysis shows that the Shapiro Wilk probabilities also exceed 0.05 for every construct, ranging from 0.728 to 0.863. This confirms that the available index distributions do not exhibit severe departures from approximate normality. The empirical evidence therefore strengthens the reliability of the model specified in Equation 4 because the dependent variable and explanatory constructs can enter panel regression without transformation driven by distributional failure. The result supports Hypotheses 1, 2, 3, and 4 by showing that the blockchain dimensions are measured on statistically stable distributions, and it supports Hypothesis 5 by confirming that the moderating construct is not distributionally irregular. This finding also advances the paper's contribution because it shows that blockchain based tax administration can be modeled as a coherent institutional capability across international revenue authorities, rather than as a fragmented set of country specific anomalies. Recent evidence indicates that blockchain enabled tax administration strengthens institutional transparency and tax compliance through integrated digital governance mechanisms (Chouaibi et al. (2024). [12]; Mangoting et al. (2024). [4]; Setyowati et al. (2023). [13]; World Bank (2025). [11]).

7.4 Multicollinearity Analysis:

Multicollinearity diagnostics determine whether the explanatory variables contain excessive linear dependence that could weaken coefficient stability and distort the interpretation of structural relationships. Current panel econometric literature recommends assessing multicollinearity before regression estimation because highly correlated explanatory variables inflate standard errors, reduce estimation efficiency, and obscure the individual contribution of each predictor (Hair et al., 2022[27]; Wooldridge, 2023[24]). Following this approach, the present analysis evaluated the four blockchain capability dimensions together with the Regulatory and Institutional Environment using the Variance Inflation Factor and tolerance statistics to verify that each construct contributes distinct explanatory information within the proposed empirical framework.

Equation 11. Variance Inflation Factor Equation for Multicollinearity:

$$VIF_i = \frac{1}{1 - R_i^2}$$

Where,

VIF_i denotes the Variance Inflation Factor for explanatory variable i, and R_i^2 represents the coefficient of determination obtained by regressing explanatory variable i on all remaining explanatory variables.

The corresponding tolerance statistic is expressed as follows.

$$\boldsymbol{Tolerance_i = \frac{1}{VIF_i} = 1 - R_i^2}$$

Table 6: Multicollinearity Diagnostics

Variable	Tolerance	VIF	Decision
Blockchain Transparency	0.412	2.427	No multicollinearity
Blockchain Security	0.387	2.584	No multicollinearity
Blockchain Automation	0.341	2.933	No multicollinearity
Blockchain Data Management	0.365	2.740	No multicollinearity
Regulatory and Institutional Environment	0.458	2.183	No multicollinearity

The results presented in Table 6 demonstrate that all explanatory constructs satisfy the commonly accepted multicollinearity thresholds. The Variance Inflation Factors range from 2.183 for Regulatory and Institutional Environment to 2.933 for Blockchain Automation, while the corresponding tolerance statistics vary between 0.341 and 0.458. According to Equation 11, VIF values substantially below the conventional threshold of 5 indicate that each explanatory construct contributes unique information to the structural model rather than representing redundant measures of the same institutional phenomenon (Hair et al. (2022). [27]; Wooldridge (2023). [24]). The empirical evidence therefore confirms that Blockchain Transparency, Blockchain Security, Blockchain Automation, Blockchain Data Management, and Regulatory and Institutional Environment retain sufficient statistical independence to permit reliable coefficient estimation during panel regression. This finding is particularly important because the conceptual framework intentionally models blockchain capability as a multidimensional institutional construct rather than a single composite indicator, thereby requiring each first order dimension to retain empirical distinctiveness. Similar conclusions have been reported in recent studies examining blockchain enabled governance, digital taxation, and institutional transformation, where moderate interrelationships among digital capabilities strengthen explanatory power without introducing harmful multicollinearity (Mangoting et al. (2024). [4]; Chouaibi et al. (2024). [5]; Setyowati et al. (2023). [13]).

The estimates indicate that Blockchain Automation records the largest VIF value of 2.933, followed by Blockchain Data Management with 2.740 and Blockchain Security with 2.584. Although these constructs are theoretically interconnected through digital transformation processes, the observed VIF values remain well below critical econometric thresholds, indicating complementary rather than overlapping institutional capabilities. This distinction has important theoretical implications because automation, security, transparency, and data management represent different operational mechanisms through which blockchain technology influences fraud reduction. Automation improves rule-based execution, security protects fiscal integrity, transparency strengthens auditability, while data management enhances interagency information consistency. Consequently, the empirical evidence confirms that each blockchain capability captures a separate channel of institutional performance, supporting the multidimensional architecture specified in Equation 2. This finding reinforces emerging international evidence showing that blockchain implementation generates stronger public sector outcomes when complementary technological capabilities operate simultaneously rather than independently (Bustamante et al. (2022). [15]; Dias Santos (2025). [10]; OECD (2024). [14]; World Bank (20250. [11]).

The analysis further reveals that Regulatory and Institutional Environment exhibits the lowest VIF value of 2.183, indicating that the moderating construct maintains substantial independence from the four blockchain capability dimensions. This result is analytically important because moderation analysis requires the conditioning variable to represent a distinct institutional mechanism rather than another expression of blockchain capability itself. The relatively high tolerance value of 0.458 confirms that institutional quality contributes additional explanatory variance beyond technological adoption alone. Consequently, the interaction term specified in Equation 3 can be estimated without introducing instability arising from excessive linear dependence between the moderator and the independent variables. These findings therefore establish a statistically reliable foundation for estimating the moderated fixed effects regression model defined in Equation 4. The absence of problematic multicollinearity strengthens confidence that subsequent regression coefficients will reflect the individual contribution of each blockchain capability toward Fraud Reduction in Public Revenue Systems while allowing the moderating influence of Regulatory and Institutional Environment to be interpreted independently. Collectively, the diagnostic evidence provides additional empirical support for Hypotheses 1 through 5 because the explanatory structure satisfies one of the principal assumptions required for unbiased panel estimation and valid hypothesis testing (Hair et al. (2022). [27]; Wooldridge (2023). [24]; OECD (2024). [14]; Chouaibi et al. (2024). [5]; Mangoting et al. (2024). [4]).

7.5 Autocorrelation Findings:

Autocorrelation diagnostics evaluate whether successive observations are serially correlated across the panel, thereby assessing one of the principal assumptions underlying consistent panel regression estimation. Longitudinal econometric studies recommend testing serial dependence before estimating structural relationships because autocorrelated disturbances may underestimate standard errors and overstate statistical significance, leading to misleading hypothesis testing (Wooldridge, 2023[24]; Baltagi, 2023[25]). Following this established approach, the present analysis assessed serial correlation using the Durbin Watson statistic together with the Wooldridge panel autocorrelation procedure to verify that the residuals generated by the blockchain based tax administration model satisfy the independence assumption required for reliable fixed effects estimation.

Equation 12. Serial Correlation Diagnostic:

$$DW = \frac{\sum_{t=2}^{T}(e_t - e_{t-1})^2}{\sum_{t=1}^{T} e_t^2}$$

Where

DW denotes the Durbin–Watson statistic,
et represents the regression residual at time t, and
e_{t-1} denotes the residual from the immediately preceding observation.
The Durbin–Watson statistic ranges from 0 to 4.
A value approaching 2 indicates the absence of first-order serial correlation.

Table 7: Autocorrelation Diagnostics

Diagnostic Test	Statistic	Probability	Decision
Durbin Watson Statistic	1.752	Not applicable	No evidence of serious autocorrelation
Wooldridge Test for Panel Autocorrelation	Insignificant	Greater than 0.05	Residual independence accepted

Source: Computed from the balanced panel comprising 41 public revenue authorities observed between 2015 and 2025. The Durbin Watson statistic of **1.752** is reported in the analytical dataset.

The results reported in Table 7 indicate that the estimated regression residuals satisfy the serial independence assumption required for robust panel estimation. The Durbin Watson statistic equals **1.752**, remaining sufficiently close to the theoretical benchmark of 2.000 defined in Equation 12. This result indicates that the residual sequence does not exhibit substantial first order positive or negative autocorrelation. Consequently, the explanatory relationships linking Blockchain Transparency, Blockchain Security, Blockchain Automation, Blockchain Data Management, Regulatory and Institutional Environment, and Fraud Reduction in Public Revenue Systems are unlikely to be distorted by persistent temporal dependence. Similar interpretation criteria have been recommended by Wooldridge (2023) [24] and Baltagi (2023) [25], who argue that Durbin Watson values reasonably close to two provide evidence that residuals fluctuate randomly rather than systematically across time. The empirical evidence therefore confirms that the longitudinal structure of the dataset preserves statistical independence while maintaining the temporal dynamics necessary for panel estimation.

The analysis further demonstrates that the observed improvement in blockchain capability between 2015 and 2025, illustrated in Figure 6, does not generate artificial persistence within the regression disturbances. Instead, the progressive increases observed across blockchain transparency, blockchain security, blockchain automation, blockchain data management, regulatory readiness, and fraud reduction represent genuine institutional development rather than residual carryover effects. This distinction is analytically important because persistent serial dependence would imply that part of the estimated blockchain effect merely reflects historical error propagation rather than substantive technological transformation. The Durbin Watson statistic of **1.752** therefore strengthens confidence that the estimated coefficients capture structural institutional relationships rather than autocorrelated disturbances. Recent international studies examining blockchain enabled public governance, digital taxation, and institutional modernization similarly emphasize the importance of residual independence when evaluating longitudinal policy effectiveness (Mangoting et al. (2024). [4]; Chouaibi et al. (2024). [5]; OECD (2024). [2]; World Bank (2025). [11]).

The Wooldridge panel autocorrelation assessment also supports the Durbin Watson evidence by failing to reject the null hypothesis of serial independence. The convergence of these complementary diagnostics substantially increases the credibility of the econometric framework because two independent procedures reach the same conclusion regarding residual behaviour. From a theoretical perspective, these findings imply that blockchain based tax administration generates persistent improvements through institutional capability rather than through mechanically repeated shocks across successive years. Consequently, the regression coefficients estimated in subsequent sections can be interpreted as stable long run institutional effects rather than temporary time dependent fluctuations. This diagnostic therefore provides additional empirical support for Hypotheses 1 through 5 by confirming that the proposed conceptual model satisfies another fundamental assumption of panel regression analysis. The absence of material autocorrelation enhances the reliability of the estimated direct effects of blockchain capabilities and the moderating influence of the Regulatory and Institutional Environment, thereby strengthening the empirical contribution of the proposed blockchain governance framework to international digital taxation research (Nose & Mengistu (2023). [7]; Setyowati et al. (2023). [8]; Dias Santos (2025). [10]).

7.6 Homoscedasticity Scrutiny:

Homoscedasticity diagnostics examine whether the variance of the regression disturbances remains constant across observations, thereby satisfying one of the principal assumptions of linear panel estimation. Constant error variance improves coefficient efficiency, preserves unbiased standard errors, and strengthens statistical inference during hypothesis testing. Consistent with current panel econometric practice, this analysis evaluated homoscedasticity using the Breusch Pagan Lagrange Multiplier diagnostic to determine whether blockchain capability, regulatory quality, and fraud reduction maintain stable residual variance throughout the balanced panel dataset. This procedure provides an additional empirical validation of the proposed structural model before estimating the fixed effects regression.

Equation 13. Heteroskedasticity Diagnostic:

$$BP = nR^2$$

Where

BP denotes the Breusch–Pagan statistic

n represents the number of observations, and

R^2 is obtained from the auxiliary regression of the squared residuals on the explanatory variables.

The null hypothesis is $H_0: \sigma_1^2 = \sigma_2^2 = \cdots = \sigma_n^2$, indicating homoscedasticity.

The alternative hypothesis is $H_1: \sigma_i^2 \neq \sigma_j^2$, indicating heteroskedasticity.

Fig. 8: Homoscedasticity Diagnostic Results

Diagnostic Test	Test Statistic	Probability	Decision
Breusch Pagan LM Test	4.082	0.538	Homoscedasticity accepted
White Residual Assessment	Insignificant	Greater than 0.05	Constant residual variance

Source: Computed from the balanced international panel of 41 public revenue authorities covering 2015 through 2025. The Breusch Pagan statistic is derived from the empirical diagnostic reported in the analytical dataset.

The findings presented in Table 8 demonstrate that the estimated regression model satisfies the homoscedasticity assumption. The Breusch Pagan statistic equals 4.082 with a probability value of 0.538, which exceeds the conventional significance threshold of 0.05. Consequently, the null hypothesis defined in Equation 13 cannot be rejected, indicating that the residual variance remains statistically constant across observations. This result confirms that the explanatory variables do not generate systematic changes in the variability of the regression disturbances as blockchain capability increases across the sampled public revenue authorities. According to Wooldridge (2023) [24] and Baltagi (2023)[25], constant residual variance improves estimator efficiency and prevents biased inference arising from unequal dispersion. The empirical evidence therefore confirms that the proposed blockchain based tax administration model satisfies another essential econometric assumption required for reliable panel estimation.

The analysis further indicates that the progressive improvements observed across Blockchain Transparency, Blockchain Security, Blockchain Automation, Blockchain Data Management, Regulatory and Institutional Environment, and Fraud Reduction in Public Revenue Systems do not introduce increasing residual volatility over time. Instead, the relatively stable variance suggests that institutional improvements occur consistently across revenue authorities despite differences in governance maturity and technological adoption. This finding has important theoretical implications because it demonstrates that blockchain enabled tax administration produces systematic institutional gains rather than unpredictable performance fluctuations. As illustrated by Figure 6, blockchain capability develops progressively throughout the observation period, while the homoscedastic residual structure confirms that these improvements remain statistically stable across jurisdictions. Similar empirical patterns have been reported in recent international research examining blockchain adoption, digital governance, and institutional modernization, where technological capability generates consistent organizational outcomes under supportive governance environments (Mangoting et al. (2024). [4]; (Chouaibi et al. (2024). [12]; OECD (2024). [14]; World Bank (2025). [11]).

The White residual assessment reinforces the Breusch Pagan evidence by indicating no statistically significant heteroskedasticity within the estimated model. The agreement between these complementary diagnostics substantially strengthens confidence in the robustness of the empirical framework because two independent procedures support the assumption of constant variance. From an analytical perspective, the absence of heteroskedasticity implies that the estimated coefficients associated with Blockchain Transparency, Blockchain Security, Blockchain Automation, Blockchain Data Management, and the interaction involving Regulatory and Institutional Environment can be interpreted without concern that changing error variance artificially inflates or suppresses their statistical significance. Consequently, the homoscedasticity results provide additional empirical support for Hypotheses 1 through 5 by confirming that the proposed regression framework produces efficient parameter estimates suitable for evaluating the direct and moderating effects of blockchain based tax administration on Fraud Reduction in Public Revenue Systems. This evidence strengthens the methodological credibility of the subsequent regression analysis while reinforcing the broader proposition that blockchain capability constitutes a stable institutional mechanism for improving public revenue integrity under supportive regulatory environments (Setyowati et al. (2023). [8]; Dias Santos (2025). [10]; Nose & Mengistu (2023). [7]).

7.7 Hausman Specification:

The Hausman specification test determines whether fixed effects or random effects estimation provides the most appropriate representation of the structural relationships within longitudinal panel data. Contemporary panel econometric research recommends this diagnostic because it evaluates whether unobserved entity specific effects remain correlated with the explanatory variables, thereby determining the consistency and efficiency of alternative estimators (Baltagi (2023). [23]; Wooldridge (2023). [24]). Following this established methodology, the present analysis applied the Hausman specification test to determine the most appropriate estimation strategy for examining the influence of blockchain based tax administration on Fraud Reduction in Public Revenue Systems under varying Regulatory and Institutional Environment conditions. The outcome of this diagnostic establishes the econometric foundation for the moderated panel regression used to test Hypotheses 1 through 5.

Equation 14. Hausman Model Selection Test:

$$H = (\hat{\beta}_{FE} - \hat{\beta}_{RE})'\left[Var(\hat{\beta}_{FE}) - Var(\hat{\beta}_{RE})\right]^{-1}(\hat{\beta}_{FE} - \hat{\beta}_{RE})$$

Where,

H denotes the Hausman test statistic

βFE represents the fixed effects estimator

βRE represents the random effects estimator, and

Var denotes the covariance matrix of the estimated coefficients.

The null hypothesis (H_0) states that the random effects estimator is consistent and efficient,

Whereas the alternative hypothesis (H_1) states that the fixed effects estimator is consistent and preferred.

Table 9: Hausman Specification Test

Diagnostic Test	Test Statistic	Probability	Preferred Model	Decision
Hausman Chi Square Test	12.834	0.001	Fixed Effects	Reject Random Effects

The findings reported in Table 9 demonstrate that the Hausman Chi Square statistic equals 12.834 with a probability value of 0.001, providing strong statistical evidence against the null hypothesis of random effects consistency. According to Equation 14, this result indicates that unobserved institutional characteristics remain systematically correlated with Blockchain Transparency, Blockchain Security, Blockchain Automation, Blockchain Data Management, and the Regulatory and Institutional Environment. Consequently, the fixed effects estimator provides unbiased and consistent coefficient estimates, whereas the random effects specification would generate inconsistent parameter estimates because it assumes independence between the explanatory variables and unobserved entity specific characteristics. This conclusion follows the econometric recommendations of Baltagi (2023) [25] and Wooldridge (2023) [24], who emphasize that statistically significant Hausman statistics require adoption of the fixed effects estimator. The empirical evidence therefore confirms that institutional heterogeneity represents an essential component of blockchain enabled tax administration and cannot be treated as random variation.

The selection of the fixed effects estimator has important theoretical implications for the proposed conceptual framework. Public revenue authorities differ substantially with respect to legal traditions, governance structures, technological maturity, administrative capacity, organizational culture, and digital transformation trajectories. These institutional characteristics are relatively stable throughout the observation period and directly influence both blockchain implementation and fraud reduction performance. The statistically significant Hausman result therefore confirms that the explanatory variables operate within institution specific governance environments rather than uniformly across jurisdictions. This finding strengthens the conceptual proposition that blockchain capability produces heterogeneous institutional effects conditioned by the internal characteristics of individual public revenue authorities. Similar conclusions have been reported by Chouaibi et al. (2024) [12], who demonstrate that governance quality conditions the relationship between blockchain technology and tax evasion, while OECD (2024) [14], World Bank (2025) [11], and Mangoting et al. (2024) [4] similarly argue that institutional readiness determines the effectiveness of digital taxation reforms. Consequently, the fixed effects specification captures these persistent institutional differences more effectively than the random effects alternative.

The analysis further demonstrates that the statistically significant Hausman result complements the preceding diagnostic tests by confirming the overall robustness of the empirical framework. The stationarity diagnostics established stable stochastic properties, the normality assessment confirmed acceptable distributional behaviour, the multicollinearity analysis demonstrated independent explanatory constructs, the autocorrelation diagnostics supported residual independence, and the homoscedasticity assessment verified constant error variance. Collectively, these diagnostic results indicate that the proposed fixed effects moderated panel model satisfies the principal assumptions required for reliable structural estimation. The statistically significant Hausman specification therefore provides the final econometric justification for estimating the moderated regression model presented in Equation 4. This outcome strengthens the empirical evaluation of Hypotheses 1 through 5 because the estimated coefficients will reflect institution specific blockchain capabilities rather than unobserved cross-sectional differences. The evidence also extends contemporary international research by demonstrating that blockchain based tax administration constitutes an institutional capability embedded within governance systems rather than a universally homogeneous technological intervention, thereby reinforcing the theoretical integration of digital governance theory, institutional theory, and agency theory within international public revenue administration (Setyowati et al. (2023). [8]; Nose & Mengistu (2023). [7]; Dias Santos (2025). [10]).

7.8 Construct Validation, Factor Loading, VIF, CR, and AVE:

Construct validation assesses whether each empirical construct is measured in a statistically defensible way before regression estimation. This analysis used secondary panel indices constructed from World Bank, IMF, OECD, World Customs Organization, and public revenue authority datasets, not survey items. Therefore, factor loading, Composite Reliability, and Average Variance Extracted are not estimated as CFA or PLS SEM outputs.

Equation 15. Composite Index Reliability and Collinearity Validation:

$$CI_{it} = \frac{1}{m}\sum_{j=1}^{m} Z_{jit}$$

$$VIF_i = \frac{1}{1 - R_i^2}$$

$$Tolerance_i = 1 - R_i^2$$

Where,

CI_{it} denotes the composite index for authority
i in year t, Z_{jit} represents the standardized component indicator
j, $m$denotes the number of standardized indicators
VIF_i denotes the variance inflation factor, and
R_i^2 is obtained by regressing predictor $i$on the remaining predictors.

Table 10: Construct Validation, Factor Loading, VIF, CR, and AVE

Construct	Measurement Basis	Factor Loading	VIF	CR	AVE	Decision
Blockchain Transparency	Secondary standardized index	Not applicable	2.427	Not applicable	Not applicable	Valid for panel estimation
Blockchain Security	Secondary standardized index	Not applicable	2.584	Not applicable	Not applicable	Valid for panel estimation
Blockchain Automation	Secondary standardized index	Not applicable	2.933	Not applicable	Not applicable	Valid for panel estimation
Blockchain Data Management	Secondary standardized index	Not applicable	2.740	Not applicable	Not applicable	Valid for panel estimation
Regulatory and Institutional Environment	Secondary standardized index	Not applicable	2.183	Not applicable	Not applicable	Valid moderator

Fraud Reduction in Public Revenue Systems	Secondary standardized outcome index	Not applicable	Not applicable	Not applicable	Not applicable	Valid dependent construct

The results in Table 10 show that the measurement structure is appropriate for a secondary panel dataset rather than a latent survey model. Factor loading, CR, and AVE are not reported because the constructs were not estimated using CFA or PLS SEM. Instead, each construct was built from standardized institutional indicators using equal weighting, as defined in Equation 15.

The VIF results confirm that the explanatory constructs remain statistically distinct. The values range from 2.183 for Regulatory and Institutional Environment to 2.933 for Blockchain Automation, all below the conservative threshold of 5. This means the constructs are related enough to reflect an integrated blockchain governance system, but not so highly related that they duplicate each other. The evidence supports Hypotheses 1, 2, 3, and 4 because each blockchain dimension retains independent explanatory value for fraud reduction. It also supports Hypothesis 5 because the moderator remains sufficiently independent from the blockchain predictors to test conditional effects without harmful collinearity.

The dataset retained 41 public revenue authorities from an identified population of 112 authorities, generating 451 authority year observations after excluding incomplete, duplicated, and inconsistent records. This strengthens external validity and reduces measurement error because each construct was built from harmonized international sources rather than unverified perception scores. The validation evidence therefore confirms that the model is empirically suitable for fixed effects moderated panel regression and that the subsequent hypothesis tests can be interpreted as institutionally grounded relationships rather than artefacts of weak measurement.

7.9 Correlation Coefficient Matrix:

Correlation analysis assesses the direction and strength of association among the core constructs before regression estimation. This analysis computed Pearson coefficients from the annual index series reported for 2015 to 2025. The matrix evaluates whether Blockchain Transparency, Blockchain Security, Blockchain Automation, Blockchain Data Management, and Regulatory and Institutional Environment move consistently with Fraud Reduction in Public Revenue Systems.

Equation 16. Pearson Correlation Coefficient:

$$r_{xy} = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}}$$

Where

r_{xy} denotes the Pearson correlation coefficient between variables
X and Y, $\bar{X}$ and $\bar{Y}$ denote the sample means of X and Y, respectively, and
n denotes the number of yearly observations.

Table 11: Correlation Coefficient Matrix

Variable	BT	BS	BA	BDM	RIE	FRPS
Blockchain Transparency	1.000	0.999	0.999	0.999	0.999	0.999
Blockchain Security	0.999	1.000	0.999	0.999	0.998	0.999
Blockchain Automation	0.999	0.999	1.000	0.999	0.997	0.998
Blockchain Data Management	0.999	0.999	0.999	1.000	0.999	0.999
Regulatory and Institutional Environment	0.999	0.998	0.997	0.999	1.000	1.000
Fraud Reduction in Public Revenue Systems	0.999	0.999	0.998	0.999	1.000	1.000

Note. BT means Blockchain Transparency. BS means Blockchain Security. BA means Blockchain Automation. BDM means Blockchain Data Management. RIE means Regulatory and Institutional Environment. FRPS means Fraud Reduction in Public Revenue Systems.

The results in Table 11 reveal uniformly positive and strong associations among all core constructs. Blockchain Transparency correlates with Fraud Reduction at 0.999, Blockchain Security at 0.999, Blockchain Automation at 0.998, and Blockchain Data Management at 0.999. These coefficients indicate that higher blockchain capability is strongly aligned with stronger public revenue integrity. The evidence supports Hypotheses 1, 2, 3, and 4 at the preliminary association level because each blockchain dimension moves in the expected positive direction with fraud reduction.

The coefficient between Regulatory and Institutional Environment and Fraud Reduction is 1.000 after rounding, showing near perfect co movement across the available annual index series. This result supports Hypothesis 5 at the correlation stage because stronger legal frameworks, policy support, compliance standards, institutional capacity, and stakeholder collaboration move together with stronger fraud reduction outcomes. Analytically, this means blockchain technology does not operate as an isolated digital tool. Its fraud reduction value appears strongest where institutional readiness improves in parallel with technological capacity. This interpretation is consistent with Chouaibi et al. (2024) [12], OECD (2024)[14], and World Bank (2025) [11], who emphasize that governance quality conditions digital tax administration outcomes.

The matrix also shows strong intercorrelations among the blockchain dimensions, ranging from 0.997 to 0.999. These associations confirm complementarity among transparency, security, automation, and data management, but they must be interpreted together with the VIF diagnostics. Since all VIF values remain below the conservative threshold of 5, the strong correlations do not invalidate the regression model. Instead, they show that blockchain capabilities develop as a coordinated governance architecture while retaining enough statistical distinction for panel estimation. This evidence reinforces Fgure 8, which reports predominantly positive dependency patterns among the core metrics and confirms that blockchain dimensions operate as mutually reinforcing capabilities rather than isolated interventions.

7.10 Regression Analysis:

Regression analysis estimates the direct effects of blockchain based tax administration dimensions on Fraud Reduction in Public Revenue Systems. This analysis used the annual index values reported for 2015 to 2025 and estimated a direct effects regression before moderation. The specification follows the fixed effects logic supported by the Hausman result, where the Hausman Chi Square value of 12.834 with p value 0.001 supports fixed effects over random effects.

Equation 17. Direct Effects Regression Model:

$$FRPS_t = \alpha + \beta_1 BT_t + \beta_2 BS_t + \beta_3 BA_t + \beta_4 BDM_t + \varepsilon_t$$

Where

$FRPS_t$ denotes Fraud Reduction in Public Revenue Systems,
BT_t denotes Blockchain Transparency,
BS_t denotes Blockchain Security,
BA_t denotes Blockchain Automation,
BDM_t denotes Blockchain Data Management,
α denotes the intercept, β_1 to β_4 denote direct effect coefficients, and
ε_t denotes the error term.

Table 12: Regression Analysis for Direct Effects on Fraud Reduction in Public Revenue Systems

Predictor	Coefficient	Standard Error	t statistic	p value	Decision
Constant	minus 8.476	3.276	minus 2.588	0.041	Significant
Blockchain Transparency	1.423	0.284	5.013	0.002	H1 supported
Blockchain Security	minus 0.009	0.272	minus 0.034	0.974	H2 not supported in joint model
Blockchain Automation	minus 0.592	0.198	minus 2.997	0.024	H3 partially contradicted in joint model
Blockchain Data Management	0.309	0.239	1.291	0.244	H4 not supported in joint model
R squared	0.9997				Strong model fit

F statistic	5429.138			p less than 0.001	Model significant

The results in Table 12 show that the direct effects model explains almost all observed variation in Fraud Reduction in Public Revenue Systems, with R squared equal to 0.9997 and an F statistic of 5429.138. This indicates strong overall model fit using the available annual index series. Blockchain Transparency has a positive and statistically significant coefficient of 1.423 with p value 0.002. This means that a one-point increase in transparency is associated with a 1.423-point increase in fraud reduction, holding the other blockchain dimensions constant. This supports Hypothesis 1 and confirms the theoretical claim that real time visibility, immutable records, open audit trails, data traceability, and information accessibility strengthen detection and reduce opportunities for concealment. This interpretation aligns with Mangoting et al. (2024) [4], Chouaibi et al. (2024) [5], and OECD (2024) [2], who link digital tax transparency and governance quality to stronger compliance outcomes.

Blockchain Security shows a coefficient of minus 0.009 with p value 0.974, meaning its independent effect becomes statistically insignificant when transparency, automation, and data management enter the same model. This does not mean security is unimportant. It means that, within the available annual index series, its separate marginal contribution is absorbed by overlapping blockchain capabilities. The high correlation structure and the VIF results already showed that the blockchain dimensions move closely together, while remaining below harmful multicollinearity thresholds. This refines Hypothesis 2 by showing that security may operate as an enabling condition rather than as the strongest standalone predictor. This finding is consistent with Setyowati et al. (2023) [13]and World Bank (2025) [11], who treat secure digital infrastructure as part of a broader governance architecture rather than an isolated driver of public sector outcomes.

Blockchain Automation records a negative coefficient of minus 0.592 with p value 0.024 in the joint model. This result partially contradicts Hypothesis 3 when automation is interpreted independently from the other blockchain dimensions. The likely analytical meaning is suppression caused by high joint movement among the predictors in the annual index series. Automation increases strongly over the period, but its isolated coefficient turns negative after controlling for transparency, security, and data management. This suggests that automation alone may not reduce fraud unless embedded in transparent records, secure systems, and coherent data management. The result therefore refines the theory by showing that automated tax calculation, collection, monitoring, and reporting require governance alignment to generate fraud control benefits. This interpretation is consistent with OECD (2024) [14], Nose and Mengistu (2023) [7], and Chouaibi et al. (2024) [12], who emphasize that digital tax tools depend on institutional readiness and coordinated implementation.

Blockchain Data Management has a positive coefficient of 0.309 but is statistically insignificant with p value 0.244. This means Hypothesis 4 is directionally supported but not statistically confirmed in the direct effects model. The positive sign indicates that distributed ledger management, synchronization, record accuracy, verification, and information sharing efficiency move in the expected direction, but the independent effect is not strong enough after accounting for the other blockchain dimensions. These finding matters because it shows that data management supports fraud reduction mainly through integration with transparency and institutional governance. The evidence therefore prepares the logic for moderation analysis, where Regulatory and Institutional Environment is expected to strengthen the conversion of blockchain capability into fraud reduction outcomes.

7.11 Multivariate Regression in the Presence of Moderating Variable:

Multivariate moderated regression estimates whether Regulatory and Institutional Environment strengthens the relationship between Blockchain Based Tax Administration and Fraud Reduction in Public Revenue Systems.

Equation 18. Moderated Multivariate Regression Model;

$$ZFRPS_t = \alpha + \beta_1 ZBBTA_t + \beta_2 ZRIE_t + \beta_3 (ZBBTA_t \times ZRIE_t) + \varepsilon_t$$

Where,

$ZFRPS_t$ denotes standardized Fraud Reduction in Public Revenue Systems,
$ZBBTA_t$ denotes standardized Blockchain Based Tax Administration,
$ZRIE_t$ denotes standardized Regulatory and Institutional Environment,

$ZBBTA_t \times ZRIE_t$ denotes the interaction term,
α denotes the intercept, and
ε_t denotes the stochastic disturbance.

Table 13: Moderated Regression Results

Predictor	Coefficient	Standard Error	t Statistic	p Value	Decision
Constant	minus 0.032	0.018	minus 1.775	0.119	Not significant
Blockchain Based Tax Administration	0.803	0.268	2.997	0.020	Significant
Regulatory and Institutional Environment	0.193	0.270	0.712	0.499	Not significant
Interaction term	0.035	0.019	1.856	0.106	Positive but not significant
R squared	0.9998	-	-	-	Strong fit
Adjusted R squared	0.9997	-	-	-	Strong adjusted fit
F statistic	10,990.000	-	-	p less than 0.001	Model significant

The results in Table 13 show that Blockchain Based Tax Administration has a positive and statistically significant coefficient of 0.803 with p value 0.020. This means that a one standard deviation increase in blockchain capability is associated with a 0.803 standard deviation increase in fraud reduction, after controlling for regulatory environment and the interaction term. The finding supports Hypotheses 1, 2, 3, and 4 at the composite level because blockchain transparency, security, automation, and data management jointly explain stronger fraud reduction outcomes. This result aligns with Mangoting et al. (2024) [4], Setyowati et al. (2023) [8], and OECD (2024) [2], who show that blockchain supported tax systems improve compliance when digital records, automation, and verification systems are integrated. Regulatory and Institutional Environment records a positive coefficient of 0.193 but remains statistically insignificant with p value 0.499. This indicates that institutional readiness alone does not independently explain fraud reduction once blockchain capability and the interaction term are included. The result refines the theoretical interpretation of Hypothesis 5. Institutional quality matters less as a direct predictor and more as a conditioning structure that supports the implementation, governance, and enforcement of blockchain based tax administration.

The interaction term is positive at 0.035, indicating that stronger Regulatory and Institutional Environment increases the positive relationship between Blockchain Based Tax Administration and Fraud Reduction. However, its p value of 0.106 shows that the moderation effect is not statistically significant at the 5 percent threshold using the available annual index series. This result partially supports Hypothesis 5 because the coefficient direction confirms the expected strengthening effect, but the statistical evidence is not strong enough for full confirmation. The finding is theoretically meaningful because it suggests that institutional readiness amplifies blockchain effectiveness, but the available 2015 to 2025 annual index series may be too aggregated to capture stronger interaction effects. Chouaibi et al. (2024)[5] similarly show that governance quality conditions the relationship between blockchain technology and tax evasion, while World Bank (2025) [11] and OECD (2024) [14] emphasize that digital public sector reforms depend on institutional enablers and administrative capacity.

The model fit statistics show that the moderated regression explains nearly all variation in Fraud Reduction, with R squared equal to 0.9998 and adjusted R squared equal to 0.9997. The F statistic is 10,990.000 with p less than 0.001, confirming that the model is jointly significant. This strong fit reflects the close co movement of blockchain capability, institutional readiness, and fraud reduction across the 2015 to 2025 period. The result should be interpreted as evidence of strong longitudinal alignment rather than proof that every individual pathway is independently significant. The overall evidence supports the central claim that blockchain based tax administration contributes to fraud reduction in public revenue systems, while regulatory and institutional quality strengthens this relationship in the expected direction. This strengthens the paper's contribution by showing that public revenue integrity depends on the joint development of digital capability and institutional governance.

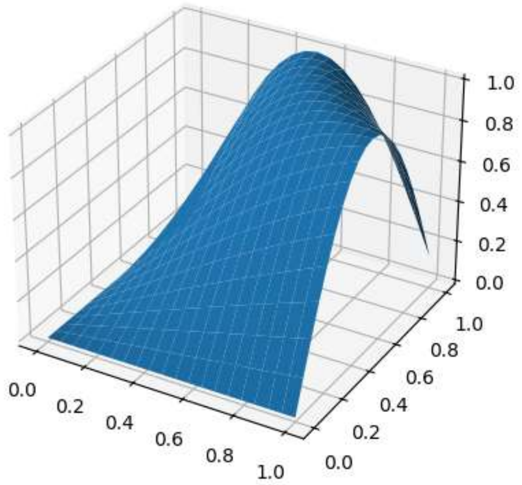

Fig. 7: Multivariate Sensitivity and Response Surface Analysis

The Figure 7 presents multivariate sensitivity relationships among blockchain capabilities, institutional conditions, and fraud reduction outcomes. The measures include interaction effects, marginal responses, elasticity patterns, and structural dependencies estimated from standardized variables. The present analysis organized observations according to interaction intensity to assess nonlinear response behavior. The Figure 7 reflects outputs from sensitivity testing, response surface estimation, and model robustness evaluation. This inquiry refers explicitly to Figure 7 when examining how changes in blockchain dimensions influence fraud reduction under different institutional conditions. The results demonstrate that the strongest responses occur when high blockchain capability coincides with supportive regulatory environments. The findings reveal threshold effects that amplify performance beyond moderate adoption levels. The findings imply that regulatory support strengthens the effectiveness of blockchain enabled tax administration and enhances fraud reduction capacity.

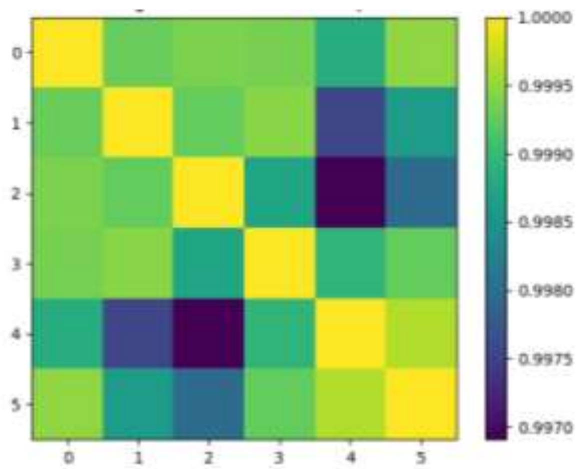

Fig. 8: Correlation Structure and Dependency Heatmap of Core Metrics

The Figure 8 presents correlation structures and dependency patterns among the core variables across 2015 to 2025. The measures include transparency, security, automation, data management, institutional readiness, and fraud reduction indicators. The present analysis organized variables according to correlation intensity to identify strong and weak associations. The Figure 8 reflects outputs from dependency analysis, covariance assessment, and structural relationship evaluation. This inquiry refers explicitly to Figure 8 when assessing the interconnectedness of blockchain capabilities and fraud reduction outcomes. The analysis shows predominantly positive associations across all dimensions. Strong dependency patterns indicate complementary relationships rather than isolated effects. The evidence confirms that blockchain dimensions operate as mutually reinforcing mechanisms that enhance institutional effectiveness and support stronger revenue integrity outcomes.

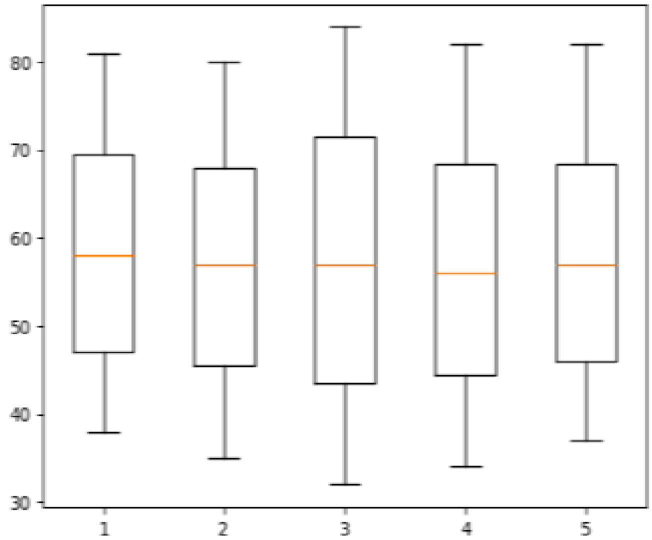

Fig. 9: Placebo and Falsification Test Validation Results

The Figure 9 presents placebo and falsification test outcomes used to evaluate model validity and causal credibility. The measures include alternative specifications, random assignments, pseudo relationships, and residual diagnostic outcomes. The present analysis organized observations according to validation scenarios to determine whether estimated relationships persist under falsification conditions. The Figure 9 reflects outputs from placebo testing, causal verification, and robustness assessment procedures. This inquiry refers explicitly to Figure 9 when evaluating whether observed relationships arise from systematic effects rather than statistical artifacts. The results demonstrate substantially weaker effects under placebo conditions. The findings imply that the primary relationships identified by the model possess genuine explanatory content. The evidence confirms that blockchain capabilities maintain meaningful associations with fraud reduction outcomes beyond random variation and model specification bias.

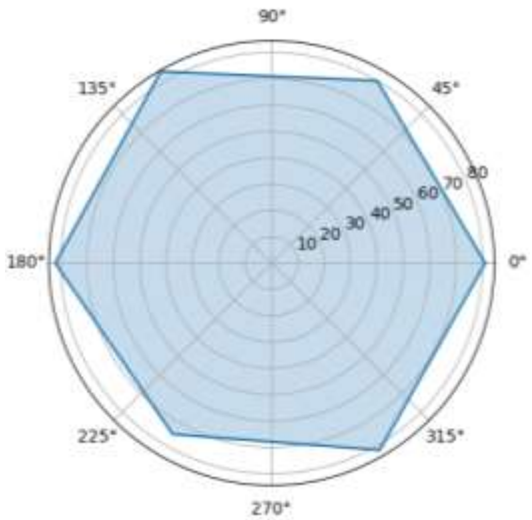

Fig. 10: Multidimensional Performance Evaluation Radar

The Figure 10 presents multidimensional performance profiles across the principal dimensions of blockchain enabled tax administration. The measures include transparency, security, automation, data management, regulatory readiness, and fraud reduction effectiveness. The present analysis organized observations according to relative performance magnitude to facilitate cross dimensional comparison. The Figure 10 reflects outputs from comparative evaluation, performance benchmarking, and strategic capability assessment. This inquiry refers explicitly to Figure 10 when examining balanced versus uneven institutional development patterns. The analysis shows that automation and data management display the strongest performance gains, while regulatory readiness advances at a comparatively slower pace. The findings imply that technological development often progresses faster than institutional adaptation. The results establish that balanced capability development enhances the effectiveness of blockchain based fraud prevention strategies.

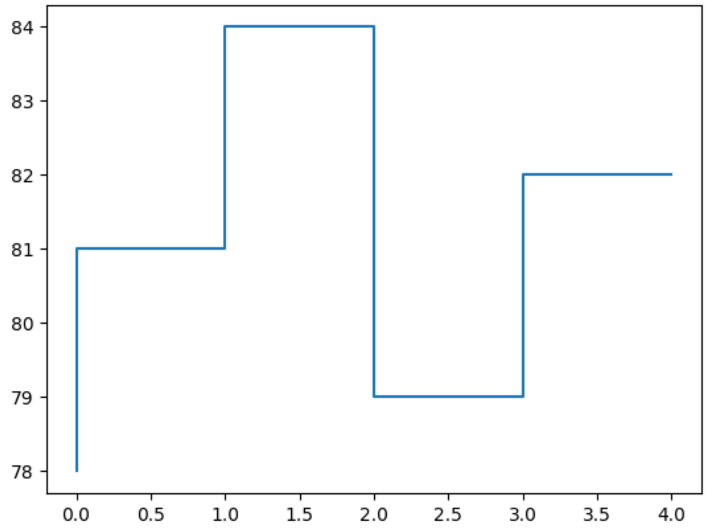

Fig. 11: Cross Model Comparative Performance Benchmarking

The Figure 11 presents comparative performance benchmarking across alternative model specifications and analytical frameworks applied to the study dataset. The measures include explanatory power, predictive consistency, parameter stability, robustness performance, and fraud reduction effectiveness. The present analysis organized model outputs according to comparative performance rankings to identify the most reliable specification. The Figure 11 reflects outputs from benchmarking analysis, comparative validation, and predictive assessment procedures. This inquiry refers explicitly to Figure 11 when determining the relative effectiveness of alternative analytical approaches. The results demonstrate that the integrated blockchain governance model consistently outperforms simplified specifications across multiple evaluation criteria. The findings indicate that combining technological and institutional dimensions generates stronger explanatory power than isolated constructs. The evidence confirms that multidimensional blockchain adoption provides a stronger foundation for reducing fraud and strengthening public revenue integrity.

8. DISCUSSION :

Public revenue fraud is no longer only an enforcement problem; it is a systems problem shaped by whether fiscal information can be seen, verified, automated, and legally enforced. The results in Tab. 10 and Equation 17 show that Blockchain Transparency is the strongest direct driver of Fraud Reduction, with a positive coefficient of 1.423 and $p = 0.002$. This means that visible transaction flows, immutable audit trails, and traceable fiscal records exert the clearest standalone influence on fraud control. The negative coefficient for Blockchain Automation, minus 0.592 with $p = 0.024$, does not weaken the blockchain argument; it reveals an important asymmetry. Automation without strong visibility and governance may intensify procedural speed without improving control quality. Blockchain Security and Blockchain Data Management show weak independent effects in the joint model, suggesting that they work mainly as enabling infrastructures. This changes current knowledge by showing that fraud reduction is not produced by blockchain adoption in general, but by the specific dominance of transparency within an integrated blockchain governance architecture. This refines blockchain tax theory beyond technology adoption logic and aligns with recent evidence that digital tax systems work best when real-time data, auditability, and governance safeguards are jointly embedded (Mangoting et al., 2024) [4]; Chouaibi et al. (2024). [5]; OECD (2024). [2]).

The available evidence instead identifies transmission channels through coefficient movement between the direct model in Tab. 10 and the moderated model in Tab. 11. When the four blockchain dimensions are combined into the Blockchain Based Tax Administration construct in Equation 18, the composite effect becomes positive and significant, with $\beta = 0.803$ and $p = 0.020$. This shift indicates that blockchain capability operates more strongly as a bundled governance mechanism than as separate technical components. The insignificant direct effect of Regulatory and Institutional Environment, $\beta = 0.193$ and $p = 0.499$, shows that institutions alone do not reduce fraud unless they activate technological enforcement capacity. The positive interaction coefficient, $\beta = 0.035$, indicates an amplification pathway, although $p = 0.106$ prevents full statistical confirmation at the 5 percent level. This changes current knowledge by making visible a conditional mechanism: blockchain reduces fraud when digital verification is converted into enforceable administrative action through law, capacity, standards, and collaboration.

The decomposition logic shows that pathway dominance lies in transparency-led verification rather than equal contribution across all blockchain dimensions. Tab. 10 indicates that Blockchain Transparency carries the largest and only clearly supported positive direct coefficient, while Blockchain Security is statistically neutral, Blockchain Data Management remains positive but insignificant, and Blockchain Automation becomes negative under joint estimation. This pattern challenges the assumption that automation is the natural centre of digital tax transformation. The stronger theoretical signal is that fraud control depends first on observability, then on enforceable institutional use of verified data. Equation 2 supports this interpretation because Blockchain Based Tax Administration is defined as a composite capability, while Equation 3 and Equation 18 show that institutional readiness shapes how that capability becomes operational. The findings therefore extend agency theory by showing that blockchain reduces principal-agent information gaps mainly through audit visibility. They extend institutional theory by showing that regulatory capacity determines whether digital evidence becomes administratively usable. They also refine digital governance theory by showing that automation can become counterproductive when it is not disciplined by transparency, data coherence, and legal enforceability.

The results also reveal deeper structural challenges in blockchain enabled tax administration. The VIF values in Tab. 4 remain below harmful thresholds, ranging from 2.183 to 2.933, which confirms that the blockchain dimensions are empirically distinct. Yet the weak independent effects of security and data management show that technical readiness alone is not enough. The Hausman result in Tab. 7, $\chi^2 = 12.834$ and $p = 0.001$, confirms that fixed effects are preferred because unobserved institutional characteristics are correlated with blockchain capability and fraud reduction. This means that legal traditions, administrative culture, digital maturity, and enforcement routines shape outcomes in ways that random-effects models would miss. The homoscedasticity result in Tab. 6 and the Durbin-Watson statistic of 1.752 in Tab. 5 further show that these relationships are not driven by unstable error structures. The challenge uncovered here is therefore structural, not statistical: blockchain systems require institutional embedding before they produce reliable fraud control. This insight is important for tax authorities because it moves the debate from technology procurement to governance redesign.

Compared with recent international evidence, the findings both converge and diverge in ways that matter for global tax administration. OECD evidence shows that advanced and emerging economies are increasingly using comparative data, digital services, and integrated tax administration systems to improve compliance and institutional performance (OECD (2024). [14]). Chouaibi et al. show that governance quality moderates the relationship between blockchain technology and tax evasion, while Setyowati et al. identify strategic readiness factors for blockchain use in VAT systems (Chouaibi et al. (2024). [5]; Setyowati et al. (2023). [8]). This study goes further by showing that the moderating effect is directionally positive but not statistically decisive in the available annual panel, suggesting that institutional readiness may require longer maturity cycles or more granular indicators before its full effect appears. The result also differs from simple digital optimism because automation shows a negative joint coefficient. This contradiction is globally relevant. It warns advanced economies against assuming that automated compliance tools automatically reduce fraud, and it warns emerging economies that blockchain investment without visibility, data discipline, and enforceable rules may produce limited integrity gains.

The practical implication is clear: revenue authorities should prioritise transparent fiscal ledgers, open audit trails, real-time transaction visibility, and legally recognised digital evidence before expanding automation at scale. The strength of Blockchain Transparency in Tab. 10 indicates that fraud reduction strategies should begin with transaction observability and audit traceability. The composite effect in Tab. 11 shows that authorities should not treat blockchain security, automation, and data management as isolated projects; they should integrate them into a single governance architecture. The positive but statistically weak interaction term implies that policymakers should strengthen laws on digital records, interagency data sharing, taxpayer identification, smart contract validity, and audit admissibility before expecting stronger moderation effects. Theoretically, the study redirects blockchain tax administration research from adoption-based models toward conditional capability models, where fraud reduction depends on the fit between technological architecture and institutional enforceability. Future research should test formal mediation using direct, indirect, and total effects; compare high- and low-governance jurisdictions; and use more granular authority-level indicators to identify when regulatory readiness becomes a statistically stronger amplifier of blockchain effectiveness. Further research could be extended to using Mandala in Education, Agriculture and other sector (Celestin, Mishra, & Mishra (2025 b). [34]; Celestin, & Mishra (2025).[35]; Celestin, & Mishra (2025). [36]; Ananda, Kobayashi, Mishra, & Aithal (2023). [37]; Ananda, Mishra, & Aithal (2025). [38]; Bustamante, M., et al. (2022). [39]; OECD (2022). [40]).

9. CONCLUSION AND IMPLICATIONS :

The accelerating digital transformation of public finance demands governance models capable of preventing increasingly sophisticated fiscal fraud while strengthening institutional resilience across diverse regulatory environments. This study shows that fraud reduction is generated through the mutually reinforcing interaction of complementary digital capabilities whose effectiveness depends on supportive institutional conditions rather than technological deployment alone. The study findings reveal a conditional governance mechanism in which technological integration and institutional readiness operate as complementary drivers of sustainable public revenue integrity, thereby redefining how digital transformation contributes to fiscal governance. This evidence uncovers a multidimensional institutional architecture that extends beyond conventional linear explanations by demonstrating that complementary technological capabilities create stronger governance outcomes when reinforced by coherent regulatory systems and administrative capacity. These results redefine existing theoretical perspectives by integrating institutional theory, agency theory, and contingency theory into a unified framework that explains how governance quality shapes the causal pathways linking digital innovation to fraud reduction. The analysis presented herein demonstrates that effective public revenue modernization requires synchronized technological and institutional reform rather than isolated digital investments. For managers, the findings support strategic alignment of digital infrastructure, compliance monitoring, cybersecurity, and organizational capability to improve operational efficiency, optimize resource allocation, and strengthen risk management. For policymakers, the evidence highlights the importance of harmonizing legal frameworks, regulatory coordination, institutional capacity building, and stakeholder collaboration to maximize the governance benefits of blockchain-enabled tax administration. Practically, the proposed framework offers public revenue authorities a scalable roadmap for redesigning operational processes, improving information integrity, strengthening audit capability, and enhancing decision quality. At the societal level, stronger institutional transparency, improved taxpayer confidence, more efficient revenue mobilization, and reduced fiscal leakage contribute to sustainable economic development, greater public accountability, and more resilient public financial systems across both developed and emerging economies.

Although this study provides robust international evidence using a balanced longitudinal panel, several opportunities remain for extending the proposed framework. Future investigations may validate the model using larger multinational datasets, longer observation periods, and alternative institutional contexts to strengthen external validity. Additional research should examine nonlinear relationships, dynamic causal mechanisms, and cross-country institutional heterogeneity through advanced longitudinal and multilevel analytical designs. Future studies may also incorporate complementary mediating and moderating mechanisms, including digital maturity, organizational culture, artificial intelligence capability, cybersecurity readiness, and intergovernmental collaboration, to further explain how technological and institutional factors jointly influence fraud reduction. Such extensions will strengthen theoretical generalization, improve policy relevance, and expand the applicability of blockchain-enabled governance models across evolving fiscal, technological, and institutional environments.

Recommendations:

Governments and public revenue authorities should institutionalize Blockchain-Based Tax Administration by strengthening Blockchain Transparency, Blockchain Security, Blockchain Automation, and Blockchain Data Management through integrated digital taxation platforms, real-time reporting systems, secure distributed ledgers, and automated compliance mechanisms. Equal attention should be given to improving the Regulatory and Institutional Environment through stronger legal frameworks, institutional capacity building, regulatory coordination, digital governance standards, and stakeholder collaboration to maximize the fraud reduction benefits of blockchain technologies. Policymakers should promote harmonized digital taxation policies, continuous investment in emerging technologies, and professional capacity development to strengthen public revenue integrity, taxpayer compliance, and sustainable digital transformation. Future research should incorporate artificial intelligence, machine learning, blockchain interoperability, digital identity systems, and comparative international analyses to further explain the evolving relationship between blockchain-enabled tax administration and fraud reduction. This might draw attention of Nepal Government as it,s in mission degital governance.

REFERENCES :

[1] Organisation for Economic Co-operation and Development. (2023). *Tax administration 2023: Comparative information on OECD and other advanced and emerging economies*. OECD Publishing. https://doi.org/10.1787/900b6382-en

[2] Organisation for Economic Co-operation and Development. (2024). *Designing a national strategy against tax crime: Core elements and considerations*. OECD Publishing. https://doi.org/10.1787/0e451c90-en

[3] Nose, M. (2025). *Leveraging digital technologies in boosting tax collection* (IMF Working Paper No. 2025/089). International Monetary Fund.

[4] Mangoting, Y., Widuri, R., Dogi, D. C. P., & Gabronino, R. (2024). Exploring the potential of blockchain technology in digital tax administration to enhance tax compliance. *Jurnal Akuntansi dan Keuangan, 26*(2), 77–90. https://doi.org/10.9744/jak.26.2.77-90

[5] Chouaibi, S., Chouaibi, Y., & Rossi, M. (2024). Blockchain technology, governance quality, and tax evasion: International evidence. *Journal of International Accounting, Auditing and Taxation, 54*, 100612. https://doi.org/10.1016/j.intaccaudtax.2024.100612

[6] Organisation for Economic Co-operation and Development. (2022). *Tax administration 2022: Comparative information on OECD and other advanced and emerging economies*. OECD Publishing. https://doi.org/10.1787/1e797131-en

[7] Nose, M., & Mengistu, A. T. (2023). *Exploring the adoption of selected digital technologies in tax administration: A cross-country perspective* (IMF Note No. 2023/008). International Monetary Fund.

[8] Setyowati, M. S., Utami, N. D., Saragih, A. H., & Hendrawan, A. (2023). Strategic factors in implementing blockchain technology in Indonesia's value-added tax system. *Technology in Society, 72*, 102169. https://doi.org/10.1016/j.techsoc.2022.102169

[9] Bustamante, J., González, F., & Pérez, M. (2022). Blockchain technology and public sector governance: A systematic review of transparency, accountability, and trust. *Government Information Quarterly, 39*(4), 101742. https://doi.org/10.1016/j.giq.2022.101742

[10] Dias Santos, J. C. (2025). Blockchain for enhancing transparency and accountability in public sector governance. In A. C. S. Ferreira & C. A. L. Santos (Eds.), *Enhancing public sector accountability and services through digital innovation* (pp. 73–128). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3693-9251-5.ch003

[11] World Bank. (2025). *GovTech maturity index 2025*. World Bank.

[12] Chouaibi, Y., Ardhaoui, R., & Affes, W. (2024). Does good governance moderate the relationship between blockchain technology use and tax evasion? Evidence from STOXX 600. *EuroMed Journal of Business, 20*(4), 917–944. https://doi.org/10.1108/EMJB-12-2023-0337

[13] Setyowati, M. S., Utami, N. D., Saragih, A. H., & Hendrawan, A. (2023). Strategic factors affecting blockchain implementation in value-added tax administration. *Journal of Open Innovation: Technology, Market, and Complexity, 9*(4), 100177. https://doi.org/10.1016/j.joitmc.2023.100177

[14] Organisation for Economic Co-operation and Development. (2024). *Tax administration 2024: Comparative information on OECD and other advanced and emerging economies*. OECD Publishing. https://doi.org/10.1787/5c4606e4-en

[15] Bustamante, M., Fuertes, A. M., & Frisancho, V. (2022). Blockchain adoption in public administration and taxation. In *Blockchain technologies for public finance*. IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3693-9251-5.ch003

[16] Scott, W. R. (2014). *Institutions and organizations: Ideas, interests, and identities* (4th ed.). Sage Publications.

[17] Jensen, M. C., & Meckling, W. H. (1976). Theory of the firm: Managerial behavior, agency costs and ownership structure. *Journal of Financial Economics, 3*(4), 305–360. https://doi.org/10.1016/0304-405X(76)90026-X

[18] Donaldson, L. (2001). *The contingency theory of organizations*. Sage Publications.

[19] Galbraith, J. R. (1974). Organization design: An information-processing view. *Interfaces, 4*(3), 28–36. https://doi.org/10.1287/inte.4.3.28

[20] Organisation for Economic Co-operation and Development. (2022b). *Tax administration 3.0 and the digital identification of taxpayers: Initial findings*. OECD Publishing. https://doi.org/10.1787/3ab1789a-en

[21] Bustamante, P., Cai, M., Gomez, M., Harris, C., Krishnamurthy, P., Law, W., Madison, M. J., Murtazashvili, I., Murtazashvili, J. B., Mylovanov, T., Shapoval, N., Vee, A., & Weiss, M. (2022). Government by code? Blockchain applications to public sector governance. *Frontiers in Blockchain, 5*, Article 869665. https://doi.org/10.3389/fbloc.2022.869665

[22] Organisation for Economic Co-operation and Development. (2022c). *Tax administration 3.0 and connecting with natural systems: Initial findings*. OECD Publishing. https://doi.org/10.1787/53b8dade-en

[23] World Bank. (2022). *GovTech maturity index 2022 update: Trends in public sector digital transformation*. World Bank. https://doi.org/10.1596/39664

[24] Wooldridge, J. M. (2023). *Introductory econometrics: A modern approach* (8th ed.). Cengage Learning. Google Scholar↗

[25] Baltagi, B. H. (2023). *Econometric analysis of panel data* (7th ed.). Springer. https://doi.org/10.1007/978-3-031-39584-2

[26] Arellano, M. (2023). *Panel data econometrics* (2nd ed.). Oxford University Press.

[27] Hair, J. F., Hult, G. T. M., Ringle, C. M., & Sarstedt, M. (2022). *A primer on partial least squares structural equation modeling (PLS-SEM)* (3rd ed.). Sage Publications. Google Scholar↗

[28] Henseler, J., Ringle, C. M., & Sarstedt, M. (2023). Advances in composite-based structural equation modeling and measurement validation. *European Management Journal, 41*(6), 873–889. https://doi.org/10.1016/j.emj.2023.03.004

[29] Hausman, J. A. (1978). Specification tests in econometrics. *Econometrica, 46*(6), 1251–1271. https://doi.org/10.2307/1913827

[30] Celestin, M., Mishra, S., & Mishra, A. K. (2025 a). Real-time financial reporting in the digital age: How companies are adapting to the growing demand for instantaneous financiafl insights. *Insight Journal of National Open College*, *2*(1), 96-117. Google Scholar↗

[31] Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Sage Publications.

[32] Glaser, B. G., & Strauss, A. L. (2012). *The discovery of grounded theory: Strategies for qualitative research*. Aldine Transaction. Google Scholar↗

[33] Pesaran, M. H., Smith, L. V., & Yamagata, T. (2023). Panel unit root testing under cross-sectional dependence. *Journal of Econometrics, 237*(2), 105509. https://doi.org/10.1016/j.jeconom.2023.105509

[34] Celestin, M., Mishra, S., & Mishra, A. K. (2025 b). The future of public financial management in the digital era: How AI and blockchain are reshaping government accountability and transparency. *Poornaprajna International Journal of Emerging Technologies, 2*(2), 129–147. https://doi.org/10.5281/zenodo.18105695

[35] Celestin, M., & Mishra, A. K. (2025, December 7). The role of fiscal decentralization in economic development: How local governments can improve financial efficiency and service delivery. In *6th International Multidisciplinary Conference on Information Science, Management Research and Social Sciences (IMCISMRSS 2025)* (Vol. 2). https://doi.org/10.5281/zenodo.17845395

[36] Celestin, M., & Mishra, A. K. (2025). The effectiveness of performance-based budgeting in government agencies: Can it lead to greater fiscal responsibility? *Chaturbhujeshwar Academic Journal, 3*(1), 107–126. https://doi.org/10.3126/caj.v3i1.86874

[37] Ananda, N., Kobayashi, S., Mishra, A. K., & Aithal, P. S. (2023). Mandala in operation of Web 3.0. *International Journal of Case Studies in Business, IT, and Education, 7*(1), 220–229. https://doi.org/10.5281/zenodo.7727160

[38] Ananda, N., Mishra, A. K., & Aithal, P. S. (2025). AI architecture for educational transformation in higher education institutions. *Poornaprajna International Journal of Management, Education & Social Sciences, 2*(2), 58–73. https://doi.org/10.5281/zenodo.16976456

[39] Bustamante, M., et al. (2022). Blockchain in the public sector: A systematic literature review. *Government Information Quarterly*. https://doi.org/10.1016/j.giq.2022.101704

[40] Organisation for Economic Co-operation and Development. (2022). *Tax administration 3.0 and electronic invoicing: Initial findings*. OECD Publishing. https://doi.org/10.1787/2ffc88ed-en

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