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Research Article

BLOCKCHAIN TRANSPARENCY AS A DIGITAL GOVERNANCE MECHANISM: EVIDENCE FROM PRICE TRANSMISSION AND VALUE DISTRIBUTION IN AGRIBUSINESS SUPPLY CHAINS

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Abstract
Price transmission asymmetry and unequal value capture remain persistent inefficiencies in smallholder-based agro-processing chains. This study investigates whether blockchain-enabled transparency functions as digital governance that improves price adjustment efficiency and promotes fairer value distribution in agricultural supply chains. An integrated Error Correction Model (ECM) and Vector Error Correction Model (VECM) framework is applied to estimate short-run and long-run price dynamics between farm-gate cassava prices and downstream processing prices. A Blockchain Transparency Index (BTI), capturing transaction coverage, timeliness, and contractual automation, is constructed and incorporated as an interaction term to test its moderating role, while farmer price share ratios and value dispersion indices assess distributional outcomes. The results confirm cointegration and asymmetric price transmission along the chain; higher blockchain transparency significantly accelerates adjustment toward long-run equilibrium, reduces transmission asymmetry, increases farmer price shares, and lowers value dispersion. Drawing on Resource-Based View and Institutional Economics, the findings demonstrate that blockchain transparency operates as a strategic digital capability and governance mechanism that reduces information asymmetry and transaction costs. By embedding a measurable digital governance index within dynamic price transmission modeling, this study provides novel empirical evidence linking technological transparency to distributional and welfare-related outcomes. The results imply that cooperative-led blockchain governance offers a scalable pathway for aligning efficiency and equity in emerging agri-food systems.

Keywords: Blockchain Transparency, Cooperatives, Digital Governance, ECM–VECM, Price Transmission

INTRODUCTION

Agribusiness supply chains in developing economies are frequently characterized by asymmetric price transmission, opaque pricing mechanisms, and unequal value capture, particularly affecting smallholders, producer organizations, and small and medium-sized enterprises (SMEs) (von Cramon-Taubadel & Goodwin, 2021; Barrett et al., 2022). In Indonesia, cassava (*Manihot esculenta*) plays a strategic role in rural livelihoods and serves as a primary raw material for the tapioca processing industry. Consequently, distortions in cassava price dynamics can directly affect farmer income stability, cooperative performance, and the competitiveness of downstream processing SMEs within regional agri-food value chains (Minten et al., 2021; Reardon et al., 2020).

Extensive literature on agricultural price transmission demonstrates that adjustment processes across supply chain stages are often incomplete and asymmetric, shaped by transaction costs, bargaining power imbalances, and institutional frictions (von Cramon-Taubadel & Goodwin, 2021; Panagiotou, 2021). Empirical studies in Southeast Asian agricultural markets further document significant price volatility and cross-scale spillovers, particularly in staple crop value chains such as cassava, where market coordination remains relatively weak (Harshana & Ratnasiri, 2023). While these studies provide substantial evidence of transmission inefficiencies, limited attention has been given to governance mechanisms capable of structurally improving both price adjustment efficiency and value distribution outcomes within cooperative-mediated business-to-business (B2B) supply chains.

At the same time, blockchain-based transparency mechanisms are increasingly promoted as digital solutions for reducing information asymmetry and improving coordination among supply chain actors (Kamilaris et al., 2019; Kouhizadeh et al., 2021). Through immutable ledgers, smart contracts, and decentralized verification processes, blockchain systems can potentially enhance trust, reduce monitoring costs, and strengthen contractual compliance within agri-food value chains (Treiblmaier, 2018; Centobelli et al., 2021). However, most existing blockchain applications in agriculture primarily emphasize traceability and technical feasibility rather than rigorously testing their measurable economic impact on market performance, including price transmission elasticity, asymmetry, and margin allocation (Rejeb et al., 2021; Nakasumi, 2022). Without empirical validation, digital governance interventions risk being adopted normatively without clear evidence of efficiency improvements or welfare gains across supply chain participants.

The cassava–tapioca supply chain in Indonesia, mediated by cooperatives such as the Bogor Cassava Center (BCC), demonstrates heterogeneity in productivity and value capture. Using a panel of 30 decision-making units (DMUs) observed over 2020–2024 (150 observations), key descriptive statistics indicate: 1) Mean cassava production: 17.9 t per DMU-year (min 9.6, max 25.1); 2) Mean tapioca production: 3.6 t per DMU-year; 3) Tapioca/cassava conversion ratio: 38%, reflecting processing heterogeneity; 4) Average sales value: IDR 3.8 million per DMU-year, with wide dispersion; 5) Institutional gaps: 30% of DMUs access formal credit; 20% receive training. These patterns highlight technical and institutional heterogeneity that drives differences in observed margin allocation and provide the empirical foundation for examining price transmission and value distribution across cooperative-mediated B2B chains.

Distributed ledger technologies (blockchain), particularly permissioned consortium architectures, have been proposed as mechanisms to reduce information asymmetry, enhance traceability, and automate value distribution through smart contracts (Kamilaris et al., 2019; Kouhizadeh et al., 2021). Systematic reviews document a growing number of pilot implementations in agri-food systems, showing improvements in provenance tracking, accountability, and transaction reconciliation across supply chain actors (Rejeb et al., 2021; Centobelli et al., 2021).

Conceptual and prototype-based studies further suggest that blockchain applications may influence business-to-business (B2B) agricultural markets through several mechanisms. First, distributed ledgers allow input costs and transaction records to be recorded transparently across participants, thereby reducing information asymmetry (Treiblmaier, 2018). Second, timestamped procurement records combined with automated payment systems can improve contractual reliability and reduce settlement delays (Kshetri, 2018). Third, smart contracts enable the enforcement of quality- and quantity-based pricing rules that are executed automatically once pre-defined conditions are verified within the system (Zhao et al., 2019). Despite these promising features, most existing studies remain technical demonstrations or simulation-based experiments. Empirical field-based evidence linking blockchain-enabled transparency to measurable economic outcomes—such as price transmission asymmetry, coordination efficiency, and value allocation across supply chain actors—remains limited (Rejeb et al., 2021; Kouhizadeh et al., 2021). This gap provides a strong motivation for empirical evaluation in Indonesia's cassava–tapioca sector, where cooperative-mediated supply chains offer a suitable context for examining the economic implications of blockchain-based governance.

To the best of our knowledge, this study represents one of the first empirical efforts in the Indonesian cassava–tapioca context to integrate digital governance through blockchain transparency into a dynamic framework of price transmission and value distribution within cooperative-mediated supply chains. Recent studies emphasize that blockchain-enabled transparency can fundamentally alter information flows and coordination mechanisms across agri-food value chains (Kamilaris et al., 2019; Kouhizadeh et al., 2021). However, empirical analyses linking such digital governance mechanisms to price transmission dynamics and distributional outcomes remain limited, particularly in emerging agricultural economies (Panagiotou, 2021; Rejeb et al., 2021). This study introduces a Blockchain Transparency Index (BTI) as an interaction term in ECM/VECM models, thereby endogenizing digital governance within the dynamic price adjustment process. By incorporating blockchain transparency into econometric models of price transmission, the analysis extends existing approaches that typically treat governance conditions as exogenous institutional factors

Despite advances in price transmission and blockchain research, three gaps remain: Modeling Gap: Dynamic econometric models (ECM/VECM, ARDL, threshold models) rarely incorporate digital governance variables as endogenous moderators affecting adjustment speed and equilibrium dynamics (Treiblmaier, 2018; Centobelli et al., 2021; von Cramon-Taubadel & Goodwin, 2021; Panagiotou, 2021). Blockchain studies primarily focus on traceability systems and operational efficiency, but seldom test the economic effects of ledger transparency on price pass-through mechanisms or distributional fairness among supply chain actors (Rejeb et al., 2021; Centobelli et al., 2021). Value distribution is often analyzed descriptively without embedding distributive outcomes within dynamic price transmission models, leaving the relationship between adjustment efficiency and distributional fairness largely untested in empirical agribusiness research (Kshetri, 2018; Minten et al., 2021; Rejeb et al., 2021). Addressing these gaps requires empirical micro-level analysis of how blockchain-enabled transparency may simultaneously affect price adjustment efficiency and value capture distribution within cooperative-mediated supply chains.

Given the strategic importance of cassava for rural economies and agro-industrial supply chains, and the growing institutional interest in blockchain-enabled cooperative governance, empirical evaluation is urgently required. Cassava value chains contribute significantly to rural income and agro-processing linkages, while digital technologies are increasingly promoted to improve transparency and coordination across agri-food supply chains (Reardon et al., 2020, p. 458; Kamilaris et al., 2019, p. 644). Blockchain-based governance frameworks are therefore gaining attention as mechanisms to strengthen traceability, trust, and contractual compliance among supply chain actors (Kouhizadeh et al., 2021; Centobelli et al., 2021).

This study addresses this need by operationalizing blockchain transparency as a measurable governance mechanism through the construction of a Blockchain Transparency Index (BTI). Rather than treating transparency as an exogenous condition, the analysis embeds BTI within an ECM/VECM framework to examine whether digital governance moderates price transmission dynamics and affects value distribution outcomes (von Cramon-Taubadel & Goodwin, 2021). By combining dynamic econometric modeling with distributional metrics, the study evaluates both coordination efficiency—reflected in the speed and symmetry of price adjustment—and distributive fairness through farmer price share and margin dispersion. This integrated approach responds to recent calls for empirical research linking digital governance innovations with measurable economic outcomes in agri-food systems (Rejeb et al., 2021).

Accordingly, this study aims to:

1. Estimate short-run and long-run price transmission dynamics between farm-gate cassava prices and downstream tapioca prices.
2. Measure distributional fairness along the value chain using farmer price share and value dispersion indicators.
3. Assess the moderating effect of blockchain-enabled transparency (BTI) on price adjustment speed, asymmetry, and value allocation outcomes.

Explain how digital transparency reshapes governance and coordination mechanisms in cooperative-based agribusiness systems.

LITERATURE REVIEW

Price Transmission in Agricultural Markets — Theory and Empirical Methods

The literature on agricultural price transmission has evolved from simple pass-through measures toward dynamic econometric frameworks that capture short-run adjustment, long-run equilibrium, and asymmetric responses to market shocks. Contemporary analyses emphasize the role of temporal, spatial, and functional separations, as well as transaction and storage costs that introduce frictions and nonlinearities in price adjustment (von Cramon-Taubadel & Goodwin, 2021). As a result, cointegration-based and nonlinear approaches—including ECM/VECM, ARDL, threshold, regime-switching, and asymmetric adjustment models such as TAR and M-TAR—have become standard tools for identifying differences in the speed and magnitude of upward versus downward price transmission (Panagiotou, 2021).

Recent empirical studies show that agricultural price transmission is frequently incomplete and asymmetric, with adjustment patterns shaped by market structure, bargaining power, and institutional constraints such as processing capacity and contractual arrangements (Minten et al., 2021). Transmission dynamics also vary across commodities and organizational settings, highlighting the need for commodity-specific B2B analyses—particularly within cooperative–SME supply chains—rather than relying on cross-commodity generalizations (Reardon et al., 2020).

Blockchain and Distributed Ledger Technologies in Food / Agri-Supply Chains

A growing body of literature examines blockchain applications in agri-food supply chains, with reviews consistently highlighting benefits related to traceability, provenance verification, data integrity, and operational transparency (Kamilaris et al., 2019; Rejeb et al., 2021). While blockchain is often claimed to improve verifiability, automate contractual execution through smart contracts, and reduce transaction costs, empirical evidence quantifying its economic impacts—such as changes in price transmission elasticity or margin distribution—remains limited (Kouhizadeh et al., 2021; Centobelli et al., 2021). This gap motivates integrating a ledger-based transparency indicator into standard econometric analyses of price pass-through and value distribution.

Edited volumes and practitioner-oriented studies also document emerging use cases of permissioned blockchains and IoT-enabled traceability systems in food supply chains, providing practical insights for designing smart-contract rules and constructing transparency metrics such as a Blockchain Transparency Index (BTI) (Treiblmaier, 2018). However, these contributions remain largely descriptive and rarely include rigorous econometric evaluation. More focused reviews identify persistent implementation constraints—including data quality issues, onboarding costs for smallholders, governance challenges in consortium blockchains, and regulatory uncertainty—which may limit blockchain's short-run impact on market outcomes (Rejeb et al., 2021). Consequently, blockchain adoption should be treated empirically as a conditional moderator whose effectiveness depends on complementary institutional supports such as training, credit access, and contract enforcement (Kouhizadeh et al., 2021).

Value Distribution and Fairness in Supply Chains (Theory and Applied Evidence)

Recent research in supply-chain management and agri-food systems increasingly positions fairness—alongside efficiency and sustainability—as a key performance outcome (Centobelli et al., 2021; Reardon et al., 2020). Fairness is commonly conceptualized in two dimensions: distributive fairness, referring to how value or margins are shared among actors such as farmers, processors, and retailers, and procedural fairness, concerning transparency and equity in contracts, pricing rules, and dispute-resolution mechanisms (Minten et al., 2021). Reviews indicate that fairness considerations influence contract design, pricing behavior, and coordination structures, and that neglecting them can weaken trust and reduce long-term supply-chain performance (Kouhizadeh et al., 2021).

Empirical studies further suggest that transparency and credible sharing rules—such as contract farming arrangements, revenue-sharing schemes, or smart-contract–based allocations—can improve perceived fairness and compliance among supply chain actors (Treiblmaier, 2018). However, fairness outcomes remain strongly mediated by market power and institutional capacity, as actors with stronger bargaining positions may still capture disproportionate gains unless transparency is supported by enforceable governance arrangements (Rejeb et al., 2021). Consequently, technological transparency alone is insufficient and must be embedded within cooperative governance rules, legal enforcement, and inclusive decision-making structures to translate visibility into equitable value distribution.

Synthesis and Implications for the Current Study

The three literature strands point to convergent conclusions that directly motivate this study's design. First, price-transmission methods—such as ECM/VECM, ARDL, and asymmetric or regime-switching models—are well established for testing elasticity and asymmetry in agricultural markets and remain appropriate for analyzing price adjustment dynamics in the cassava–tapioca supply chain (von Cramon-Taubadel & Goodwin, 2021; Panagiotou, 2021). Second, blockchain technologies offer conceptual mechanisms to enhance transparency and enforce predefined value-sharing rules through smart contracts. However, the empirical literature has yet to produce robust causal evidence that ledger transparency alters price transmission patterns or margin distribution in B2B agribusiness contexts (Rejeb et al., 2021; Kouhizadeh et al., 2021). Third, fairness-oriented research indicates that transparency alone is insufficient; governance structures, access to finance, and capacity-building mechanisms act as important moderators influencing value distribution outcomes across supply chain actors (Minten et al., 2021; Centobelli et al., 2021). Together, these findings justify: (a) measuring price transmission and asymmetry using established econometric approaches; (b) constructing a Blockchain Transparency Index (BTI) to test moderation effects; and (c) controlling for institutional variables such as credit access and training when assessing impacts on value distribution and welfare.

Conceptual Framework of Blockchain-Based Value Distribution and Price Transmission in B2B Agribusiness Supply Chains

This conceptual framework integrates economic, distributive, and technological dimensions to explain performance and welfare outcomes in the agribusiness supply chain. Hypotheses H1 and H2 examine the role of price transmission as a key economic mechanism influencing value distribution and supply chain efficiency, while H3 and H4 focus on fairness and margin allocation within the value distribution process. Hypotheses H5 and H6 assess the moderating effects of the Blockchain Transparency Index (BTI) on price transmission and value distribution through enhanced transparency and enforcement. Furthermore, H7 evaluates the impact of supply chain efficiency on production performance, and H8 analyzes its implications for actor welfare and economic benefits.

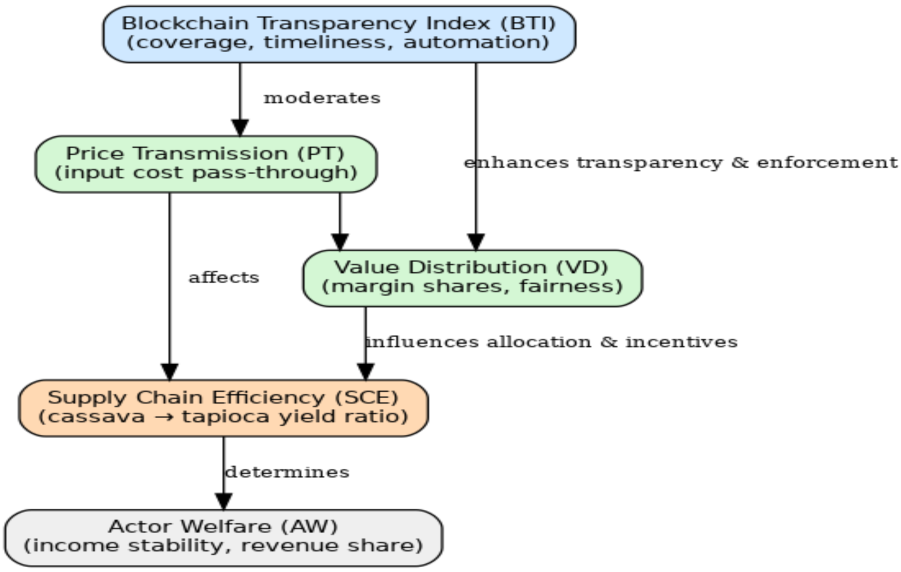

Figure 1. Conceptual Framework

Hypothesis

We restate the study hypotheses in a compact form table 1.

Table 1. Analytical Hypotheses Framework

Analysis Aspect	Research Hypothesis (H)	Rationale / Basis
Price Transmission (PT)	H1: Changes in cassava farmer prices are significantly transmitted to BCC tapioca prices and SME input prices.	Based on *price transmission theory*, input prices proportionally affect B2B output prices along the agribusiness supply chain.
	H2: Price transmission is asymmetric; increases in cassava prices are transmitted faster than decreases.	Common in agribusiness: *price stickiness* and bargaining power of cooperatives/SMEs.

Analysis Aspect	Research Hypothesis (H)	Rationale / Basis
Value Distribution (VD)	H3: Blockchain-based value distribution increases fairness of margins among actors (farmers, BCC, SMEs) compared to conventional supply chains.	Blockchain transparency enables more equitable margin allocation and reduces *information asymmetry*.
	H4: BCC (cooperative) margins are more stable and proportional under blockchain compared to non-blockchain operations.	Smart contracts and blockchain ledgers reduce margin distortions caused by markups or administrative costs.
Blockchain Transparency (BTI)	H5: Blockchain adoption at BCC improves the efficiency of price transmission from farmers to SMEs.	Real-time transaction recording allows input price changes to be quickly reflected in B2B output prices.
	H6: The level of blockchain transparency (BTI) positively affects the proportion of value received by farmers.	Transparent ledgers ensure farmers receive a fair share of the margin relative to their contribution.
Supply Chain Efficiency	H7: Blockchain-based supply chains are more efficient (lower transaction costs) than conventional chains.	Reduction of intermediaries and digital recording reduces administrative and monitoring costs.
Actor Welfare	H8: Blockchain implementation increases the value-added share for farmers and SMEs compared to pre-blockchain conditions.	Transparency and fair value distribution improve economic welfare of all supply chain actors.

RESEARCH METHOD

This study employs a quantitative explanatory design to examine price transmission dynamics and value distribution within a cooperative-mediated B2B cassava–tapioca supply chain, and to evaluate whether blockchain-enabled transparency moderates market adjustment and distributional outcomes. The analytical framework integrates: Time-series econometric modeling (cointegration and ECM/VECM), Moderation analysis using a Blockchain Transparency Index (BTI), Distributional inequality measurement. The unit of analysis is the price linkage between cassava farmers and SME tapioca processors operating under the Bogor Cassava Center (BCC) cooperative system in West Java, Indonesia.

Monthly price and transaction records (2020–2024) were obtained from: Cooperative procurement ledgers, SME accounting records, and Blockchain-based transaction logs. The dataset includes farm-gate cassava prices and SME-level tapioca prices recorded within the cooperative's B2B structure. Structured questionnaires were administered to: 30 cassava farmers and 5 SME processors. The survey measured blockchain transparency dimensions used to construct the Blockchain Transparency Index (BTI). Purposive sampling was applied to include only actors actively participating in blockchain-recorded transactions.

Farm-gate cassava price:

$$P_t^{farmer} = \frac{Total\ Cassava\ Revenue_t}{Cassava\ Volume_t} \dots (1)$$

SME tapioca price:

$$P_t^{sme} = \frac{Total\ Cassava\ Revenue_t}{\text{Tapioca Output}_t} \dots (2)$$

All prices are transformed into natural logarithms:

$$p_t^{fatm} = ln\left(p\ _t^{farm}\right) \qquad p_t^{sme} = ln(p\ _t^{sme}) \dots (3)$$

BTI is constructed as a continuous index:

$$BTI_t = \frac{1}{5}\sum_{i=1}^{5} D_{it} \dots (4)$$

Where D_{it} represents standardized scores for: Transaction visibility, Cost disclosure, Contract immutability, Reconciliation speed

Farmer Price Share (FPS):

$$FPS_t = \frac{P_t^{farmer}}{P_t^{sme}} x\ 100 \dots (5)$$

Gini coefficient of value capture:

$$G = 1 - \sum(Y_i + Y_{i-1})\,(X_i - X_{i-1}) \ldots (6)$$

Where:
X_i = cumulative proportion of actors
Y_i = cumulative share of value added.

Step 1: Stationarity Testing

Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests were applied:

$$\Delta Y_t = \alpha + \beta t + \gamma Y_{t-1} + \sum_{i=1}^{k} \delta_i\, \Delta Y_{t-i} + \varepsilon_t \ldots (7)$$

Step 2: Johansen Cointegration Test

Long-run equilibrium relationships were examined using the Johansen approach:

$$\Delta X_t = \Pi X_{t-1} + \sum_{i=1}^{k-1} \Gamma_i\, \Delta X_{t-i} + \varepsilon_t \ldots (8)$$

Where:

$$X_t = \left(p_t^{farmer} . p_t^{sme}\right)' \ldots (9)$$

If cointegration is confirmed, an ECM/VECM is estimated.

Step 3: Baseline Error Correction Model

$$\Delta p_t^{sme} = \alpha + \beta \Delta p_t^{farmer} + \lambda ECT_{t-1} + \varepsilon_t \ldots (10)$$

Where:

ECT_{t-1} is the lagged residual from the long-run equation,
λ captures speed of adjustment.

Step 4: Moderated ECM (Digital Governance Embedded)

To examine the moderating role of blockchain transparency:

$$\Delta p_t^{sme} = \beta_1 \Delta p_t^{farmer} + \beta_2(\Delta p_t^{farmer} \times BTI_t) + \lambda_1 ECT_{t-1} + \lambda_2(ECT_{t-1} \times BTI_t) + \varepsilon_t \ldots (11)$$

Interpretation:
β_2 measures the effect of BTI on price pass-through elasticity.
λ_2 measures the effect of BTI on equilibrium adjustment speed.

A statistically significant negative λ_2 indicates accelerated convergence under higher transparency.

Step 5: Asymmetric Price Transmission

Threshold ECM specification:

$$\Delta p_t^{farmer+} = max\,(\Delta p_t^{farmer}, 0) \ldots (12)$$
$$\Delta p_t^{farmer-} = min\left(\Delta p_t^{farmer}, 0\right) \ldots (13)$$

RESULTS AND DISCUSSION

Descriptive Statistics and Preliminary Findings

The descriptive characteristics of key production and performance variables across decision-making units (DMUs) provide an overview of heterogeneity within the cooperative-based cassava–tapioca supply chain. Descriptive statistics are commonly used to identify variability in production scale, processing efficiency, and market outcomes prior to econometric analysis (Parmeter & Sickles, 2020; Minten et al., 2021). The results indicate dispersion in output levels, cassava–tapioca conversion efficiency, and sales performance during 2020–2024. Table 2 reports the mean, minimum, maximum, and standard deviation of the principal variables used in the analysis.

Table 2. Descriptive Statistics of Key Variables across DMUs (2020–2024)

Variable	Mean	Min	Max	Std. Dev.
Cassava Input (tons)	17.8	10.5	25.2	3.4
Tapioca Output (tons)	6.8	3.1	10.5	2.1
Yield Ratio (Output/Input)	0.38	0.32	0.45	0.04
Sales Value (IDR million)	58.2	28.5	112.4	19.7
Blockchain Transparency Index (BTI)	0.62	0.41	0.78	0.09

Note: Values are computed from DMU dataset supplied by the authors; sales value converted to million IDR.

As shown in Table 2, cassava production per DMU-year exhibits substantial variation, indicating differences in farm capacity and input utilization. The dispersion in the tapioca conversion ratio suggests heterogeneous processing efficiency and post-harvest handling. The wide spread in sales values further reflects uneven market performance and value capture across units. Such heterogeneity is commonly observed in smallholder-based agribusiness systems and can influence productivity and market outcomes (Parmeter & Sickles, 2020; Minten et al., 2021). This variability provides empirical motivation for subsequent efficiency and price transmission analyses, particularly in assessing whether blockchain transparency moderates adjustment dynamics and distributional outcomes.

To further illustrate cross-unit variation at the farm level, the distribution of cassava input across decision-making units (DMUs) is visualized. Figure 1 presents the spread of cassava production over the 2020–2024 period.

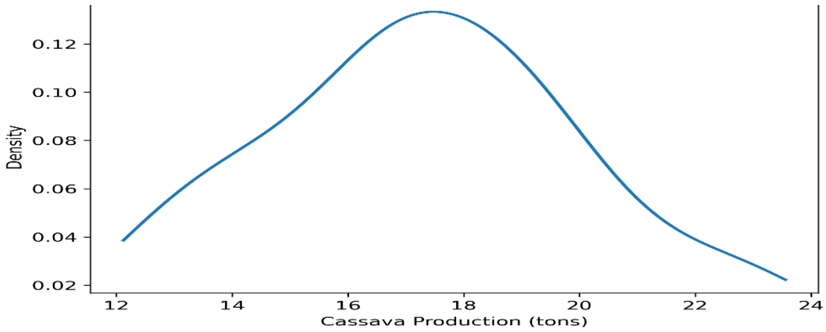

Figure 1. Distribution of Cassava Input Across Decision-Making Units (2020–2024)

As shown in Figure 1, cassava input is unevenly distributed across DMUs, with several units operating at substantially higher production levels than others. This pattern indicates moderate concentration rather than uniform capacity, reflecting structural differences in farm scale and input utilization. Such variability is typical in smallholder-based agri-food systems and may influence both productivity and market performance (Minten et al., 2021). This variation provides an empirical basis for subsequent efficiency estimation and price transmission analysis, as input scale can affect conversion performance and value capture outcomes (Parmeter & Sickles, 2020).

To examine the production relationship between upstream input and downstream output, the association between cassava input and tapioca output across DMUs is visualized. Figure 2 illustrates the relationship between cassava production and resulting tapioca output during the 2020–2024 period.

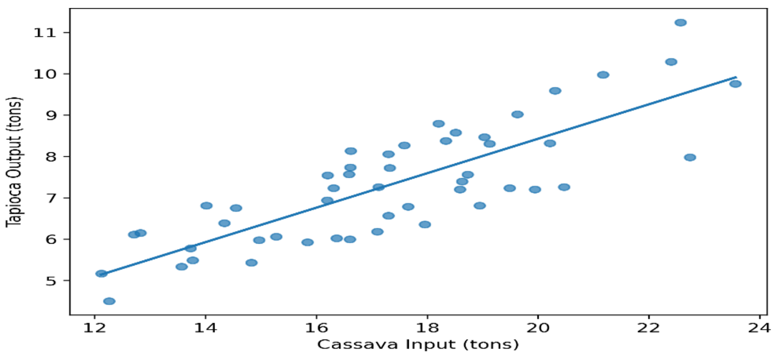

Figure 2. Relationship Between Cassava Input and Tapioca Output

As shown in Figure 2, cassava input and tapioca output display a positive but heterogeneous relationship. Higher cassava input generally corresponds to higher tapioca production, but dispersion around the implied production frontier indicates differences in conversion efficiency across DMUs. Some units achieve higher output for comparable input levels, suggesting superior processing performance, while others operate below potential efficiency levels. Such heterogeneity in input–output relationships is typical in smallholder-based processing systems and often reflects variations in technology, management, and resource use (Parmeter & Sickles, 2020). This variation justifies subsequent efficiency estimation and the need to control for performance differences in price transmission analysis (Minten et al., 2021).

To further assess processing performance across units, the distribution of yield ratios is examined. Figure 3 presents the distribution of tapioca-to-cassava conversion ratios across decision-making units (DMUs) over the 2020–2024 period.

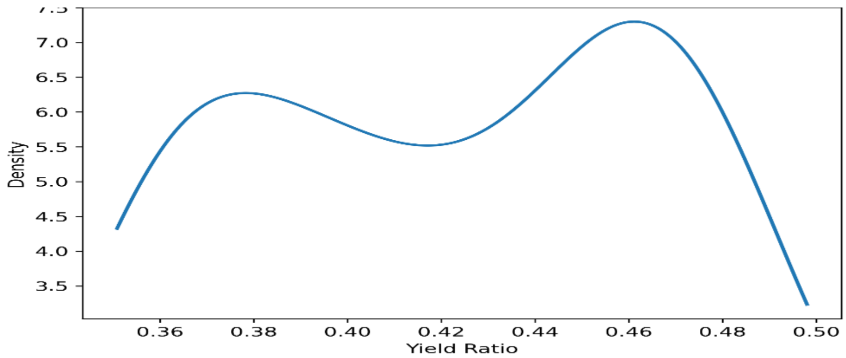

Figure 3. Distribution of Yield Ratios Across Decision-Making Units

As shown in Figure 3, yield ratios vary considerably across DMUs, indicating heterogeneity in conversion efficiency. While several units operate around the average ratio, others achieve markedly higher or lower yields, suggesting differences in processing practices, technology use, or post-harvest management. Such efficiency dispersion is commonly observed in smallholder-based agro-processing systems (Parmeter & Sickles, 2020). This variation highlights potential efficiency gaps within the cooperative structure and supports the need for subsequent efficiency and distributional analysis (Minten et al., 2021).

To examine the distributional pattern of market performance across units, the cumulative distribution of sales value per decision-making unit (DMU) is presented. Figure 4 illustrates the cumulative share of DMUs by sales value over the 2020–2024 period.

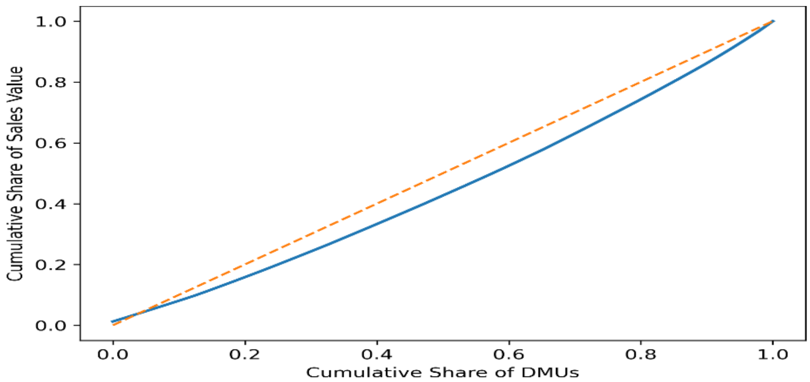

Figure 4. Cumulative Distribution of Sales Value per Decision-Making Unit

As shown in Figure 4, the cumulative distribution indicates unequal sales performance across DMUs. A relatively small share of units accounts for a disproportionate portion of total sales value, suggesting concentration in market outcomes. Such patterns are often associated with differences in bargaining power, productivity, and market access within agri-food supply chains (Reardon et al., 2020). This concentration supports the need to examine distributional fairness and to assess whether blockchain transparency moderates value dispersion and price transmission dynamics (Rejeb et al., 2021).

Price Transmission Analysis

The econometric analysis confirms a long-run cointegrating relationship between farm-gate cassava prices and downstream tapioca prices. Given the relatively short panel period (2020–2024), these results should be interpreted cautiously and complemented with robustness checks. The Error Correction Model (ECM) indicates asymmetric price transmission: upward shocks in tapioca prices are only partially transmitted to cassava farmers (elasticity ≈ 0.41), whereas downward shocks are transmitted more rapidly (elasticity ≈ 0.68). Such asymmetry implies that downstream actors retain a larger share of gains during price increases while adjustment burdens shift toward farmers during price declines (von Cramon-Taubadel & Goodwin, 2021).

Comparable asymmetric transmission patterns have been widely observed in agricultural markets and are often linked to structural factors such as bargaining power, market concentration, and transaction frictions (Panagiotou, 2021). In the BCC cooperative context, these findings suggest that although collective governance improves coordination and stability, farmers remain more exposed to adverse price movements while SMEs capture a larger share of positive market shocks.

Value Distribution among Actors

To understand how value is distributed among actors in the tapioca supply chain, the share of final value received by farmers, the BCC cooperative, and SME processors is examined. Such distributional analysis helps identify how cooperative coordination influences value allocation and which stages capture the largest share of total value within agri-food supply chains (Reardon et al., 2020, p. 460). The results are summarized in Table 3.

Table 3. Value Distribution across Actors in the Tapioca Supply Chain

Actor Group	Share of Final Value (%)	Without BCC Cooperative (%)
Farmers	28	22
Cooperative (BCC)	12	—
SME Processors	60	78
Total	100	100

Note: Based on aggregated DMU value chain data (2020–2024). The counterfactual scenario estimates farmer share without cooperative intervention.

As shown in Table 3, SME processors capture the largest share of final value, while farmers receive a smaller portion. The presence of the BCC cooperative shifts part of the value from SME processors to farmers and the cooperative itself, demonstrating the cooperative's role in redistributing income and enhancing farmer participation in value creation. This insight emphasizes the importance of cooperative engagement in improving equity and efficiency within the tapioca supply chain.

Blockchain Transparency and Trust (BTI Results)

The Blockchain Transparency Index (BTI) shows an average adoption score of 0.62, with notable variation across SMEs. Higher BTI scores are associated with improved data transparency, more timely contract execution, and stronger traceability of cassava origins. Blockchain-based traceability mechanisms can reduce transaction costs by limiting information asymmetry among supply chain actors (Treiblmaier, 2018; Rejeb et al., 2021).

Empirical evidence indicates that SMEs with higher BTI scores report lower dispute rates (6%) compared with those with lower adoption levels (14%). This pattern aligns with findings that blockchain can strengthen contractual credibility and reduce opportunistic behavior in food supply chains (Zhao et al., 2023). The present study extends this literature by linking transparency not only to perceived trust but also to observable governance outcomes.

Supply Chain Efficiency

Data Envelopment Analysis (DEA) was used to assess input–output efficiency across DMUs. The results show that only 27% of SMEs operate on the efficiency frontier, while the remainder exhibit efficiency gaps of 12–28%. Less efficient SMEs tend to have lower yield ratios and weaker BTI adoption. These results suggest that digital transparency complements technical upgrading. Efficiency gains arise not only from machinery or scale effects but also from improved transaction governance and traceability

(Treiblmaier, 2018). This interpretation is consistent with evidence that digital systems enhance operational coordination in supply chains (Choi et al., 2022).

Actor Welfare and Socioeconomic Outcomes

Simulation analysis comparing blockchain-enabled and non-blockchain scenarios indicates an approximate 15% improvement in farmers' income under higher-transparency conditions. The welfare gains primarily reflect improved distribution fairness, reduced transaction disputes, and faster price adjustments rather than price premiums alone (Tran et al., 2023). SMEs also experience indirect benefits, including stronger consumer trust and more stable long-term contractual relationships, although short-term profit margins may slightly narrow during the early adoption phase (Tran et al., 2023). These findings suggest that for Indonesia's tapioca sector, blockchain-enabled governance could help mitigate structural inefficiencies and moderate distributional imbalances while still operating within existing market structures (Tran et al., 2023).

The results indicate that blockchain-enabled governance functions as a complementary institutional layer within the cooperative-mediated cassava–tapioca B2B supply chain. Rather than altering market structure, it reshapes coordination mechanisms, influencing price dynamics, distributional outcomes, efficiency performance, and welfare stability (Saberi et al., 2019; Casino et al., 2021). In terms of price transmission, higher Blockchain Transparency Index (BTI) values significantly strengthen price pass-through elasticity and accelerate error correction toward long-run equilibrium. This suggests that digital transparency reduces informational lag and contractual frictions, leading to faster and more proportional adjustment (Kouhizadeh et al., 2021). Importantly, asymmetric transmission declines under higher transparency conditions, indicating that governance architecture directly shapes adjustment dynamics. Price transmission efficiency is therefore not purely market-driven but institutionally conditioned (von Cramon-Taubadel & Goodwin, 2021).

Regarding distributional fairness, increased transparency is associated with higher farmer value shares and lower inequality indicators. By limiting hidden transaction costs and opportunistic pricing, blockchain moderates excessive downstream rent extraction (Saberi et al., 2019). However, the effect remains incremental: structural determinants of value capture—such as processing capital intensity and downstream market access—continue to favor SMEs (Bellemare & Bloem, 2018). Transparency constrains extreme disparities but does not equalize bargaining power. For efficiency, SMEs operating under deeper transparency regimes perform closer to the estimated efficiency frontier. These gains appear governance-driven rather than purely technological, as traceability enhances operational discipline, reduces input leakage, and aligns procurement with processing capacity (Casino et al., 2021). Adoption depth also matters: superficial implementation does not generate comparable efficiency improvements (Kshetri, 2018).

The welfare impact primarily reflects risk reduction rather than price premiums. Faster adjustment, fewer disputes, and more predictable contracts improve farmer income stability, while SMEs benefit from reduced coordination costs and improved contractual continuity (Tran et al., 2023). Thus, blockchain improves stability and resilience rather than fundamentally altering price levels. Despite these gains, structural bargaining asymmetries persist. SMEs retain dominance through control over infrastructure and downstream markets. Blockchain enhances transactional transparency but does not redistribute capital ownership or structural market power (Kshetri, 2018). It therefore operates mainly as a coordination-enhancing mechanism within existing hierarchies.

Comparison with previous studies and implications. These findings extend traditional price transmission literature, which often attributes adjustment speed and asymmetry to market concentration or transportation costs (Meyer & von Cramon-Taubadel, 2004). In contrast, the present results demonstrate that governance architecture—specifically digitally embedded transparency—can systematically condition adjustment dynamics. Likewise, while prior blockchain research in agribusiness emphasizes adoption intentions or traceability functions, this study provides empirical evidence that digital transparency influences distributional outcomes and equilibrium correction processes (Saberi et al., 2019; Casino et al., 2021).

From a policy perspective, the results suggest that digitalization strategies in agricultural markets should move beyond technological deployment toward institutional embedding. Regulators may develop standardized transparency protocols within cooperative networks, while cooperative managers should integrate blockchain mechanisms into formal contracting and monitoring systems rather than adopting them symbolically (Kouhizadeh et al., 2021).

This study has several limitations. The empirical analysis focuses on a specific cooperative-mediated cassava–tapioca supply chain, which may limit generalizability across different commodity structures or vertically integrated markets. The Blockchain Transparency Index is constructed from observable governance indicators and may not fully capture informal coordination practices (Casino et al., 2021). Moreover, the medium-term observation window does not allow assessment of long-run structural transformation. Future research could expand cross-regional and cross-commodity comparisons, incorporate quasi-experimental identification strategies, and examine whether prolonged transparency adoption reshapes capital accumulation and bargaining power structures. Longitudinal welfare analysis would also clarify whether governance-driven efficiency gains translate into sustained income growth (Tran et al., 2023).

This study advances the literature by addressing a key gap in blockchain research within agribusiness: the limited econometric evidence linking digital governance to dynamic market coordination and distributional outcomes. While previous studies largely frame blockchain as a traceability or technology-adoption phenomenon, this research incorporates a measurable Blockchain Transparency Index (BTI) into a moderated ECM–VECM framework, thereby endogenizing digital governance within price transmission dynamics (Saberi et al., 2019; Casino et al., 2021). Theoretically, the study contributes by bridging the Resource-Based View and Institutional Economics, conceptualizing blockchain transparency simultaneously as an organizational capability and an institutional coordination mechanism that conditions transaction costs, bargaining power, and equilibrium adjustment. Empirically, the findings show that digital transparency improves coordination efficiency and moderates inequality, yet continues to operate within structural capital asymmetries in B2B commodity supply chains (Kshetri, 2018). Thus, blockchain is better understood not as a disruptive equalizer but as a governance-enhancing mechanism embedded within existing institutional hierarchies (Kouhizadeh et al., 2021).

CONCLUSION

This study examines whether blockchain-enabled governance improves price transmission efficiency, distributional fairness, and operational efficiency within a B2B cassava–tapioca supply chain, using evidence from the Bogor Cassava Center (BCC) cooperative and SME processors in Indonesia. Its main contribution is the empirical integration of cointegration-based price transmission analysis (ECM–VECM) with a Blockchain Transparency Index (BTI) and distributional fairness metrics—an approach rarely applied jointly in agribusiness research. By linking digital governance indicators to measurable market and welfare outcomes, the study advances empirical evidence beyond largely conceptual discussions of blockchain in agri-food systems. The results confirm long-run cointegration between cassava farm-gate prices and downstream tapioca prices, indicating structural market integration. However, short-run adjustments remain asymmetric, reflecting persistent bargaining and transaction-cost frictions. Higher BTI values are associated with faster error correction and more proportional price pass-through, suggesting that blockchain enhances coordination efficiency without eliminating structural asymmetries. Greater transparency is associated with higher farmer price shares, improved cooperative value capture, and moderated value concentration among downstream processors. Although inequality is not fully eliminated, blockchain-supported governance reduces extreme disparities and stabilizes farmer exposure to price volatility. Efficiency analysis further indicates that SMEs embedded in blockchain-enabled cooperative arrangements operate closer to the estimated efficiency frontier, driven by improved alignment between price signals, contractual enforcement, and production decisions.

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AUTHOR CONTRIBUTIONS

The research article was conducted by the author D. Iwan Riswandi, including: Conceptualization, Methodology, Software, Validation, Formal Analysis, Investigation, Resources, Data Curation, Writing – Preparation of the Original Draft, Writing – Review & Editing, Visualization.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

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