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ORIGINAL

Performance-Based Adaptive Revenue Sharing in the Indonesian Natural Rubber Supply Chain: Model Design, AHP Calibration, and Simulation Evidence

Distribución adaptativa de ingresos basada en el desempeño en la cadena de suministro del caucho natural en Indonesia: diseño del modelo, calibración por AHP y evidencia de simulación

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ABSTRACT

Introduction: the study addressed income inequities in Indonesia's natural rubber supply chain by redesigning revenue sharing among farmers, collectors, processors and exporters in Padang Lawas, North Sumatra, aligning income allocation with observable contributions and risk.
Method: the study employed a developmental research approach to specify a performance-based, adaptive revenue-sharing model, calibrate it with Analytic Hierarchy Process (AHP) weights, and test it through multi-scenario simulations using field parameters on dry rubber content, market price, on-time delivery and actor-specific risk; the stability and consistency of the AHP weighting vector were assessed.
Results: the AHP weights were stable, prioritising product quality, followed by price and timeliness, while risk received a smaller but meaningful weight; the consistency ratio remained below 0,10. Relative to a fixed baseline split, the adaptive mechanism reallocated income toward verified performance improvements, increasing farmers' share from 11 % to 22 % under a moderate-price scenario with high on-time delivery, while preserving incentive compatibility and channel coordination.
Conclusions: the study transformed revenue sharing from a static proportional rule into a transparent, auditable, learning-oriented mechanism that operationalised distributive justice through normalised performance indices. The model could be encoded in contract clauses with measurable quality metrics and public price benchmarks and implemented with low-cost traceability; broader field pilots and multi-region validation were required to generalise the results.

Keywords: Adaptive Revenue Sharing; Dry Rubber Content; Performance-Based Contracting; Supply Chain Coordination; Smallholders; Indonesia.

RESUMEN

Introducción: el estudio abordó las inequidades de ingresos en la cadena de suministro de caucho natural de Indonesia mediante el rediseño del reparto de ingresos entre agricultores, recolectores, procesadores y exportadores en Padang Lawas, Sumatra del Norte, alineando la distribución de ingresos con contribuciones y riesgos observables.
Método: el estudio empleó un enfoque de investigación de desarrollo para especificar un modelo de reparto de ingresos adaptativo y basado en el desempeño, calibrarlo con pesos del Proceso de Análisis Jerárquico (AHP) y probarlo mediante simulaciones de múltiples escenarios utilizando parámetros de campo sobre contenido de caucho seco, precio de mercado, puntualidad en la entrega y riesgo específico de cada actor; se evaluaron la estabilidad y la consistencia del vector de ponderaciones AHP.

Resultados: los pesos AHP fueron estables, priorizando la calidad del producto, seguida del precio y la puntualidad, mientras que el riesgo recibió una ponderación menor pero significativa; la razón de consistencia se mantuvo por debajo de 0,10. En comparación con una distribución fija de referencia, el mecanismo adaptativo reasignó los ingresos hacia mejoras verificadas del desempeño, incrementando la participación de los agricultores de 11 % a 22 % bajo un escenario de precio moderado con alta puntualidad en la entrega, preservando al mismo tiempo la compatibilidad de incentivos y la coordinación de la cadena.
Conclusiones: el estudio transformó el reparto de ingresos de una regla proporcional estática en un mecanismo transparente, auditable y orientado al aprendizaje que operacionalizó la justicia distributiva mediante índices de desempeño normalizados. El modelo podría codificarse en cláusulas contractuales con métricas de calidad medibles y referencias públicas de precios, e implementarse con sistemas de trazabilidad de bajo costo; se requirieron pilotos de campo más amplios y una validación multirregional para generalizar los resultados.

Palabras clave: Reparto de Ingresos Adaptativo; Contenido de Caucho Seco; Contratación Basada en el Desempeño; Coordinación de la Cadena de Suministro; Pequeños Productores; Indonesia.

INTRODUCTION

Agriculture plays a central role in Indonesia's economy and rural livelihoods because it absorbs a large share of the labor force and supports national food security.[1] Sector performance depends not only on land productivity but also on the effectiveness of supply-chain governance that channels value from upstream to downstream.[2] The ongoing transformation of agri-food systems in developing countries shows that the way value is distributed along the chain is critical for competitiveness and smallholder welfare at the farm-gate level.[3] In natural rubber, the interaction among farmers, collectors, processors, and exporters shapes the architecture of value that determines who captures the largest income share.[4] Quality variation and coordination frictions often depress farmers' bargaining power and prevent prices from reflecting intrinsic product quality at the point of exchange.[5]

A growing body of work documents several interconnected challenges in agricultural supply chains.[6] Value added frequently concentrates downstream, which makes the farmer's share of income fall short of the contribution made at the production stage.[7] Dependence on intermediaries and information asymmetries weakens smallholders' bargaining positions and expands margins captured at distribution stages.[8] Price volatility driven by trade policy dynamics and global market shocks raises income risk that is borne most heavily by upstream actors.[9] Limited transparency of quality and traceability along product flows increases transaction costs and hinders coordination across actors, which constrains overall system efficiency.[10] Together, these conditions reinforce what is often described as value asymmetry along agricultural supply chains.[11]

Against this backdrop, the analytical object of this study is the revenue-sharing mechanism within the agricultural supply chain, viewed as a system of linked actors and value flows. The formal focus covers three lenses: the structure of value distribution through prevailing contracts and market rules, proportionality between contribution and income, and distributional inequities that often disadvantage upstream actors.[3,7,14]

In natural rubber, the coordination problem has distinctive features because product quality depends strongly on dry rubber content.[12] Measuring dry rubber content is a technical prerequisite for assessing quality and serves as a reference for fair price setting at delivery points.[13] Field practice shows that fixed-proportion revenue splits are not sensitive to performance signals such as measured quality, on-time delivery, and supply reliability.[14] This weakens incentives for quality upgrading and disciplined delivery at the farm level and maintains dependence on intermediaries when price and quality information are not shared symmetrically.[15] When quality transparency is weak, the allocation of value can diverge from distributive-justice principles that are needed to sustain motivation and collaboration over time.[16]

Revenue sharing is recognized in the operations and supply-chain literature as a coordination mechanism that can align incentives and reduce double marginalization.[17] Prior research has outlined strengths, limitations, and contractual variants that are relevant for improving system performance.[5,18,19,20,21] Evidence, however, remains concentrated in manufacturing and retail contexts, so the specific characteristics of agricultural value chains are not fully internalized. Studies that integrate agribusiness performance indicators such as dry rubber content, on-time delivery, and supply reliability into revenue-allocation rules are still limited. Contextual evidence from Indonesia is also scarce, including evaluations of robustness to price volatility, the cost of quality verification, and the readiness of cooperatives and offtakers to implement auditable rules.[22,23,24] The need for transparency and traceability further calls for data governance so that performance signals are converted into fair income distribution across actors.[10,25,26]

Although coordination theory in supply chains is well established, context-specific designs for food and agricultural systems remain limited, especially where smallholders dominate. In many settings, fixed revenue shares neither reward observable improvements in performance nor buffer upstream exposure to risk, which sustains value asymmetry along the chain.(7,14,18) The topic is therefore urgent due to persistent income gaps in smallholder agriculture, and existing models seldom integrate contribution and risk in agrifood contexts, highlighting the need for fair and sustainable governance instruments.(7,14,18) This study addresses that gap by integrating four measurable drivers: dry rubber content as a quality proxy, market price level, delivery timeliness, and actor risk.(18,27)

Responding to these gaps, this study designs and evaluates a performance-based revenue-sharing model for Indonesia's rubber supply chain. The model ties each actor's revenue share to measurable and auditable dimensions, namely product quality through dry rubber content, on-time delivery, and supply reliability reflected in volume consistency. We calibrate the model to the Indonesian context and conduct multi-scenario simulations that vary quality distributions, delivery compliance, and market-price paths. Outcomes are benchmarked against a fixed-proportion baseline to assess effects on the farmer share, margins across actors, total surplus, and fairness indicators relevant for decision-making.(4,7,18,20) First, the study evaluates the extent to which an adaptive revenue-sharing system can increase the proportion of income received by farmers within the agricultural supply chain. Second, it analyzes the main factors that drive inequality in income distribution along the chain. Third, it develops a performance-based revenue-sharing model that improves the fairness of income distribution among farmers, collectors, processors, and exporters in the Indonesian rubber context. Accordingly, the main objective of this investigation is to design and assess an adaptive, performance-based revenue-sharing mechanism that enhances equity while maintaining coordination across the natural rubber supply chain.

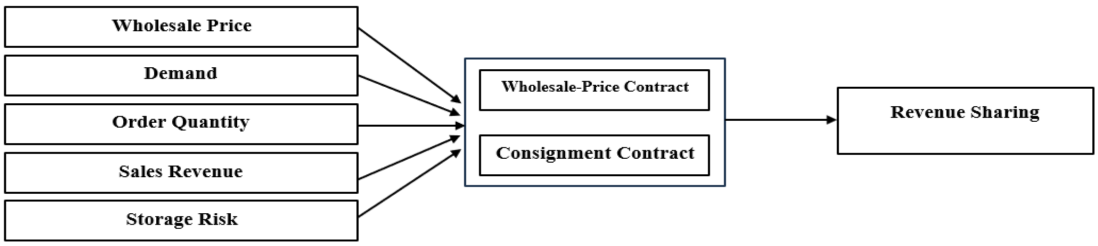

Figure 1. Initial Research Model (2019)

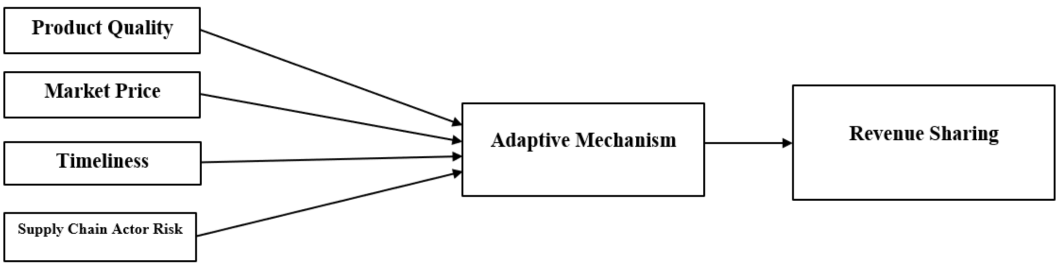

Figure 1. Proposed Conceptual Model 2025

METHOD

Research Design

This study employs a developmental research approach in the design science tradition to build, demonstrate, and assess an adaptive revenue-sharing model for agricultural supply chains. A developmental design is appropriate because the primary objective is not to estimate population parameters, but to construct and iteratively refine a decision artifact that is both theoretically grounded and practically usable. In line with design science, the workflow covers problem identification, conceptual modeling, quantitative formulation, simulation, and validation so that the artifact is anchored in coordination theory and distributive justice while remaining implementable in real supply-chain settings.(29)

Study setting

The empirical context is agrarian districts with active and structured agricultural supply chains that allow realistic observation of multi-actor revenue allocation. Field implementation focuses on Padang Lawas Regency, North Sumatra, a major smallholder rubber-producing area where rubber farming is a dominant livelihood and marketing channels involve village collectors, processors, and exporters. Sites were selected purposively to capture dominant farm production, multi-actor coordination, and heterogeneous income sharing that are suitable for testing a performance-based revenue-sharing mechanism.[5]

Data sources and procedures

We combined secondary and primary evidence to parameterize and test the model. Secondary data on prices, costs, and quality standards were taken from official statistics, provincial plantation reports, and commodity-exchange bulletins, complemented by peer-reviewed studies on revenue sharing in agri-food chains. Primary data came from focused interviews and structured field forms with farmers, collectors, processors, and exporters to map practices, risks, and operational constraints, while expert consultations were used to refine the model structure, variable definitions, and parameter values and to check face validity of assumptions.[5,29]

In Padang Lawas, primary data were collected from forty smallholder farmers, five local collectors who actively transact with farmers and cooperatives, and one crumb-rubber plant manager as the downstream actor. Respondents were selected purposively to reflect typical smallholder conditions in the area, including rubber stands of 20 to 25 years, similar local varieties, and approximately one hectare of land per farmer. This composition mirrors the actual structure of the local chain, where a small number of intermediaries coordinate flows from many farmers to a single processor. Although the sample size is modest for statistical generalization, it is adequate for the design-oriented objective of specifying and stress-testing a revenue-sharing mechanism, and its implications for external validity are acknowledged as a limitation in the discussion.

A structured questionnaire and field form were drafted and pre-tested with a small group of farmers and one collector to check clarity, timing, and plausibility of response ranges. After minor wording adjustments, face-to-face interviews were conducted by trained enumerators using a standardized protocol and pre-coded response options. Most actors approached agreed to participate, so non-response bias is expected to be limited. Interviewer bias was mitigated through enumerator training, neutral wording of questions, and supervision by the research team, including random back-checks of completed interviews.

Each performance driver was measured with low-cost and auditable procedures, then normalized to the unit interval. Dry Rubber Content Q was measured at delivery points following ISO 126 by sampling, oven drying, and computing the dry rubber percentage that serves as the quality index.[4,10] On-time delivery T was calculated as the share of shipments that arrived on or before the agreed date using time-stamped receipts. The market-price index H was built from public benchmarks for RSS3 or SIR20 within the evaluation window. Actor risk R was proxied by the frequency of operational incidents, defined as events within a harvest-delivery cycle that caused quantity or quality loss, delayed delivery beyond the agreed window, or led to partial or full rejection at the next stage. Incident frequency was computed as the number of such events divided by the total number of shipments over a rolling reference period, so that higher values indicate greater exposure to operational risk. All indicators were transformed with min-max normalization $X'=(X-X_{min})/(X_{maks}-X_{min})$ prior to scoring to ensure commensurability across variables with different units.

Across the three calibration scenarios in table 4, the farmer indices have mean values of Q=0,57(SD 0,01), T=0,63(SD 0,08), R=0,48(SD 0,10), and H=0,47(SD 0,08), which are consistent with field conditions in the study area.

Model formulation

This study maps four observable drivers into actor shares using a normalized, weighted score. For each actor i in {farmer, collector, processor, exporter}, the indicators are product quality Qi, market-price index Hfor the period, delivery timeliness T_i, and actor-specific risk R_i. Each raw variable Xis scaled to the unit interval with min-max normalization:

$$X' = \frac{X-X_{min}}{X_{max-}X_{min}} \quad (1)$$

A contribution score combines a baseline entitlement $\propto_i$ and performance components

$$S_i = \propto_i + \beta_Q Q_i + \beta_H H + \beta_T T_i + \beta_R \emptyset(R_i) \quad (2)$$

Where β_Q, β_H, β_T, $\beta_R \geq 0$ and $\sum_k \beta_k=1$. In the baseline specification, α_i represents the legacy share or minimum guarantee for actor i, derived from the prevailing fixed-proportion revenue split in the study area. For example, the farmer's baseline share is set at α_"farmer" =0,11, consistent with the current allocation of 11 % of value added to farmers reported in table 9, while collectors, processors, and exporters retain their observed baseline proportions. This term anchors the adaptive mechanism in current practice and preserves continuity with existing contractual expectations; α_i may be set to zero for a purely performance-based regime.

An additive specification in equation (2) is adopted because it preserves linear separability across drivers, facilitates interpretation of marginal contributions, and avoids strong interaction assumptions implicit in multiplicative forms. This choice is consistent with multi-criteria decision-making models in which normalized indicators are aggregated through weighted sums.

The risk transform φ(R_i) captures how operational risk is treated within the sharing rule. In the main simulations, we specify $\varphi(R_i)=R_i$, so that actors facing greater operational risk receive higher scores, reflecting a risk-loading approach that compensates exposure. As a robustness check, we also explore $\varphi(R_i)=1-R_i$, which rewards risk mitigation; these alternative specifications are discussed in the sensitivity analysis.

Scores are converted to revenue shares through normalization:

$$P_i = \frac{s_i}{\sum_j s_j} \qquad (3)$$

And period incomes are obtained as:

$$Income_i = P_i \times TotalRevenue \qquad (4)$$

Equations (2) to (4) ensure that verifiable improvements in quality and timeliness raise an actor's entitlement while the risk term either protects exposed actors or encourages mitigation, depending on the chosen transform.

Weighting of drivers

Relative-importance weights β_k were derived using the Analytic Hierarchy Process with expert pairwise comparisons and a target consistency ratio below 0,10. Pairwise-comparison judgments were obtained from five experts: two academics specializing in supply-chain management and smallholder agriculture, one cooperative manager, one processing-plant manager, and one export-company representative. This mix reflects both scientific and practitioner perspectives and enhances the practical relevance of the resulting weights.

Judgments were compiled in a 4×4 matrix for product quality (Q), market price (H), on-time delivery (T), and actor risk (R). The matrix was normalized to obtain the principal right eigenvector as priority weights. Consistency was evaluated using the maximum eigenvalue λ_{max}, the consistency index $CI=(\lambda_{max}-n)/(n-1)$, and the consistency ratio CR=CI/RI with n=4 and RI=0,90. The resulting λ_{max}=4,135 gives CI=0,045 and CR=0,050, which satisfies the ≤0,10 benchmark and indicates acceptable internal coherence of judgments. Table 1 reports the reference weights used in the simulations. A compact version of the comparison matrix is shown in table 2, and the full matrix is available upon request.

Table 1. AHP weights for allocation drivers

Driver	Description	Weight (β)
(Q)	Product quality index	0,471
(H)	Market price index	0,284
(T)	On-time delivery index	0,171
(R)	Actor risk index	0,074

Table 2. Pairwise-comparison matrix used for AHP (summary)

	(Q)	(H)	(T)	(R)
(Q)	1,00	2,00	3,00	5,00
(H)	0,50	1,00	2,00	4,00
(T)	0,33	0,50	1,00	3,00
(R)	0,20	0,25	0,33	1,00

System definition

The model operates as a simple input-process-output system that can be audited and recalibrated periodically.

Table 3. System components of the adaptive revenue-sharing model

Component	Content
Inputs	Q_i, H, T, R_i for each actor and baseline α_i
Process	Normalization (Eq.1), scoring (Eq.2), share normalization (Eq.3), and periodic recalibration
Outputs	Actor-level shares and simulated monetary allocations
Feedback	Scheduled review of parameters and weights based on observed outcomes

Simulation design

We simulate the model under three policy-relevant operating conditions that reflect typical variability in the Indonesian rubber chain, namely a normal state, a high-risk state, and an oversupply state. Within each scenario we vary the quality distribution, delivery reliability, and the market price index while holding the baseline shares α and non-target driver values constant at their empirical means to isolate performance effects. The simulations generate actor shares and monetary allocations for each scenario using the calibrated AHP weights and the normalization–scoring–normalization sequence defined in the method. Non-farmer parameters for collectors, processors, and exporters are fixed at their observed period averages unless otherwise stated, and the price index H applies symmetrically to all actors in a given run. This design follows established practice in stress-testing performance-contingent contracts under volatility and uncertainty.[18,19,28]

Table 4. Scenario parameters used in simulations

Scenario	Q_farmer	T_farmer	R_farmer	H	α_farmer	Notes
Normal	0,58	0,70	0,40	0,55	0,11	Baseline calibration
High risk	0,56	0,55	0,60	0,45	0,11	Logistics disruptions
Oversupply	0,57	0,65	0,45	0,40	0,11	Weak market prices

Validation and robustness checks

Validation combines expert review for face validity, one-factor-at-a-time sensitivity analysis on the weighting vector β and the driver indices, and out-of-sample scenario tests to assess stability under uncertainty. The sensitivity analysis perturbs each calibrated factor to identify which levers most influence the actor shares P_i, while the AHP pairwise-comparison matrix is checked for internal consistency and the model is recalibrated whenever the consistency ratio exceeds 0,10, consistent with recommended practice for rigorous assessment of decision models and simulation artifacts. Results indicate that the farmer's share is most responsive to quality Qand timeliness T, with a 20 % increase in β_Q yielding a large rise in $P_{\text{"farmer"}}$, a 20 % increase in β_T producing a moderate rise, a 10 % lift in the price index Hgiving a moderate gain, and changes in risk Rshowing smaller effects under the baseline compensation setting.

Table 5. Sensitivity summary for farmer share

Parameter increased	Change applied	ΔP_{farmer}
β_Q	+20 %	large increase
β_T	+20 %	moderate increase
H	+10 %	moderate increase
R	+20 %	small increase

Implementation protocol

For implementation, all indicators are measured using low-cost and auditable procedures that can be embedded in routine operations. Product quality is monitored through dry rubber content testing at delivery points. Timeliness is tracked using time-stamped delivery receipts. The price index is derived from agreed public benchmarks, such as published RSS3 or SIR20 prices within the settlement period. Risk is proxied by incident frequency or rejection rates calculated over a rolling reference window using simple tally sheets or digital logs. Revenue shares are then updated on a fixed cadence (for example, monthly or quarterly) to maintain transparency and trust while preserving incentives for continuous improvement among all actors in the chain.[7,10]

RESULTS

Study Area, Respondents, and Data Collection

This study was conducted in Padang Lawas Regency, South Tapanuli, which was selected purposively because it is a major smallholder rubber-producing area in North Sumatra and rubber farming is a dominant livelihood. A survey design was used with purposive sampling of smallholders whose rubber stands were 20 to 25 years old, of the same local variety, and with approximately one hectare of land. The respondent set comprised forty individual farmers, five local collectors who actively transact with farmers and cooperatives, and one crumb rubber plant manager as the downstream actor.

Data were gathered through direct observation of tapping, harvesting, aggregation, and primary processing activities; structured questionnaires on volume, quality, price, and delivery timing; in-depth interviews with each actor to capture contextual practices; and documentation of market prices from the Singapore Commodity Exchange together with historical records from the Provincial Plantation Office. These data provide the empirical basis for calibrating the model parameters and constructing the simulation scenarios.

Analysis of Price and Income Fluctuations

Monthly observations from 2023 to 2025 indicate pronounced volatility in the international RSS3 rubber price, with a range from IDR 13,500 to IDR 18,700 per kilogram based on the Singapore Commodity Exchange and the Ministry of Agriculture. Figure 3 shows a decline from IDR 18,200 in March 2023 to IDR 14,000 in June 2023, followed by a recovery to IDR 18 000 in December 2023, then a sharp drop to IDR 13,500 in January 2024, a steady rise to a peak of IDR 18,700 in October 2024, and a correction to IDR 15 400 in February 2025. This pattern reflects seasonal production, shifts in global demand, and exchange-rate movements and establishes the market context in which any distribution rule must operate.

Given a constant harvested volume of 600 kilograms per month in the sampled plots, these price swings translate directly into swings in farmer income. Figure 3 and table 6 report income of IDR 10 920 000 in March 2023 at IDR 18 200 per kilogram, a drop to IDR 8 400 000 in June 2023 at IDR 14 000 per kilogram, a rise to IDR 11 220 000 in October 2024 at the price peak, and an easing to IDR 9 240 000 in February 2025 at IDR 15 400 per kilogram. These descriptive results contextualise the income risk faced by farmers before introducing the simulation model.

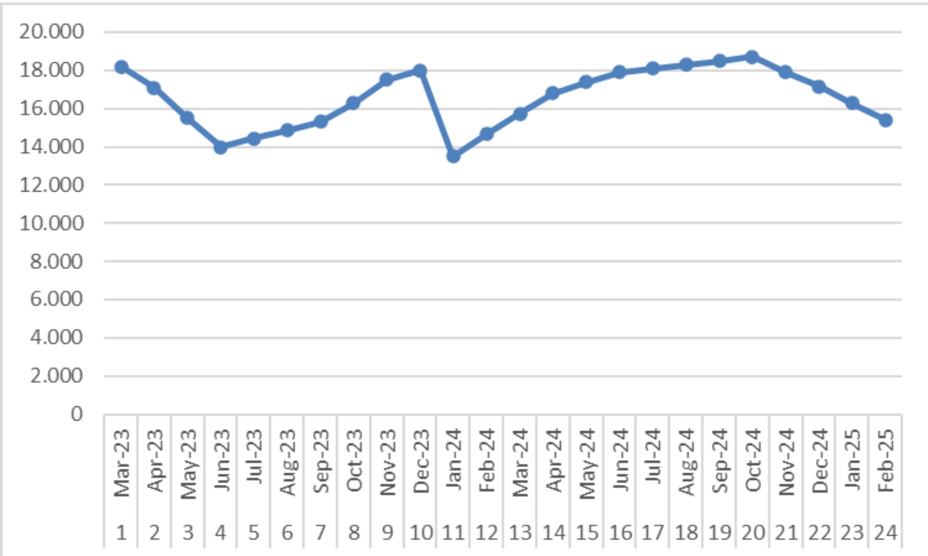

Figure 3. Monthly RSS3 Rubber Price Trend, March 2023-February 2025

Table 6. Farmer Income Details

Month	Price (IDR/kg)	Harvest Volume (kg)	Farmer Income (IDR)
Mar-23	18 200	600	10 920 000
Jun-23	14 000	600	8 400 000
Jan-24	13 500	600	8 100 000
Apr-24	16 800	600	10 080 000
Oct-24	18 700	600	11 220 000
Feb-25	15 400	600	9 240 000

Individual Performance Analysis

Field observations show heterogeneous monthly harvests per farmer from 300 to 850 kilograms and confirm that quality, measured by dry rubber content, is the primary price determinant at the farm gate. Table 7 illustrates three representative cases. Farmer A produces 650 kilograms per month with 61 % dry rubber content graded as RSS2 and is purchased without penalty at IDR 17 000 per kilogram. Farmer B produces 470 kilograms with 54 % dry rubber content graded as RSS3 and receives a price penalty that reduces the purchase price to IDR 15 800 per kilogram. Farmer C produces 300 kilograms with 58 % dry rubber content graded as RSS3 and is accepted at IDR 16 500 per kilogram.

These examples illustrate the qualitative pattern that higher dry rubber content is associated with higher prices and that quality penalties can substantially reduce income at a given volume. Given the small number of illustrative cases, these observations are treated as contextual examples rather than as a formal statistical test of the relationship between dry rubber content and farm-gate prices.

Table 7. Dry Rubber Content and Purchase Price

Farmer	Monthly Harvest Volume (kg)	Dry Rubber Content (%)	Quality Grade	Acceptance Status	Purchase Price (IDR per kg)
A	650	61	RSS2	Accepted	17 000
B	470	54	RSS3	Price penalty applied	15 800 (penalty 1200)
C	300	58	RSS3	Accepted	16,500

Supply Chain Structure and Value-Added Analysis

This subsection explains how value is created and captured along the natural rubber chain from farmers to collectors, processors, and exporters. Table 8 summarises stepwise transaction prices from the farm gate to the international market, and table 9 presents costs, margins, and the share of value added for each actor. The pattern reveals cumulative mark-ups as the product advances to higher-value stages: downstream actors capture larger margins through coordination, processing, and market access, while farmers perform most production tasks yet receive the smallest share of value added.

Under the prevailing arrangement in the study area, farmers receive 11 % of value added, collectors 29 %, processors 32 %, and exporters 28 %. This descriptive baseline motivates contractual and institutional adjustments to strengthen upstream bargaining power and to reward verified improvements in quality and timeliness with a higher share of revenue.

Table 8. Stepwise Transaction Prices (IDR per kg)

Transaction Stage	Selling Price
Farmer to Collector	5500
Collector to Processor	10 000
Processor to Exporter	15 500
Exporter to International Market	20 200

Table 9. Prices, Costs, Margins, and Value Added by Actor (IDR per kg)

Actor	Selling Price	Cost	Margin	Share of Value Added
Farmer	5500	4150	1350	11 %
Collector	10 000	900	3600	29 %
Processor	15 500	1500	4000	32 %
Exporter	20 200	1200	3500	28 %

Evaluation of the Revenue Sharing Model

The prevailing distribution of proceeds in the Indonesian rubber chain allocates fixed shares of the prevailing fixed distribution of proceeds in the Indonesian rubber chain allocates 11 % of value added to farmers, 29 % to collectors, 32 % to processors, and 28 % to exporters. Evidence from the value-added profiles in table 9 shows that this static rule systematically favours downstream actors even though farmers bear the bulk of agronomic effort and primary production risk. Because the split never adjusts to measured quality, delivered quantity, delivery timeliness, or contemporaneous market prices for RSS3 and SIR20, it fails to reward improvements in

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on-farm practices and does not buffer farmers when prices fall. This configuration is consistent with settings where upstream bargaining power is weak and traditional arrangements dominate coordination.

The simulation-based results (reported in the dedicated simulation-results subsection) indicate that an adaptive allocation that increases the farmer share when dry rubber content and on-time delivery improve, and that provides protection bands when market prices decline, would better connect rewards to real contributions while preserving incentives for collectors, processors, and exporters to coordinate volumes and quality. From a coordination perspective, such an adaptive rule is closer to revenue-sharing and risk-sharing contracts that aim to align incentives across decentralised actors and to reduce double marginalisation through outcome-contingent terms. Embedding this design in transparent contracts referenced to verified quality metrics and public price benchmarks would narrow upstream-downstream disparities, strengthen collaboration, and raise the resilience of the chain under volatile market conditions.[7,14,18]

Simulation Results

The simulation results compare the fixed baseline revenue split with the adaptive performance-based model across three scenarios (normal, high-risk, and oversupply) and show a consistent reallocation of income toward farmers. Under the normal scenario, the farmer's share increases from 11 % under the fixed baseline to 22,0 % under the adaptive model, reflecting the model's emphasis on verified improvements in dry rubber content and on-time delivery at the farm level. In the high-risk scenario, where the farmer's risk index rises and the market-price index declines, the adaptive rule still allocates about 20,8 % of revenue to farmers, compared with 11 % under the baseline split, while in the oversupply scenario the farmer's share remains around 20,7 %, again exceeding the fixed 11 % share. Thus, even when prices are weaker or risks are higher, the performance-based rule prevents the farmer's entitlement from collapsing to the low baseline level and narrows upstream-downstream disparities without eliminating the margins required by collectors, processors, and exporters to coordinate processing and market access.

Table 10. Farmer revenue shares under baseline and adaptive models by scenario

Scenario	Baseline farmer share (%)	Adaptive farmer share (%)
Normal	11	22,0
High risk	11	20,8
Oversupply	11	20,7

DISCUSSION

This study yielded three main findings. First, descriptive evidence from Padang Lawas shows that farmers face substantial income volatility driven by international rubber price fluctuations, while existing marketing arrangements allocate only 11 % of value added to farmers and concentrate margins with downstream actors. Second, individual performance profiles and field observations indicate that dry rubber content and delivery timeliness are the primary observable drivers of price and income at the farm gate. Third, the simulation results demonstrate that an adaptive, performance based revenue sharing rule can increase the farmer share from 11 % to 22,0 % under normal conditions and maintain higher entitlements of about 20,8 % and 20,7 % in high risk and oversupply scenarios, respectively, without eliminating the margins required by collectors, processors, and exporters.

These findings can be related to the literature on revenue sharing, value based pricing, and supply chain coordination. The result that dry rubber content is the main determinant of price and allocation supports the principle of value based pricing in agricultural markets, where higher intrinsic quality is expected to command higher returns,[7,10] but extends this principle by operationalising quality in a multi actor revenue sharing contract rather than a bilateral price schedule. The inclusion of on time delivery alongside quality supports previous arguments that service performance and logistics reliability should be reflected in contractual terms,[18,20] and translates them into a simple index that can be used to update revenue shares. The finding that the adaptive rule increases the farmer share from 11 % to 22,0 % in the normal scenario while leaving room for positive margins downstream is consistent with coordination theory and revenue sharing contracts that reduce double marginalisation and improve channel efficiency.[7,14,18] At the same time, it extends this body of work to a smallholder dominated natural rubber chain in a developing country context, where information asymmetries and weak upstream bargaining power often prevent proportional allocation. By tying shares to observable performance indices, the model supports distributive justice perspectives that emphasise proportionality between contribution, risk, and reward, and it offers a concrete mechanism to implement these principles with auditable data. The behaviour of the model in high risk and oversupply scenarios, where the farmer share remains well above the fixed 11 %, aligns with theories that advocate outcome contingent contracts to cushion upstream actors against adverse shocks while preserving incentives for downstream coordination.[18,28]

From a managerial perspective, the results suggest that cooperatives, processors, and exporters can translate the adaptive rule into concrete contract clauses rather than generic commitments to reward quality. A simple template might state: "The baseline revenue share for farmers is set at 11 %, which increases to 22 % when, within the settlement period, the average dry rubber content delivered is at least 58 % and at least 70 % of deliveries arrive on or before the agreed date. The applicable unit price is derived from the public benchmark for RSS3 or SIR20 published by the agreed exchange." A complementary clause could define a protection band for low price periods, for example: "If the benchmark price falls below IDR X per kilogram, the farmer share shall not fall below Y %, with the adjustment financed by a proportional reduction in intermediary margins." Such clauses, supported by low cost procedures for testing dry rubber content, recording delivery times, and tracking benchmark prices, provide managers with a practical starting point for renegotiating contracts in ways that align incentives, enhance perceived fairness, and strengthen long term relationships along the chain.

Limitations

This study has several limitations that should be acknowledged explicitly. First, the empirical calibration is based on a relatively small sample of forty farmers, five collectors, and one processor in a single district, which limits the generalisability of the findings to other regions and commodity chains. Second, the AHP based weights, although internally consistent, rely on expert judgement and are therefore subjective and context dependent; different expert panels in other locations might assign different priorities to quality, price, timeliness, and risk. Third, the simulation scenarios treat the parameters of collectors, processors, and exporters as fixed, which simplifies strategic responses and may not fully capture the dynamic adjustments in behaviour and investment that would occur if an adaptive rule were implemented in practice. These limitations should be taken into account when interpreting the results and deriving policy or managerial recommendations.

Future research

Future research can build on this work in at least three directions. First, a multi country comparative study could assess how performance based revenue sharing operates in natural rubber or other perennial crop chains under different institutional environments, governance structures, and price regimes, thereby testing the external validity of the model. Second, a pilot implementation with a farmer cooperative or producer organisation could be used to test behavioural responses to the adaptive rule, including acceptance by different actors, perceived fairness, and changes in production, quality management, and delivery behaviour over time. Third, an optimisation model could be developed to endogenously determine the weight vector that maximises total chain welfare or a combined efficiency-equity criterion, subject to incentive compatibility and participation constraints for each actor. Such extensions would deepen understanding of how performance based revenue sharing can be designed and implemented to improve both fairness and resilience in agricultural supply chains.

CONCLUSIONS

This study developed an adaptive revenue sharing model for the Indonesian natural rubber supply chain that updates income allocations among farmers, collectors, processors, and exporters based on observed performance. The mechanism links four measurable drivers to the final shares, namely product quality, market price conditions, delivery timeliness, and operational risk, and aggregates them using Analytic Hierarchy Process weights with a consistency ratio below 0,10. Simulation results show that, under normal conditions, the adaptive rule increases the farmer share from a fixed baseline of 11 % to 22,0 %, while in high risk and oversupply scenarios the farmer share remains around 20,8 % and 20,7 %, respectively. These reallocations make rewards more proportional to contributions and risk exposure, while preserving positive margins for downstream actors so that coordination along the chain remains feasible.

Conceptually, the research reframed revenue sharing from a static proportional rule into a performance linked mechanism that operationalised value based pricing and distributive justice principles in a multi actor contract. Methodologically, it integrated multiple drivers within a single quantitative framework using auditable indices that can be implemented with low cost measurement procedures. From a policy and managerial perspective, the model can be translated into explicit contract clauses that adjust farmer shares when verified dry rubber content and on time deliveries reach agreed thresholds and that reference public price benchmarks for RSS3 or SIR20. Taken together, the findings indicate that performance based revenue sharing can balance efficiency with fairness, narrow upstream downstream disparities, and provide a stronger foundation for long term collaboration and resilience in smallholder dominated agricultural supply chains.

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