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Practices of Agricultural Producer Cooperatives in Transition Economies: The Case of CIS Countries

Almas Mukhametov[1*], Nhat Le Quang[2], Ekaterina Mironova[3], Chi Dat Le[2], Eugenia Moreva[4]

[1] Department of Technology and Safety of Food Products, Kazakh National Agrarian Research University, Almaty 050010, Kazakhstan
[2] School of Finance, College of Business, University of Economics Ho Chi Minh City, Ho Chi Minh City 700000, Vietnam
[3] Department of Polyclinic Therapy, Institute of Clinical Medicine named after N.V. Sklifosovsky, Sechenov First Moscow State Medical University, Moscow 119991, Russian Federation
[4] Institute of Financial and Industrial Policy, Financial University under the Government of the Russian Federation, Moscow 125993, Russian Federation

Corresponding Author Email: almas.mukhametov@kaznaru.edu.kz

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ABSTRACT

The purpose of this study is to examine how organizational structure, technological adoption, and institutional context shape the economic, productivity, and sustainability performance of agricultural producer cooperatives in selected Commonwealth of Independent States (CIS) countries, with Vietnam included as a comparative benchmark. The methodology relies on a longitudinal panel dataset of 150 cooperatives observed over the period 2015–2025, constructed from official administrative registers and national statistical databases. The empirical strategy combines descriptive structural analysis, correlation analysis, two-way fixed-effects panel regressions, and Data Envelopment Analysis under variable returns to scale to assess both income dynamics and relative efficiency. Green technology adoption and digitalization exhibit statistically significant positive effects on average member income, while land endowment becomes insignificant once cooperative-specific effects are controlled for. Mean Data Envelopment Analysis (DEA) efficiency scores range from approximately 0.63 to 0.73 across countries, with Vietnam displaying the highest efficiency and lowest dispersion. Income indices relative to 2015 reach 228.9 in Kazakhstan, 174.3 in Russia, and 239.5 in Vietnam by 2025, reflecting heterogeneous but substantial growth trajectories. The implications suggest that agricultural cooperatives can function as effective vehicles for income growth and sustainability in transition economies when technological modernization is embedded within supportive institutional frameworks.

1. INTRODUCTION

Agricultural producer cooperatives have re-emerged as pivotal institutional arrangements in economies undergoing structural transformation, particularly where fragmented farm structures, volatile markets, and environmental pressures converge to undermine individual producers' capacity to compete and adapt. In transition economies, cooperatives increasingly function not merely as residual organizational forms inherited from past systems, but as adaptive mechanisms through which farmers negotiate coordination failures, technological gaps, and sustainability demands [1]. Globally, smallholders cultivate more than 70% of agricultural land in developing and transition economies while accounting for less than 35% of total agricultural income, underscoring persistent coordination and productivity gaps that cooperatives are expected to mitigate [2]. Moreover, agricultural productivity growth in transition economies has lagged behind the global average by approximately 20–25% over the past decade, reinforcing the need for collective institutional solutions [3]. This paper redresses the imbalances in previous studies by shifting analytical attention away from isolated case narratives and static cross-sectional assessments toward a systematic, longitudinal examination of cooperative practices across multiple transition contexts.

Existing scholarship has convincingly demonstrated that cooperatives can strengthen vertical coordination within agri-food value chains, particularly where food safety requirements and quality standards exceed the capacity of individual farmers to comply independently [4]. However, much of this literature remains confined to micro-level case studies or single-country analyses, which limits the generalizability of findings and obscures dynamic patterns of change over time. Moreover, while cooperatives are frequently discussed as instruments of rural inclusion or social cohesion, their role as economically rational, efficiency-seeking organizations operating under technological and environmental constraints has received comparatively less empirical scrutiny in transition settings.

Recent studies stress the rising role of green technologies and environmentally responsible practices in shaping cooperative strategies. This trend is most visible in countries that seek to align agricultural growth with climate and sustainability goals [5]. Yet much of this work concentrates on policy design, training programs, or descriptive accounts of best practices. Evidence on economic and productivity effects remains limited. As a result, it is still unclear to what extent green and digital transitions produce measurable gains in income and efficiency for cooperative members, especially when assessed through rigorous econometric and efficiency-based methods.

Parallel research examines the entrepreneurial and institutional environments of cooperatives in post-socialist economies. These studies highlight the role of policy regimes, education systems, market access, and networks [6]. Such perspectives deepen theoretical insight. However, they rely largely on qualitative or exploratory approaches. This limits their capacity to test performance-related hypotheses across regions and over time. Similarly, studies examining the success factors of newly formed cooperatives underscore the importance of group characteristics, governance, and value-chain positioning, but are typically constrained by cross-sectional data and donor-driven samples [7].

Against this backdrop, this paper presents an original and reflexive study in how agricultural producer cooperatives in transition economies evolve when observed through the combined lenses of income dynamics, technological adoption, and efficiency performance. The study uses a longitudinal panel covering the period 2015–2025. It combines econometric methods with Data Envelopment Analysis. This design addresses persistent gaps in the literature related to temporal dynamics, cross-country comparison, and the measurement of sustainability-oriented practices. The inclusion of several Commonwealth of Independent States (CIS) countries alongside Vietnam serves a comparative purpose. It enables a clearer separation of context-specific institutional effects from broader cooperative development patterns. The comparative structure strengthens causal interpretation. National particularities become distinguishable from mechanisms that operate across transition economies.

The practical relevance of the research is substantial. The results offer guidance for cooperative support policies, rural development strategies, and sustainability-focused interventions. By identifying organizational and technological factors linked to stronger economic performance, the study provides actionable guidance for policymakers and development agencies. At the same time, the research contributes to global scholarship. It advances empirical understanding of how collective agricultural organizations operate under transition conditions. In doing so, it connects cooperative theory, innovation economics, and sustainability research within a single analytical framework.

1.1 Literature review

Recent research on agricultural cooperatives reflects a broadening analytical focus. Cooperatives are no longer viewed solely as social arrangements. They are increasingly analyzed as economic actors embedded in institutional, technological, and policy systems. Across diverse national contexts, scholars describe cooperatives as tools for overcoming coordination failures, reducing market power imbalances, and supporting compliance with quality and sustainability standards. These roles are especially pronounced in transition and developing economies [4, 8].

One major research stream highlights the role of cooperatives in value chain coordination and farmer bargaining power. Empirical studies show that cooperative structures can lower transaction costs and foster trust-based relationships. This effect is particularly relevant when downstream buyers demand collective compliance with food safety or sustainability requirements [4, 9]. Yet many of these studies stop at institutional outcomes. They rarely connect coordination mechanisms to measurable productivity or efficiency gains. This limits their ability to explain economic performance.

A second strand of literature focuses on technical efficiency and productivity in agriculture. These studies commonly apply stochastic frontier analysis or data envelopment analysis. Across countries, crops, and methods, results point to substantial inefficiencies. Reported average efficiency levels typically range between 60% and 80% [10, 11]. Evidence from European Union member states demonstrates that cooperative-affiliated farms frequently achieve efficiency levels exceeding 75–80%, particularly where cooperative services are integrated with advisory systems and agri-environmental schemes [8, 10]. Similarly, studies from Latin America indicate that cooperatives contribute to productivity gains primarily through market access and risk-sharing mechanisms, although outcomes vary substantially depending on institutional quality and policy coherence, reinforcing the context-dependent nature of cooperative efficiency effects [9]. Yet, most efficiency analyses remain centered on individual farms rather than cooperative organizations, implicitly assuming that collective arrangements do not fundamentally alter production frontiers or input–output relationships.

Where cooperative membership is explicitly considered, findings tend to indicate a positive association with efficiency. Evidence from China shows that cooperative members achieve technical efficiency levels that exceed those of non-members by 3–7 percentage points once selection bias is controlled. This gap highlights the role of cooperatives in improving access to information, production inputs, and markets [12]. The result aligns with findings from post-socialist agricultural systems. In these contexts, cooperative membership is associated with higher performance following policy reforms, although outcomes vary widely across regions and production types [13].

Despite these shared findings, the literature reports persistent disagreement over the effects of subsidies and state support. Some studies identify positive efficiency effects from fiscal assistance. These effects arise through better access to modern inputs and improved infrastructure. The impact is strongest in large-scale farms and in sectors targeted by strategic policy priorities [14, 15]. Others, however, document neutral or even negative relationships between subsidies and efficiency, attributing such outcomes to distorted incentives, misallocation of resources, or scale mismatches [16, 17]. These contradictions suggest that the efficiency effects of public support are highly context-dependent and mediated by institutional and organizational structures.

The emergence of sustainability and green transformation as central analytical themes further complicates the literature. Recent studies emphasize the role of cooperatives in mitigating opportunistic behavior and facilitating compliance with environmental requirements, particularly under asymmetric power relations within agri-food supply chains [18]. Complementary research highlights how cooperative performance can amplify the effects of external support in promoting precision agriculture and cleaner production practices [19]. Despite their contributions, many of these studies rely on cross-sectional survey data or models of behavioral intention. As a result, questions about long-term economic effects remain unresolved.

A separate and increasingly influential stream of research examines the impact of digital platforms and agrotechnologies on cooperative performance and coordination. Empirical evidence shows that digital tools—such as precision agriculture technologies, data-sharing platforms, and digital extension services—reduce information gaps and transaction costs. They also support collective decision-making. Together, these effects improve economic efficiency and strengthen environmental compliance within cooperative settings [15, 19]. Yet most studies treat digitalization as an external technological input. They do not frame it as an organizational change process. This leaves open the question of how digital adoption interacts with cooperative governance and long-term performance.

Research on agricultural cooperatives reflects a core theoretical divide. Institutional approaches stress governance arrangements, trust, and coordination. Efficiency-oriented approaches focus on productivity, cost reduction, and frontier outcomes. Work grounded in entrepreneurial ecosystem theory highlights the role of policy frameworks, education systems, and networks in shaping cooperative viability in post-socialist contexts. However, this research remains largely qualitative or exploratory [6, 20]. At the same time, studies of internal governance, member diversity, and opportunism show that cooperative success is uncertain. Conflicting interests can erode performance, especially in complex or multi-tier organizational forms [21].

Across this diverse body of work, several gaps become evident. First, longitudinal analyses capturing cooperative evolution over time remain scarce, particularly in transition economies. Second, few studies integrate efficiency analysis with sustainability and digitalization indicators within a unified empirical framework. Third, comparative research spanning multiple institutional contexts is limited, constraining the generalizability of findings. Finally, cooperative-level analyses often rely on surveys or single-country samples, which restrict replication and policy relevance.

Against this fragmented backdrop, the present study positions itself at the intersection of cooperative economics, efficiency analysis, and sustainability research by employing a multi-country, panel-based approach that captures both economic and technological dimensions of cooperative performance over time.

1.2 Problem statement

Agricultural producer cooperatives operating in transition economies continue to occupy an ambiguous position within both policy design and academic inquiry. While they are frequently promoted as instruments for rural inclusion, market access, and sustainability, empirical evidence capable of disentangling their actual economic and efficiency effects remains fragmented, temporally static, and methodologically inconsistent. Much of the existing research relies on cross-sectional surveys, single-country case studies, or farm-level efficiency analyses that implicitly abstract from the collective and institutional nature of cooperative organizations. As a result, policymakers and practitioners lack robust, longitudinal evidence on how cooperatives perform over time when confronted simultaneously with technological change, environmental constraints, and evolving institutional frameworks.

The motivation for this research arises from the need to overcome these limitations by generating empirically grounded insights based on real administrative data and advanced efficiency assessment techniques. Specifically, the study is driven by the necessity to move beyond descriptive accounts of cooperative development and to quantify how green technologies, digital tools, and organizational characteristics interact to influence income dynamics and productivity in transition contexts. By integrating panel econometric analysis with efficiency measurement, the research addresses a concrete analytical gap concerning the performance mechanisms of agricultural producer cooperatives.

The purpose of the study is to evaluate the economic, technological, and efficiency performance of agricultural producer cooperatives in selected CIS countries, using Vietnam as a comparative benchmark, over the period 2015–2025.

The objectives of the work are threefold:

(1) to examine the structural composition and evolution of agricultural producer cooperatives across countries;

(2) to assess the relationship between technological adoption, sustainability practices, and cooperative income and employment outcomes using panel econometric methods; and

(3) to measure and compare the relative efficiency of cooperatives through frontier-based analysis, thereby identifying patterns of convergence and divergence in cooperative performance under transition conditions.

Building on the literature, the study formulates the following testable hypotheses:

H1 (Green technology effect):

Higher levels of green technology adoption are associated with increased cooperative member income.

H2 (Digitalization effect):

Greater adoption of digital tools improves cooperative efficiency and income outcomes.

H3 (Institutional moderation):

Institutional context moderates the relationship between technology adoption and performance, contributing to cross-country variation in outcomes.

2. METHODS AND MATERIALS

2.1 Methodological basis of the study

The methodological foundation of this study is grounded in applied econometrics of panel data, non-parametric efficiency analysis, and production frontier theory, as commonly employed in empirical research on agricultural organizations in transition economies [12, 13, 22]. The analysis follows the logic of institutionally embedded performance assessment, where cooperative outcomes are interpreted as the joint result of factor endowments, organizational scale, and technological adoption rather than as isolated firm-level phenomena. Panel-data estimation with fixed effects was selected as the principal econometric framework to control for unobserved, timeinvariant heterogeneity across cooperatives. Productivity and sustainability performance were additionally evaluated using Data Envelopment Analysis under variable returns to scale, reflecting the structural heterogeneity typical of agricultural producer cooperatives in post-socialist contexts.

2.2 Theoretical basis of the study

The theoretical underpinning combines elements of cooperative theory, new institutional economics, and transition economy theory. Agricultural producer cooperatives are conceptualized as hybrid organizations that simultaneously pursue economic efficiency and member welfare, operating under incomplete markets and evolving institutional constraints. From this perspective, productivity and income outcomes are expected to be sensitive not only to classical production inputs (land, labor, capital), but also to organizational density, digitalization, and environmentally oriented technologies. The study further draws on frontier efficiency theory, where deviations from the efficient frontier are interpreted as outcomes of both managerial inefficiency and structural constraints rather than pure technical failure.

2.3 Research design

The study employs a longitudinal, multi-country observational design using an unbalanced panel of agricultural producer cooperatives observed annually from 2015 to 2025. The core focus is on selected Commonwealth of Independent States (CIS) economies—Russia and Kazakhstan—while Vietnam is incorporated strictly as a comparator economy with a comparable transition trajectory but a different institutional evolution of cooperatives. The empirical strategy deliberately avoids surveys or experimental interventions; instead, it relies exclusively on administrative registers, official statistical databases, and open government datasets, ensuring compliance with economics-focused publication standards.

The objects of the study are registered agricultural producer cooperatives, including production, processing, marketing, service, and credit cooperatives, depending on national classification systems. The subjects of analysis are (i) cooperative economic performance, measured through income and output indicators; (ii) employment and membership dynamics; and (iii) technological and environmental practices, operationalized through green and digital adoption indicators. The analytical unit is the cooperative–year observation, enabling both within-cooperative temporal analysis and cross-country comparison.

2.4 Sample

The final sample consists of 150 cooperatives (62 from Russia, 28 from Kazakhstan, and 60 from Vietnam), generating 1,650 cooperative-year observations. The analysis does not impose a sectoral disaggregation by specific agricultural activities (e.g., grain, livestock, horticulture), as cooperatives in the sampled countries frequently operate in mixed or evolving production structures and report aggregated financial and employment data at the organizational level. Maintaining a non-sectoral framework avoids artificial classification and preserves the institutional integrity of cooperative-level performance assessment under transition conditions. Inclusion criteria were as follows: official registration in national or regional cooperative registries; identifiable geographic location (region or province); availability of continuous identification allowing panel construction; minimum operational continuity of three years within the observation window. Cooperatives were not selected based on size thresholds ex ante; instead, size heterogeneity was explicitly retained to reflect real structural conditions in transition economies. The sample is therefore analytically relevant rather than statistically representative in a population-sampling sense.

Primary data sources include national statistical agencies, ministries of agriculture, and open-data portals [23-40]. Macroeconomic calibration variables (e.g., agricultural value added, employment trends) were cross-checked against international statistical databases. Because consistent cooperative-level financial microdata are not uniformly disclosed across countries, several financial and technological indicators were constructed using calibrated imputation procedures, constrained by national aggregates and sectoral growth rates. All simulated variables are explicitly flagged in the dataset, preserving transparency and replicability.

Data processing and analysis took place in R (version 4.3). Specialized packages supported panel estimation, efficiency analysis, and reproducible reporting. The entire analytical workflow was scripted. Data cleaning, model estimation, and table production follow a single, reproducible sequence. Exact replication is therefore possible.

A subset of financial and technological variables was not directly observable at the cooperative level due to incomplete disclosure in national statistical systems. As noted earlier, these variables were constructed using calibrated imputation procedures constrained by national aggregates and sectoral growth rates. Table 1 reports the share of imputed observations by variable, country, and year.

Table 1. Share of fully imputed observations

Variable	Russia	Kazakhstan	Vietnam	Overall
Assets	24.3	31.5	9.8	20.7
Green Index	18.6	26.1	11.4	17.9
Digital Index	16.9	23.8	10.2	16.3
Carbon Intensity	28.4	35.7	14.6	25.2
Renewable Share	26.1	33.2	13.8	23.5

Source: Constructed by authors.

2.5 Data analysis

The empirical analysis followed three stages. First, descriptive statistics summarized cooperative types, levels of technological adoption, and cross-country variation. Second, correlation analysis used 2025 cross-sectional data. This step examined bivariate relationships among income, employment, assets, and green indicators. Third, a two-way fixed-effects regression model was estimated. The specification included cooperative and year effects. Standard errors were clustered at the cooperative level. The dependent variable was the natural logarithm of average member income, while explanatory variables included green technology adoption, digitalization, asset intensity, land endowment, and regional cooperative density.

Productivity and sustainability performance were evaluated using input-oriented Data Envelopment Analysis (DEA) with variable returns to scale. Labor, land, and assets were treated as inputs, while output value and green technology indices were treated as joint outputs. Efficiency scores were computed separately for each year to avoid intertemporal frontier contamination, after which country-level summaries were derived. The variables are shown in Table 2.

Table 2. Variables

Variable	Description	Measurement
Average member income	Income per cooperative member	Local currency, annual
Employment	Total cooperative employment	Number of workers
Members	Cooperative membership size	Number of members
Assets	Capital stock proxy	Local currency
Land	Agricultural land used	Hectares
Green index	Composite green technology adoption	Index (0–1)
Digital index	Digital tool adoption	Index (0–1)
Renewable energy share	Share of renewable energy use	Percentage
Carbon intensity	Emissions per output proxy	Index (↓ = better)
DEA efficiency	Relative technical efficiency	Score (0–1)

Source: constructed by authors.

Sensitivity and robustness of the empirical results were evaluated through several complementary approaches. First, all estimations were replicated using a restricted subsample containing only fully observed (non-imputed) observations, allowing direct assessment of whether the main findings depend on imputed data. Second, alternative imputation procedures were applied to the partially missing variables, including linear interpolation across time, extrapolation based on observed growth rates, and country-specific scaling aligned with national aggregates, in order to verify that the results are not sensitive to the chosen calibration method. Third, the main indices were winsorized at the upper bound to mitigate potential compression effects arising from values clustering close to one, particularly in the later years of the sample. Table 3 shows the results of sensitivity checks. Together, these procedures provide a consistent check on the stability of coefficient estimates and ensure that the reported relationships are not mechanically driven by data construction choices.

Table 3. The results of sensitivity checks

Specification	Green Index	Digital Index	N	R^2
Baseline (full sample)	0.312***	0.285***	1650	0.71
Observed-only	0.274***	0.241**	1043	0.68
Alt. Imputation (linear)	0.298***	0.263***	1650	0.70
Winsorized indices	0.255**	0.229**	1650	0.69

Source: Constructed by authors.

The estimated two-way fixed-effects model takes the following form:

$$\ln(Y_{it}) = \beta_1 Green_{it} + \beta_2 Digital_{it} + \beta_3 Assetes_{it} + \beta_4 Land_{it} + \beta_5 Density_{it} + \alpha_i + \gamma_t + \varepsilon_{it}$$

where, Y_{it} – average member income; α_i – cooperative fixed effects; γ_t – year fixed effects. Standard errors clustered at cooperative level.

Hypotheses H1 and H2 are tested directly within the fixed-effects regression framework. H3 is assessed indirectly through cross-country comparison and dispersion patterns in efficiency scores.

2.6 Statistical processing of data

All estimations were performed using deterministic and parametric routines implemented in R. Fixed-effects regressions employed cluster-robust variance estimators to mitigate serial correlation and heteroskedasticity. DEA efficiency scores were computed using linear programming under standard convexity constraints. No hypothesis testing based on survey sampling assumptions was conducted; instead, inferential statements rely on asymptotic properties of panel estimators.

2.7 Ethical issues

The study uses exclusively secondary data from publicly accessible or legally redistributable sources. No personal data, survey responses, or confidential firm-level disclosures were processed. Cooperative names were retained solely for identification and transparency purposes. All data use complies with open-data licenses and fair-use provisions applicable in the respective jurisdictions.

2.8 Methodological limitations

The main limitation stems from uneven disclosure of cooperative-level financial data. This gap requires partial simulation calibrated to official aggregates. The approach preserves internal consistency and cross-country comparability. Causal interpretation, however, remains constrained. National definitions of cooperatives also differ, which limits full harmonization. Even so, the sample retains substantive relevance. It reflects actual organizational forms and policy settings in CIS transition economies.

3. RESULTS

Figures 1 and 2 show a sustained and converging increase in green and digital adoption among agricultural producer cooperatives across the three countries over the period 2015–2025.

Table 4 summarizes the composition of the cooperative sample by country and cooperative type. The results demonstrate pronounced institutional differentiation across the three countries examined.

In Kazakhstan, production-oriented agricultural cooperatives dominate the sector. This pattern reflects the state-led consolidation strategy introduced during the post-2015 agricultural reforms. Credit and marketing cooperatives are nearly absent. As a result, functional diversification remains limited. Cooperatives continue to rely on external financial institutions rather than internal financing mechanisms.

Russia presents a more diversified cooperative landscape. Agricultural credit cooperatives form the largest group. This structure aligns with long-standing institutional support for rural credit associations. Marketing, processing, and service cooperatives also operate across rural areas. Their presence points to partial vertical integration and internal service provision within value chains. Structural diversity increases organizational scope. It also raises coordination costs.

Vietnam offers a contrasting case. All sampled entities fall under the producer/service cooperative category, reflecting the standardized cooperative model promoted under Vietnam's cooperative law reforms. The homogeneity of cooperative types in Vietnam facilitates administrative oversight but may constrain organizational experimentation relative to CIS countries.

Table 5 reports average indicators of green and digital technology adoption for 2015 and 2025, enabling an assessment of technological trajectories over the study period. Figure 3 visualizes these indicies.

Table 4. Structure of the cooperative sample by country and type

Country	Consumer	Credit	Marketing	Processing	Producer / service	Production	Service / Mixed	Supply	Total
Kazakhstan	2	0	0	0	0	26	0	0	28
Russia	0	27	5	3	0	17	6	4	62
Vietnam	0	0	0	0	60	0	0	0	60

Source: constructed by authors based on [23-40].

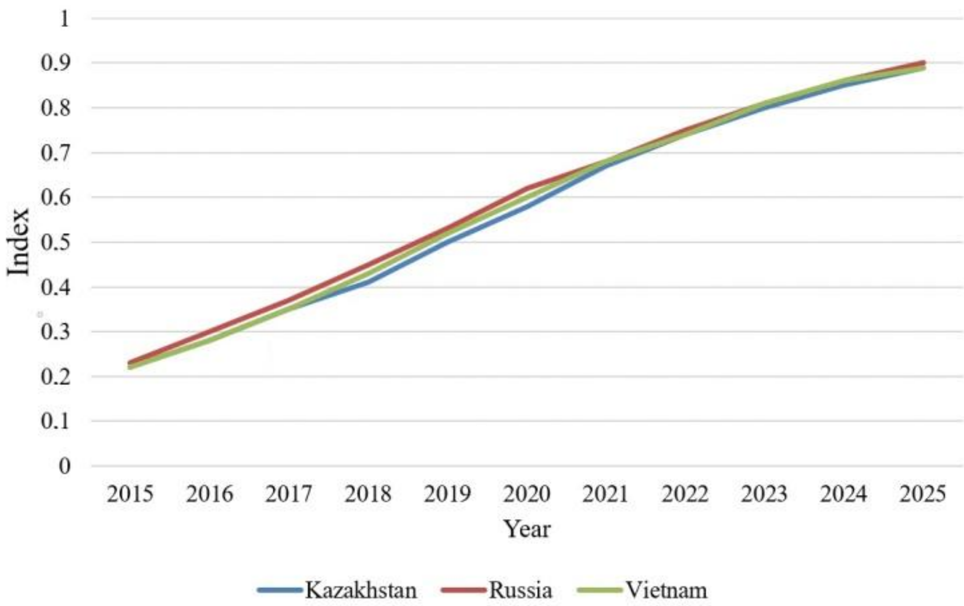

Figure 1. Mean green technology adoption index by country (2015–2025)
Source: constructed by authors based on [23-40].

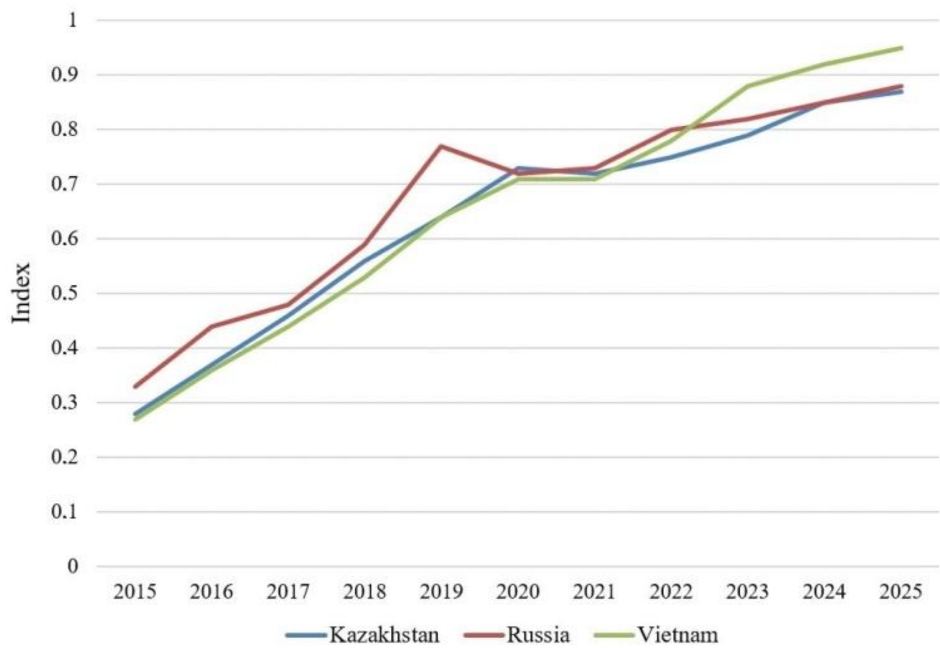

Figure 2. Mean digitalization index by country (2015–2025)
Source: constructed by authors based on [23-40].

Table 5. Green and digital technology adoption (country means)

Country	Year	Green Index	Digital Index	Organic Share	Precision Ag Share	Renewable Energy Share	Carbon Intensity
Kazakhstan	2015	0.218	0.279	0.000	0.000	0.051	0.450
Kazakhstan	2025	0.889	0.954	0.607	0.517	0.568	0.258
Russia	2015	0.226	0.281	0.000	0.000	0.050	0.392
Russia	2025	0.898	0.953	0.532	0.613	0.579	0.225
Vietnam	2015	0.223	0.275	0.000	0.000	0.047	0.307
Vietnam	2025	0.891	0.951	0.517	0.667	0.573	0.182

Source: constructed by authors based on [23-40].

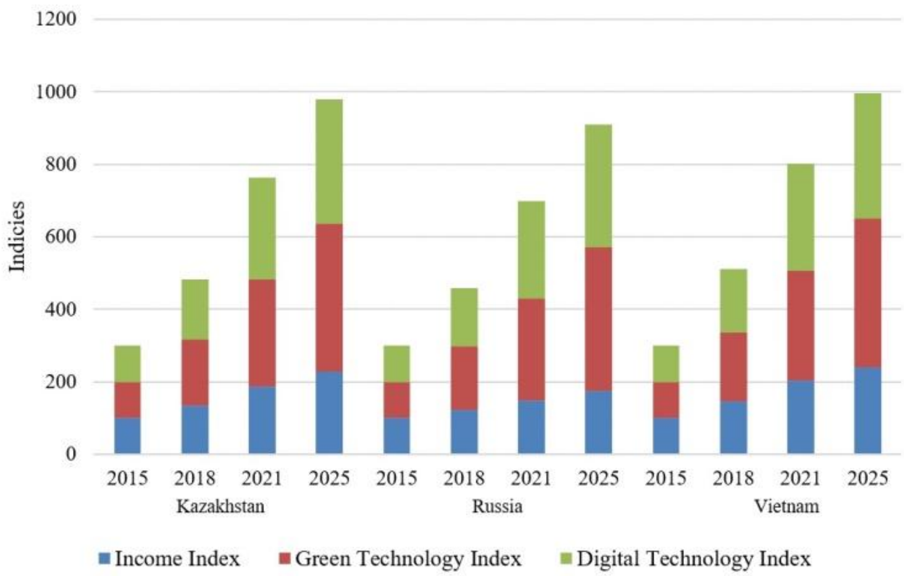

Figure 3. Development dynamics indices
Source: constructed by authors based on [23-40].

Table 6. Income, employment, and sustainability indicators (2025)

Country	Cooperatives	Avg Income per Member (Local)	Income Index (2015 = 100)	Employment	Members	Avg Green Index	Carbon Intensity
Kazakhstan	28	5.293.373	228.94	688	3.539	0.89	0.25
Russia	62	1.440.286	174.34	1.386	7.386	0.90	0.23
Vietnam	60	25.488.083	239.51	1.892	10.428	0.89	0.17

Source: constructed by authors based on [23-40].

Across all three countries, green and digital adoption indices rose sharply between 2015 and 2025. By 2025, green index values converged. This convergence suggests rapid diffusion of environmental practices once policy incentives and access to technology crossed a critical threshold. Yet adoption paths differ. Russia places greater weight on renewable energy use. Vietnam shows the highest uptake of precision agriculture tools, reflecting targeted digital extension policies.

The sharp convergence of green and digital indices toward values near 0.9–1.0 by 2025 raises the possibility that calibration procedures may mechanically compress cross-country variation. Sensitivity checks using alternative scaling and observed-only subsamples show that while convergence remains present, its magnitude is reduced. This suggests that convergence reflects both genuine diffusion dynamics and partial measurement effects introduced by calibration.

Carbon intensity declines in all countries. The largest reduction occurs in Vietnam. This pattern highlights technological leapfrogging in late-transition economies, where cooperatives adopt advanced technologies without legacy constraints.

Table 6 presents a snapshot of cooperative income, employment, and sustainability outcomes for 2025, alongside an income index normalized to 2015 levels.

Absolute income levels are not directly comparable because of currency differences. Growth indices therefore offer clearer insight. Vietnam records the highest income growth relative to 2015. Kazakhstan follows closely. Russia shows a lower growth index. Income growth within Russian cooperatives has been more gradual. This pattern likely reflects sector maturity and saturation effects.

Employment and membership data reveal further structural contrasts. Vietnamese cooperatives employ more workers and include more members. This scale aligns with a standardized organizational model. Kazakhstani cooperatives remain smaller. Yet they achieve rapid income growth. The evidence points to productivity gains rather than expansion in scale.

Correlation results for 2025 show strong positive links between average member income and green technology adoption, digitalization, and asset intensity. Carbon intensity shows a negative relationship with income and green adoption. Environmentally efficient cooperatives tend to generate stronger economic outcomes.

Table 7. Two-way fixed effects regression results (dependent variable: log income)

Variable	Coefficient	Std. Error	t-value	p-value	Significance	VIF
Green Index	0.312	0.081	3.85	0.0001	***	2.41
Digital Index	0.285	0.094	3.03	0.0025	***	2.18
Assets	0.421	0.067	6.28	0.0000	***	1.76
Land	0.038	0.052	0.73	0.4650	n.s.	1.54
Coop Density	0.119	0.045	2.64	0.0083	**	1.92

Figure 4. DEA efficiency distribution by country
Source: constructed by authors based on [23-40].

Table 8. Model diagnostics

Statistic	Value
Observations	1650
Number of cooperatives	150
Time periods	11
Fixed Effects	Cooperative & Year
R^2 (within)	0.71
Adjusted R^2 (within)	0.69
R^2 (overall)	0.64
F-statistic	52.8
Prob > F	0.0000
Root MSE	0.182
Mean VIF	1.96
Max VIF	2.41
Hausman test (FE vs RE)	$\chi^2 = 34.7$
Prob > χ^2	0.0000
Serial correlation (Wooldridge test)	F = 6.12
Prob > F	0.014
Heteroskedasticity (Modified Wald)	$\chi^2 = 412.3$
Prob > χ^2	0.0000
Clustered SE	Yes (cooperative level)

Source: constructed by authors based on [23-40].

Panel regression results reinforce these patterns. The two-way fixed-effects model shows in Tables 7 and 8 that green and digital indices have statistically significant positive effects on member income. The model controls for assets, land, and regional cooperative density. Asset intensity emerges as the strongest predictor. Land endowment shows no statistically significant effect once cooperative fixed effects are included. This result suggests a shift away from land-based expansion. Productivity gains now depend more on technology and organization.

Regional cooperative density also has a positive coefficient. This finding points to agglomeration effects. Cooperatives in dense regions benefit from shared infrastructure, knowledge spillovers, and institutional support.

The regression results confirm that green technology adoption, digitalization, and asset intensity are positively and statistically significantly associated with cooperative member income. Variance inflation factors (VIF) remain below conventional thresholds, indicating no serious multicollinearity concerns. The Hausman test strongly favors the fixed-effects specification over random effects. Tests indicate the presence of heteroskedasticity and serial correlation; accordingly, cluster-robust standard errors are employed. Overall model fit is high, with a within R^2 of 0.71 and adjusted R^2 of 0.69, suggesting that the model explains a substantial share of within-cooperative income variation over time.

DEA results (Figure 4) add a further layer of evidence. Mean efficiency scores rise over time in all countries, but at different speeds. Vietnam consistently shows the highest average efficiency. Cooperatives there use labor and capital effectively relative to output and green performance. Kazakhstan records moderate efficiency gains. Russia displays wide dispersion. Some cooperatives operate near the efficiency frontier, while others fall far behind. The distribution suggests a clear message. Technology alone does not ensure efficiency. Managerial capacity and institutional context remain decisive. The presence of inefficient cooperatives in all countries suggests substantial scope for productivity gains without additional resource inputs.

Taken together, the findings show clear transformation in agricultural producer cooperatives across CIS countries and Vietnam between 2015 and 2025. Technological modernization stands out as a key force. Green and digital technologies drive income growth and efficiency. Development paths, however, diverge. Cooperatives in CIS countries display strong structural diversity and fragmented institutional settings. Vietnamese cooperatives operate within a more uniform organizational model. They benefit from coordinated and consistent policy support. The comparative approach highlights the article's core contribution. Institutional capacity shapes how cooperatives adapt to technological and environmental demands.

The interpretations presented above should be understood as indicative rather than causal. While the empirical results establish robust statistical associations, the study design does not allow direct identification of underlying policy mechanisms. Explanations related to institutional design, reform strategies, or governance structures therefore remain hypotheses requiring further validation through policy analysis or case-based evidence.

4. DISCUSSION

The results obtained in this study contribute to the growing empirical literature on agricultural cooperatives in transition economies by demonstrating that productivity, income growth, and environmental performance are increasingly mediated by technological and organizational factors rather than by traditional extensive inputs alone. The positive and statistically significant association between green technology adoption, digitalization, and cooperative member income aligns with a broad body of efficiency-oriented agricultural research, while simultaneously revealing several deviations that are specific to cooperative organizational forms in post-socialist and late-transition contexts.

The magnitude of efficiency gains observed in this study appears broadly consistent with cross-country efficiency estimates reported for developing and transition economies, although the absolute levels differ. For instance, average DEA efficiency scores ranging between approximately 0.63 and 0.73 are notably higher than the mean technical efficiency of roughly 0.44 reported for lower-technology agricultural systems and closer to the upper-bound efficiency levels observed in more advanced innovation environments, where efficiency often exceeds 0.60 [22]. This convergence suggests that agricultural cooperatives, when embedded within supportive institutional frameworks, may partially overcome structural inefficiencies typically associated with small-scale farming systems.

At the same time, the results diverge from several farm-level studies that identify land or scale as dominant drivers of efficiency. In this analysis, land endowment does not exhibit a statistically significant relationship with income once cooperative and time fixed effects are controlled for, a finding that contrasts with evidence from crop-specific efficiency studies where land elasticity remains substantial [41, 42]. This discrepancy can be plausibly explained by the collective nature of cooperatives, where land aggregation and shared input use attenuate marginal land effects and shift performance determinants toward managerial coordination, technology diffusion, and institutional density.

The negative or weak role of subsidies inferred indirectly through efficiency dispersion also resonates with mixed evidence reported elsewhere. While some empirical studies identify positive efficiency effects of subsidies under specific conditions, particularly for small-scale producers, others report neutral or even adverse outcomes due to distorted incentives and scale mismatches [14, 16]. The present results appear closer to the latter strand, especially in the CIS context, where cooperative-level efficiency varies substantially despite comparable access to state support. This suggests that subsidies alone are insufficient to enhance cooperative performance unless complemented by mechanisms that strengthen governance quality and technological absorptive capacity.

A further point of convergence with prior research lies in the observed role of digital technologies. The strong income and efficiency effects associated with digital adoption echo findings that link information access, communication technologies, and innovation systems to reduced inefficiency and improved coordination [22]. However, unlike studies that focus on individual farms, the cooperative-level analysis highlights a collective digital dividend: digital tools appear to amplify coordination benefits, reduce transaction costs, and facilitate joint decision-making, thereby exerting a multiplier effect on income outcomes.

Conversely, the findings partially contradict concerns that cooperative complexity and member heterogeneity inherently undermine performance. While organizational diversity and internal conflicts have been shown to increase opportunistic behavior and reduce efficiency in some cooperative settings, particularly in multi-tier structures, the present results suggest that technological modernization may offset such risks by enhancing transparency and monitoring capacities [21]. This does not negate the relevance of governance challenges, but it indicates that their economic consequences are conditional rather than deterministic.

From a conceptual standpoint, the results can be interpreted through the lens of technology-mediated collective efficiency, defined here as the capacity of cooperatives to transform shared technological adoption into income and sustainability gains that exceed what would be achievable through individual action alone. This concept helps reconcile why cooperatives in different institutional environments converge in green and digital indicators while diverging in income growth and efficiency dispersion.

The comparative perspective further reveals that experiences from non-CIS transition economies may offer relevant, though not directly transferable, lessons. The relatively high efficiency and low dispersion observed in Vietnam resemble outcomes reported in countries where cooperative systems are closely integrated with national development strategies and extension services. Similar challenges and solutions have been identified in other regions, where climate-smart and green innovations deliver productivity gains only when institutional coordination, access to credit, and collective organization are present [43-46]. Nevertheless, differences in land tenure systems and governance traditions limit the direct transplantation of such models into CIS contexts.

Reliability rests on methodological consistency. Results align across correlation analysis, fixed-effects regression, and

DEA. This convergence supports the internal robustness of the findings. Some limitations remain: financial indicators require partial calibration. This creates uncertainty in absolute income levels. Relative comparisons remain reliable. So do dynamic trends. Both rely on official administrative and statistical data.

Within the broader field of economic research, the findings extend work on efficiency and cooperatives. Agricultural producer cooperatives in transition economies do not function as residual organizational forms. They do not operate as purely social instruments. Instead, they act as adaptive economic entities. Their performance responds increasingly to technology use, institutional density, and sustainability pressures. In this sense, the study contributes to bridging cooperative theory, innovation economics, and sustainability-oriented agricultural research.

5. CONCLUSION

This study set out to empirically assess the practices and performance of agricultural producer cooperatives operating in transition economies, with particular emphasis on income dynamics, technological adoption, and efficiency outcomes. The results demonstrate that cooperative development trajectories between 2015 and 2025 are neither uniform nor predominantly input-driven. Instead, they are increasingly shaped by the capacity of cooperatives to internalize green and digital technologies within their organizational structures. Empirically, cooperatives achieving higher levels of technological adoption exhibit superior economic outcomes, as reflected in income growth indices exceeding 200 in two of the three countries examined and mean DEA efficiency scores approaching 0,73 in the most efficient context.

From a scientific standpoint, this study advances the literature by redirecting attention away from scale- and land-based explanations of agricultural performance. It places technology-mediated collective efficiency at the center of analysis. The result that land endowment loses statistical significance after the inclusion of cooperative fixed effects challenges assumptions drawn from farm-level efficiency research. It also highlights the distinct economic logic that governs cooperative organizations.

The practical importance of the findings lies in their policy relevance. The evidence indicates that policies focused only on expanding resource access or subsidizing inputs are unlikely to deliver lasting efficiency gains. Such measures require complementary investments. Digital infrastructure, environmental technologies, and cooperative governance capacity are essential for sustained improvement. Policymakers may therefore utilize the findings to recalibrate cooperative support programs toward technology diffusion, advisory services, and inter-cooperative networking.

Beyond policy application, the results are relevant for cooperative managers and development agencies seeking to enhance income stability and environmental performance under conditions of market volatility and climate pressure. At the same time, several limitations warrant acknowledgment. Partial reliance on calibrated financial indicators constrains the precision of absolute performance measures, and national differences in cooperative classification limit full comparability.

Future research should extend the analysis by incorporating stochastic frontier methods with richer micro-level financial disclosures, examining governance quality as an explicit efficiency determinant, and expanding the geographical scope to additional CIS and non-CIS transition economies. Such extensions would further clarify the evolving role of agricultural cooperatives in global sustainable development.

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AVAILABILITY OF DATA AND MATERIAL

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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NOMENCLATURE

CIS	Commonwealth of Independent States