

Article

Causality Between Participatory Governance, Private Credit and the Performance of the Sesame Supply Chain: Evidence from Chad

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Abstract

Background: This study analyses the predictive causal relationships between sesame supply chain performance, participatory governance, and domestic credit to the private sector in Chad. In Sahelian economies, agricultural value chains continue to be subject to structural constraints relating to limited access to finance and substandard institutions. Therefore, understanding the interactions between local governance, productive finance and agricultural performance is essential for guiding public policy. **Methods:** This analysis uses annual data from 2002 to 2021. Sesame production serves as an indicator of supply chain performance, while participatory governance is assessed using a composite index based on citizen participation, government effectiveness, and regulatory quality. The study applies the Granger causality test in the Toda–Yamamoto sense. **Results:** The findings reveal unidirectional causality from participatory governance to sesame production. The findings also reveal bidirectional causality between domestic credit to the private sector and sesame production. No direct causality was observed between participatory governance and private credit. Impulse response functions confirm that institutional and financial effects on production manifest themselves gradually over time. **Conclusions:** These results imply that sustainable development of the sesame sector in Chad necessitates an integrated strategy combining stronger local governance, improved access to private finance, and agricultural value chain modernisation.

Keywords: sesame; supply chain; participatory governance; domestic credit to the private sector; Toda–Yamamoto causality; Chad



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1. Introduction

Agriculture remains a key pillar of many African economies, particularly in Sahelian countries, where it plays a significant role in terms of employment, rural incomes, food security, and social stability. In many sub-Saharan African countries, the agricultural sector also plays a key role in reducing poverty and driving structural transformation. However, the sector's performance is hampered by several persistent challenges, including weak rural infrastructure, market fragmentation, limited access to finance, climate vulnerability,

and sometimes inadequate public institutions [1–3]. In this context, enhancing the efficiency of agricultural supply chains is crucial for improving competitiveness, economic resilience and inclusive growth.

Among high-potential cash crops, sesame is playing an increasingly significant role in global agricultural trade due to rising demand in the agri-food sector, its relatively high market value, and its suitability for arid and semi-arid regions. For several Sahelian economies, this crop represents a strategic opportunity to diversify agricultural exports and increase rural household incomes [4]. In Chad, for example, the sesame sector has significant potential for economic development, revitalising rural areas and promoting regional trade integration. Nevertheless, development is hindered by low yields, logistical issues, limited storage capacity and imperfect access to organised markets and financing options that are poorly suited to the needs of agricultural stakeholders.

The economic literature shows that the performance of agricultural supply chains is not solely dependent on technical production factors. It is also influenced by governance quality, coordination between public and private actors, institutional capacity, and access to financial resources. More effective institutions can reduce transaction costs, improve the flow of information, secure trade and facilitate productive investment. Similarly, a more inclusive financial system enables producers and agricultural enterprises to acquire resources, modernise equipment, improve storage facilities and access markets more easily. Conversely, a high-performing value chain can strengthen the creditworthiness of economic actors and stimulate demand for financial services [5–7].

Despite these advances, few empirical studies have examined the dynamic interactions between participatory governance, private financing, and the performance of a specific agricultural value chain simultaneously, particularly in Central African and Sahelian countries. In Chad, for example, this gap is particularly pronounced despite the significant economic potential of the sesame value chain. Existing research generally addresses agricultural production, institutional constraints, and financing issues in isolation, without analysing the direction of causal relationships between these factors. However, it is essential to determine whether institutional improvements stimulate productive performance, whether credit promotes sector expansion, or whether a dynamic sector attracts more financing, in order to design effective public policies [1].

Consequently, this study aims to answer the following research questions: Does participatory governance influence the performance of the sesame supply chain in Chad? Is there a causal relationship between domestic credit granted to the private sector and the performance of the sesame supply chain? Is there a causal relationship between domestic credit granted to the private sector and participatory governance?

This study aims to analyse the predictive causal relationship between sesame supply chain performance, participatory governance, and domestic credit to the private sector in Chad between 2002 and 2021. Supply chain performance is approximated using sesame production as an observable indicator of the sector's productive and organisational capacity. Because comprehensive time-series indicators describing logistics performance (transport efficiency, storage capacity, processing activities, distribution efficiency, export logistics and market integration) are not available for Chad over a sufficiently long period, this study uses sesame production as a proxy for supply chain performance. Although production does not capture every operational dimension of the supply chain, it reflects the productive capacity around which upstream and downstream logistics activities are organised. In agricultural value chains characterised by severe data limitations, production has frequently been used as an aggregate indicator of overall chain performance. Accordingly, the empirical results should be interpreted as referring to the productive dimension of sesame supply chain performance rather than to the operational efficiency of all logistics activities within

the supply chain. Participatory governance is measured using a composite index incorporating citizen participation, government effectiveness, and regulatory quality. The study employs the Toda-Yamamoto approach methodologically, which is particularly suited to time series with mixed integration orders $I(0)/I(1)$ and enables the direction of causality to be identified without imposing excessive restrictions on the statistical properties of the variables [8].

This study contributes to the growing literature on agricultural supply chains. Firstly, it is among the few studies of the sesame sector in Chad to consider governance, financing and productive performance together. Secondly, it introduces a composite index of participatory governance, enabling the institutional dimension to be rigorously integrated into the analysis of agricultural value chains. Thirdly, it enriches the debate on agricultural transformation in the Sahelian region of Africa by demonstrating that value chain performance depends on dynamic interactions between institutions, the financial system, and productive capacity.

Although this study is published within the field of logistics, its contribution does not consist of modelling operational logistics activities directly. Instead, it investigates the institutional and financial conditions that shape the performance of an agricultural supply chain. In agricultural value chains operating under severe data constraints, governance quality and access to finance are widely recognized as enabling factors influencing coordination among actors, investment in storage and transportation facilities, market access, commercialization efficiency and the overall organization of the supply chain. Consequently, this study adopts a systemic supply-chain perspective rather than an operational logistics optimization perspective.

The remainder of the article is organised as follows. Section 2 presents the literature review. Section 3 describes the data and methodology. Section 4 presents the empirical results and discusses them. Finally, Section 5 concludes by formulating economic policy recommendations.

2. Literature Review

2.1. Agricultural Supply Chain Performance: Logistics Dimensions and the Sesame Sector

The performance of agricultural supply chains is a key issue for African economies, particularly in sectors where smallholder farmers dominate. In low-income countries, agricultural value chains continue to face numerous structural constraints, including poor coordination between stakeholders, inadequate rural infrastructure, post-harvest losses, limited market access, and vulnerability to climatic and geopolitical shocks. Consequently, a sector's performance depends not only on production levels but also on the capacity to organise collection, storage, processing and marketing activities effectively [9–11].

In agricultural logistics, supply chain performance is generally assessed through dimensions including transportation efficiency, warehousing capacity, inventory management, processing, lead-time reduction, market accessibility and export performance. However, in many developing countries, these indicators are unavailable as consistent long-term time series. Consequently, several macro-level studies rely on agricultural production as an aggregate indicator reflecting the overall functioning of the value chain while explicitly acknowledging that it does not measure each logistics component individually.

In the case of sesame, the literature highlights the growing economic potential of this crop for rural African economies. Drawing on the Tanzanian case, Ref. [12] shows that low sesame productivity is linked to limited access to improved seeds, inputs, technical support and market opportunities. Ref. [13] also indicates that the economic and environmental efficiency of sesame production hinges on the optimal use of resources and the management of production costs. These findings are particularly relevant for Chad, where,

although sesame is a promising export crop, it is still held back by logistical, financial and organisational shortcomings.

Recent research also shows that collaboration between stakeholders significantly improves the performance of agricultural value chains. Ref. [14] demonstrates that cooperation between producers, processors, traders and public institutions enhances market access, product quality and productivity. Similarly, Ref. [15] emphasises that high-performing agricultural value chains generally evolve towards more integrated and better-coordinated forms of governance. Therefore, the performance of the sesame sector must be understood as the result of organisational interactions extending beyond the productive sphere. Table 1 summarizes the literature review for this section.

Table 1. Literature Review Summary: Agricultural supply chain performance.

Study	Methodology	Period	Key Findings	Strengths	Limitations and Challenges/Notes
[9]	deductive thematic analysis, competitiveness mapping across five theories, and systems-based causal loop modeling.	Literature published up to 2025	Agrifood value chain competitiveness is mainly driven by productivity, value chain networking, product diversification, market access, and extension services. Public policies are the overarching driver of competitiveness. Short-term policies improve market access, while long-term policies strengthen access to finance and production inputs.	Comprehensive literature coverage. Integrates multiple theoretical perspectives. Systems-based approach captures interactions among competitiveness factors. Strong policy relevance.	Based solely on existing literature without empirical validation. Findings depend on the quality of selected studies. Causal relationships remain conceptual.
[10]	Development and application of a multi-level analytical framework. Rapid case studies assessing COVID-19 impacts on agricultural sectors in seven low- and middle-income countries.	COVID-19 period (2020–2021)	The framework links agricultural sector performance to broader food system outcomes. It reduces silo-based approaches and supports integrated food systems analysis and policymaking.	Practical analytical framework applicable across agricultural sectors. Validated in multiple countries. Strong systems perspective for decision-making.	Rapid assessments limit analytical depth. Primarily methodological. Limited quantitative comparative evidence.
[11]	Empirical analysis of governance arrangements within agricultural supply chains and their influence on farmers' adoption of Sustainable Agricultural Practices.	Contemporary data published in 2024	Supply chain governance strongly influences farmers' adoption of sustainable agricultural practices. Formal and informal governance mechanisms are as important as socioeconomic and psychological factors.	Introduces supply chain governance as a major determinant of sustainable practice adoption. Provides a novel perspective beyond farmer-level factors.	Limited information on differences across value chains and countries. Findings remain context-specific.

Table 1. *Cont.*

Study	Methodology	Period	Key Findings	Strengths	Limitations and Challenges/Notes
[12]	Survey of 240 sesame farmers using semi-structured questionnaires and interviews. Descriptive statistical analysis.	2023	Major production constraints include insect pests (23.6%), diseases (15.7%), drought (10.1%), weeds (9.9%), limited capital, and lack of improved seeds. Farmers prefer high-yielding, disease-resistant, and early-maturing varieties.	Valuable field data. Clearly identifies production constraints and farmer preferences. Useful for sesame breeding and varietal improvement programs.	Limited to southeastern Tanzania. Does not address economic or organizational dimensions of the value chain.
[13]	Life Cycle Assessment (LCA), Data Envelopment Analysis (DEA), surveys and face-to-face interviews with 41 farmers.	2025	Sesame production is more energy-efficient and environmentally sustainable than mung bean production. Greenhouse gas emissions are mainly driven by agricultural inputs, especially diesel use. Optimizing input use significantly improves sustainability.	Combines two robust analytical methods (LCA and DEA). Simultaneously evaluates energy efficiency, environmental impacts, and technical efficiency. Provides practical recommendations.	Small sample size (41 farms). Conducted in a single region of Iran. Results require validation in other production contexts.
[14]	Scoping review based on systematic searches of CAB Abstracts, EconLit, and Agricola. Review of 59 studies published between 2005 and 2023.	2005–2023	The main drivers of collaboration are improved market access and product quality. Collaboration enhances farmers' income, production, market participation, and well-being. Government and NGO support facilitate collaboration, while resource constraints and stakeholder conflicts remain major barriers.	Comprehensive synthesis of collaboration models in developing countries. Identifies policy gaps and practical recommendations. High relevance for agricultural development programs.	Potential publication bias, as unsuccessful collaborations are rarely reported. Limited evidence on long-term impacts and risk management.
[15]	Comparative analysis of rice value chains in Ghana and Côte d'Ivoire using quantitative data and stakeholder interviews.	2025	Both countries are experiencing technical modernization and more integrated governance in the rice milling segment. Vertical integration is more advanced in Ghana.	Compares two countries. Examines the often-overlooked processing segment. Clearly links policy, markets, and value chain organization.	Findings are specific to the rice sector and the two study countries. Drivers remain context-dependent.

2.2. Participatory Governance, Institutions and Agricultural Performance

Beyond technical factors, economic literature emphasises the crucial role of institutions in agricultural performance. Effective institutions can reduce transaction costs, improve the dissemination of information, enhance trade security and facilitate productive investment. In rural economies, participatory governance can promote better alignment between local needs, public policies, and resource allocation.

Studies [16] have shown that participatory mapping is an effective tool in African contexts characterised by data scarcity, as it enables local knowledge to be incorporated

into spatial planning. Ref. [17] emphasise that participatory approaches strengthen climate resilience and sustainable land management through collective learning and coordination among stakeholders. Ref. [18] also observe a gradual shift in land policies towards more adaptive and inclusive approaches.

More broadly, several institutional dimensions appear essential to agricultural development, including citizen participation, government effectiveness, and regulatory quality. Ref. [19] demonstrate that public institutions can strengthen agricultural resilience by improving access to services, promoting sustainable resource management, and fostering connections between stakeholders. Ref. [20] also emphasise the need for a coherent regulatory framework to support agricultural transformation. Taken together, these contributions suggest that better-quality participatory governance could be a key driver of performance in Chad's sesame sector. Table 2 summarizes the literature review for this section.

Table 2. Literature Review Summary: Participatory governance, institutions and agricultural performance.

Study	Methodology	Period	Key Findings	Strengths	Limitations and Challenges/Notes
[16]	Six case studies in Tanzania using interviews, focus group discussions with practitioners, participant surveys, and high-resolution remote sensing imagery.	2021	Participatory mapping improves stakeholder participation, spatial understanding, and decision quality while strengthening practitioners' skills.	Strong practical orientation. Includes perspectives from both practitioners and participants. Highly relevant in data-scarce regions.	Technical challenges, shortage of skilled experts, and limited institutional support restrict broader adoption.
[17]	Systematic review of 46 studies following PRISMA guidelines, examining participatory scenario planning for sustainable land management and climate resilience.	Studies published before 2026	Participatory scenario planning supports inclusive future scenarios linking ecological, social, and economic drivers, improving sustainable land management and climate resilience.	Rigorous PRISMA methodology. Comprehensive synthesis. Demonstrates the evolution of participatory scenario planning toward integrated sustainability challenges.	Participation is often uneven. Power imbalances and stakeholder representation remain challenges. Future scenarios require regular updating.
[18]	Systematic review of 137 studies published over 25 years using bibliometric analysis, methodological review, and qualitative content analysis.	Approximately 2000–2025	Peri-urban land policies have shifted from top-down planning toward adaptive, resilient, and participatory approaches. Major challenges include fragmented governance, land insecurity, and exclusion of vulnerable groups.	Large evidence base. Combines bibliometric and qualitative analyses. Provides practical recommendations for peri-urban governance.	Significant gap between policy design and implementation. Weak institutional coordination and uneven regional evidence.

Table 2. *Cont.*

Study	Methodology	Period	Key Findings	Strengths	Limitations and Challenges/Notes
[19]	Qualitative case study in the Talensi District using primary data collected from eight institutions. Analysis focused on scale, scope, and sustainability.	2026	Institutions promote climate adaptation through training, technology transfer, input provision, and value chain integration, improving productivity, resilience, and livelihoods.	Strong empirical field evidence. Valuable for local adaptation policy. Identifies concrete institutional mechanisms.	Limited resources, weak coordination, donor-driven priorities, and low transparency reduce effectiveness. Informal institutions are insufficiently addressed.
[20]	Global systematic review combined with cross-case analysis of Ireland, Pennsylvania, and the Philippines, examining social, market, and policy drivers.	2025	Regulatory instruments have the strongest influence, especially when combined with softer policy tools. Social and contextual factors strongly shape farmers' land-use decisions.	Global perspective with contrasting case studies. Strong analysis of interactions among markets, policies, and society. Produces transferable governance principles.	Governance outcomes vary across institutional contexts. Policy contradictions and market pressures reduce effectiveness.

2.3. Agricultural Finance, Private Credit and Productive Dynamics

Financing is another key factor in the performance of agricultural supply chains. Credit constraints can limit producers' ability to acquire inputs, invest in equipment, improve storage facilities, access markets, and manage production-related risks. Studies [21] have shown that the structure of credit markets significantly influences agricultural productivity in sub-Saharan Africa. Using the example of Kenyan coffee, Ref. [22] demonstrates that productivity improves when financial arrangements are tailored to sectoral needs.

However, access to finance is often limited by rural households' vulnerability, lack of collateral, low savings and information imperfections. Ref. [23] highlights that health shocks and economic fragility reduce farmers' access to credit. Ref. [24] also demonstrates that social networks and collective behaviour influence individuals' access to finance.

The relationship between finance and agricultural performance can also be bidirectional. On the one hand, credit supports productive investment and the modernisation of farms. Conversely, a high-performing sector improves the creditworthiness of stakeholders and stimulates demand for financial services. Ref. [25] demonstrate that credit channels interact with other macroeconomic variables to explain agricultural development. Ref. [26] also highlights the long-term positive effects of credit on agricultural productivity. These results justify a dynamic analysis of the relationship between private credit and the performance of the sesame sector. Table 3 summarizes the literature review for this section.

Taken together, the literature suggests that the performance of agricultural supply chains depends on the interaction between institutional quality and financial development. Participatory governance is expected to strengthen coordination among stakeholders and improve the institutional environment, whereas private credit facilitates productive investment and the modernization of agricultural activities. These complementary institutional and financial mechanisms provide the conceptual basis for examining the dynamic relation-

ships between participatory governance, domestic credit to the private sector and sesame supply chain performance in Chad.

Table 3. Literature Review Summary: Agricultural finance, private credit and productive dynamics.

Study	Methodology	Period	Key Findings	Strengths	Limitations and Challenges/Notes
[21]	Econometric panel data analysis using advanced estimation techniques accounting for endogeneity and cross-sectional dependence.	West African countries (period not specified in the abstract)	Agricultural credit and credit to agricultural enterprises significantly promote agricultural development. Policy reforms targeting these specific credit channels are more effective than general private sector credit.	Strong regional analysis. Addresses endogeneity issues. Highly relevant for agricultural finance policy.	Does not directly examine farmers' individual behavior. Effects may vary across countries and financial institutions.
[22]	Survey of 174 smallholder coffee farmers comparing credit beneficiaries and non-beneficiaries. Malmquist DEA Index and Bayesian Model Averaging (BMA).	2015–2019	Farmers receiving agricultural credit achieved higher productivity, technical efficiency, and scale efficiency. Coffee variety, education, extension services, and farming system positively influenced productivity.	Robust quantitative methodology. Direct comparison between beneficiaries and non-beneficiaries. Identifies key productivity determinants.	Limited to coffee production in Kiambu County. Relatively small sample. Productivity is influenced by climatic and market conditions.
[23]	105 semi-structured household interviews, 10 key informant interviews, ANOVA, and logistic regression analysis.	Before and during the COVID-19 pandemic	The COVID-19 pandemic changed the determinants of agricultural credit access. Before the pandemic, marital status, organizational membership, and household labor were important. During the pandemic, gender, savings, household labor, and livestock ownership became the main determinants.	Original analysis linking health shocks to rural credit access. Strong field-based evidence. Compares pre- and post-pandemic conditions.	Study limited to one district in Ghana. Findings are context-specific to COVID-19. Relies on self-reported data.
[24]	Cross-sectional survey of 400 farming households using a Spatial Durbin Model (SDM) and control function approach.	2025	Peer credit behavior positively influences farmers' own credit access but reduces household savings. Social networks play an important role in financial decision-making.	Highlights the importance of social networks. Appropriate spatial econometric approach. Large sample size.	Cross-sectional data limit causal inference. Potential dependence on existing social networks. Contextual effects remain inconclusive.

Table 3. *Cont.*

Study	Methodology	Period	Key Findings	Strengths	Limitations and Challenges/Notes
[25]	Panel data analysis using the Autoregressive Distributed Lag (ARDL) model and Generalized Method of Moments (GMM) for robustness.	2001–2021	Credit channels have mixed effects on agricultural development, while energy production and oil revenues significantly influence agricultural performance. The study recommends improving agricultural credit systems and promoting mechanization.	Integrates credit, energy, and oil revenue dimensions. Long study period. Robustness verified using GMM.	Some results differ between short- and long-run estimates. Regional aggregation may mask country-specific differences.
[26]	Autoregressive Distributed Lag (ARDL) model combined with wavelet coherence analysis using annual time-series data.	1998–2022	Inflation, rural population decline, economic growth, and institutional conditions reduce access to agricultural finance, whereas official development assistance positively supports agricultural financing.	Country-specific analysis. Combines ARDL with wavelet analysis. Relevant for food security and climate resilience policies.	Focused on a single small country. Macroeconomic indicators may not fully capture farm-level realities. Continued dependence on external aid.

Accordingly, the following empirical analysis investigates whether these institutional and financial factors exhibit dynamic causal relationships with sesame supply chain performance in Chad.

2.4. Empirical Gap and Contribution of the Study

Despite the abundance of research on agricultural value chains, few studies have focused specifically on the sesame sector in Central Africa and the Sahel. In Chad, for example, empirical research remains limited despite the significant potential of this crop for agricultural diversification, rural incomes and exports.

Furthermore, most studies analyse the effects of institutions, financing or agricultural production in isolation. Few examine the simultaneous interactions between participatory governance, domestic credit to the private sector, and the performance of a specific agricultural value chain. Moreover, existing approaches often rely on descriptive or static analyses that do not clearly identify the direction of causality between variables.

This study aims to address this gap by analysing the causal relationships between sesame supply chain performance, participatory governance and domestic credit to the private sector in Chad using the Toda–Yamamoto approach.

3. Data and Methodology

3.1. Data

In this section, we present the data and methodology used to analyse the causal relationship between the performance of the sesame supply chain, participatory governance,

and domestic credit to the private sector in Chad. Chad was chosen as the case study country due to the persistent structural challenges it faces in organising its agricultural value chains, particularly the sesame value chain. These challenges are linked to the weak organisation of stakeholders, limited access to productive and commercial infrastructure, and the restricted availability of bank financing for small-scale producers and agricultural enterprises, among other things. In this context, participatory development initiatives can play a significant role in enhancing stakeholder coordination, local governance, and, consequently, the performance of agricultural supply chains.

The aim of this study is therefore to empirically test the existence of a causal relationship between the performance of the sesame supply chain, participatory governance, and domestic credit to the private sector. The limited number of observations is mainly determined by data availability rather than by methodological choice. The analysis is based on annual data covering the period 2002–2021. It corresponds to the longest period for which consistent information on sesame production and governance indicators is simultaneously available from international databases. Extending the sample was therefore not feasible without compromising data consistency and comparability.

Sesame production (LPROD) is employed as a proxy for the productive performance of the sesame supply chain. This choice was motivated by the fact that production represents the core activity around which upstream and downstream supply chain operations, including collection, storage, transportation, and commercialization, are organized. Nevertheless, we agree that this proxy does not encompass every operational dimension of supply chain performance. Data on sesame production are drawn from the Food and Agriculture Organization's database [27].

Participatory governance is measured using a composite index constructed from three institutional indicators: Voice and Accountability, Government Effectiveness, and Regulatory Quality. These indicators are drawn from the World Development Indicators database [28]. These three dimensions were chosen because they complement each other in assessing the institutional framework conducive to stakeholder participation, the effectiveness of public action, and the quality of the regulatory environment. Voice and Accountability, for example, captures the degree of citizen participation, freedom of expression, and consideration of stakeholders' preferences in decision-making processes. Government Effectiveness reflects the quality of public services, administrative capacity, and the effectiveness with which public policies are implemented. Finally, Regulatory Quality measures the ability of public authorities to formulate and enforce regulations that promote economic development.

The Participatory Governance Index (PGI) is calculated as the simple arithmetic mean of these three indicators. Using the simple arithmetic mean is justified because the three selected components represent complementary institutional dimensions of the same concept. This method involves assigning an equal weight to each indicator, which is appropriate when there is no theoretical or empirical basis for prioritising the components or assigning a higher weight to any of them. In the literature on composite indicators, weighting is an important methodological step as it can influence the final value of the index. Ref. [29] emphasises that composite indicators synthesise several quantitative dimensions into a single measure whilst demonstrating that the choice of weighting scheme remains a potential source of subjectivity in their construction. In this context, using a simple arithmetic mean reduces the arbitrariness of choosing weights while ensuring the index is transparent and easy to interpret. This approach is also consistent with the work of [30], which demonstrates that the selection of weighting and aggregation methods depends on the objective of the study, the nature of the indicators, and the available theoretical justification. When the selected indicators are considered complementary and

no clear hierarchy can be established between them, simple equal-weight aggregation can be adopted as a consistent, easily interpretable method.

Domestic credit to the private sector (LCPS) is also extracted from the World Development Indicators database [28]. This variable was chosen because of its role in financing productive and commercial activities. In the context of agricultural value chains, access to credit can facilitate the acquisition of resources, investment in equipment, improvements to storage capacity, and strengthening of marketing channels. We prefer domestic credit to the private sector to other measures of financial inclusion because credit granted to private enterprises is directly linked to the financing of economic activities, including those associated with agricultural supply chains, and this limits potential endogeneity bias.

Finally, only the variables relating to the performance of the sesame supply chain and domestic credit to the private sector are transformed into natural logarithms. This transformation aims to reduce the influence of outliers, mitigate potential heteroscedasticity issues, and facilitate the interpretation of the estimated coefficients. It also enables the relationships between these variables to be analysed in terms of relative changes, which is particularly useful for an econometric analysis of annual time series. In contrast, the participatory governance index is not transformed into a logarithm as it is a composite indicator constructed from institutional variables that can be negative or near zero.

3.2. Methodology

In order to achieve the objectives of this research, the study adopts an adapted version of the Granger causality approach, as proposed in [8]. This method provides a robust and convergent Wald test statistic for causality analysis, even when the series are level-stationary (I(0)), first-order integrated (I(1)), or a combination of the two (I(0)/I(1)). Compared to classical causality tests, this approach offers several methodological advantages. It is based on a vector autoregressive (VAR) structure ($k + d_{max}$), where k represents the optimal order of the model and d_{max} represents the maximum order of integration of the variables. This limits the number of estimated parameters and helps reduce the risk of over-parameterization in a relatively small sample. The methodological contribution of this study does not lie in proposing a new econometric estimator but rather in applying the Toda–Yamamoto causality framework to investigate the interactions between participatory governance, private credit and agricultural supply chain performance in a data-constrained developing economy. Unlike the conventional Granger causality test, the Toda–Yamamoto procedure avoids pre-testing bias related to cointegration and remains valid when variables exhibit mixed orders of integration. This characteristic is particularly suitable for the present study given the limited sample size and the combination of I(0) and I(1) variables. In the context of this study, the Toda–Yamamoto model is formulated as shown in Equations (1)–(3).

$$\begin{aligned} LPROD_t &= \alpha_0 + \sum_{i=1}^k \beta_{1i} LPROD_{t-i} + \sum_{j=k+1}^{d_{max}} \beta_{2j} LPROD_{t-j} + \sum_{i=1}^k \lambda_{1i} PGI_{t-i} \\ &+ \sum_{j=k+1}^{d_{max}} \lambda_{2j} PGI_{t-j} + \sum_{i=1}^k \Phi_{1i} LCPS_{t-i} + \sum_{j=k+1}^{d_{max}} \Phi_{2j} LCPS_{t-j} \\ &+ \varepsilon_{1t} \end{aligned} \quad (1)$$

$$\begin{aligned} PGI_t &= \alpha_1 + \sum_{i=1}^k \beta_{1i} PGI_{t-i} + \sum_{j=k+1}^{d_{max}} \beta_{2j} PGI_{t-j} + \sum_{i=1}^k \lambda_{1i} LPROD_{t-i} \\ &+ \sum_{j=k+1}^{d_{max}} \lambda_{2j} LPROD_{t-j} + \sum_{i=1}^k \Phi_{1i} LCPS_{t-i} + \sum_{j=k+1}^{d_{max}} \Phi_{2j} LCPS_{t-j} \\ &+ \varepsilon_{1t} \end{aligned} \quad (2)$$

$$\begin{aligned}
 LCPS_t &= \alpha_2 + \sum_{i=1}^k \beta_{1i} LCPS_{t-i} + \sum_{j=k+1}^{d_{max}} \beta_{2j} LCPS_{t-j} + \sum_{i=1}^k \lambda_{1i} PGI_{t-i} \\
 &+ \sum_{j=k+1}^{d_{max}} \lambda_{2j} PGI_{t-j} + \sum_{i=1}^k \Phi_{1i} LPROD_{t-i} + \sum_{j=k+1}^{d_{max}} \Phi_{2j} LPROD_{t-j} \\
 &+ \varepsilon_{1t}
 \end{aligned} \tag{3}$$

Figure 1 summarizes the steps of the method followed.

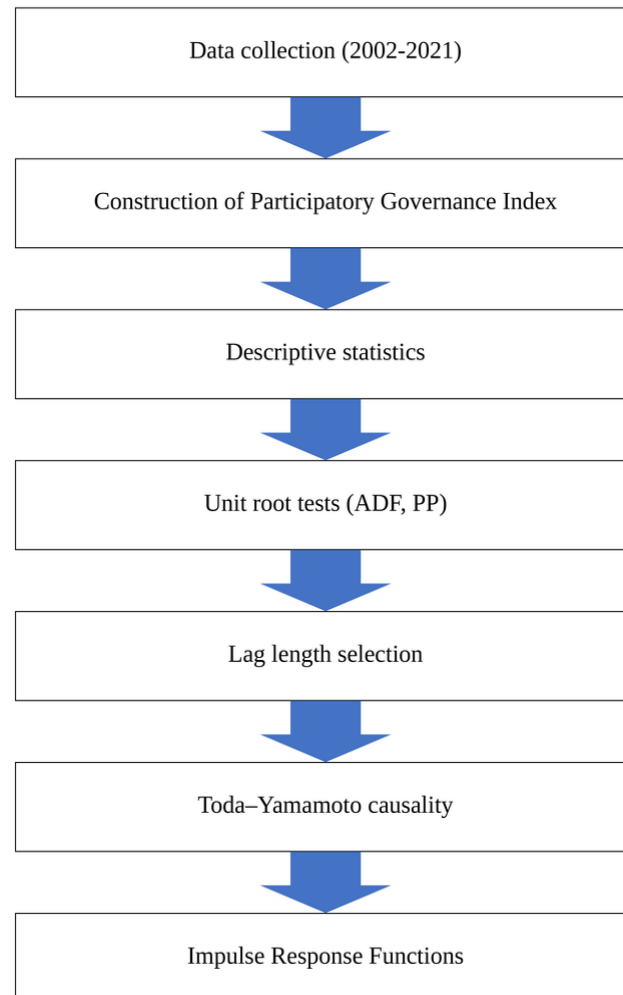


Figure 1. Research methodology.

The empirical strategy follows four sequential steps. First, descriptive statistics summarize the data. Second, unit root tests determine the order of integration of each variable. Third, the Toda–Yamamoto causality procedure identifies predictive causal relationships. Finally, impulse response functions are estimated to analyse the dynamic propagation of shocks within the VAR system.

4. Results and Discussion

4.1. Descriptive Statistics

Table 4 provides a descriptive overview of the variables used in this study. It shows that sesame production, the participatory governance index, and domestic credit to the private sector all follow a normal distribution, as indicated by the Jarque–Bera probability of 5% [31].

Table 4. Descriptive statistics.

	LPROD	PGI	LCPS
Mean	11.59635	−1.264000	1.472359
Median	12.00860	−1.135000	1.435085
Maximum	12.56137	−0.980000	2.272126
Minimum	10.04321	−1.530000	0.530628
Std. Dev.	0.854789	0.205565	0.549099
Skewness	−0.534993	−0.294335	−0.139856
Kurtosis	1.817635	1.306794	1.837306
Jarque–Bera	2.119049	2.677900	1.191747
Probability	0.346621	0.262121	0.551081
Sum	231.9270	−25.28000	29.44718
Sum of Squares	13.88261	0.802880	5.728687
Observations	20	20	20

Note: LPROD is sesame production, PGI is the participatory governance index and LCPS is domestic credit to the private sector.

4.2. Stationarity of Variables and Number of Lags

To continue applying the modified approach to causality testing as described in [8], Table 5 presents the results of the Augmented Dickey–Fuller and Phillips–Perron stationarity tests. The sesame production variable is stationary at level I (0), while the participatory governance index and domestic credit to the private sector are stationary at first difference I (1). There are no I(2) variables. Using the econometric causality tools of the Toda and Yamamoto approach requires selecting an appropriate lag length for the causality model due to the particular order of integration of the observed variables. The results of the selection criteria (AIC, SIC and HQ) for determining the optimal number of lags are presented in Table 6. Based on these results, the optimal lag length is considered to be 1 according to the AIC criterion, which is suitable for small samples [32].

Table 5. Stationarity of the variables.

Variables	Level		First Difference		Decision
	ADF	PP	ADF	PP	
LPROD	−3.95 *** (0.00)	−8.54 *** (0.00)	-	-	I (0)
PGI	−2.64 (0.10)	−2.64 (0.10)	−5.08 *** (0.00)	−5.13 *** (0.00)	I (1)
LCPS	0.58 (0.83)	0.29 (0.75)	−2.64 ** (0.01)	−2.45 ** (0.01)	I (1)

Note. *** Significant at 1%; ** Significant at 5%.

Table 6. Number of delays.

Lag	LogL	LR	FPE	AIC	SIC	HQ
0	−24.47803	NA	0.003621	2.892424	3.041546	2.917662
1	9.822942	54.15943 *	0.000257 *	0.229164 *	0.825652 *	0.330113 *

Note * indicates lag order selected by the criterion, LR: sequential modified LR test statistic (each test at the 5% level), FPE: Final prediction error, AIC: Akaike information criterion, SIC: Schwarz information criterion, HQ: Hannan–Quinn information criterion.

4.3. Granger Causality as Defined by Toda and Yamamoto

The Granger causality test method, developed by Toda and Yamamoto, is applied to determine the predicted relationship between the time series. To improve the performance of the sesame supply chain through participatory governance, Chadian policymakers will find knowledge of the direction of causality between the time series useful.

Table 7 shows the results of the Toda–Yamamoto Granger causality test. There appears to be bidirectional Granger causality between domestic credit to the private sector and

sesame production, suggesting dynamic feedback effects between productive financing and agricultural expansion. Unidirectional Granger causality is also observed running from the participatory governance index to sesame production, indicating that improvements in the institutional environment are associated with subsequent gains in the productive performance of the sesame sector. Figure 2 summarises all the causal relationships obtained from these variables.

Table 7. Results of the Toda–Yamamoto causality test.

Dependent Variables	Explanatory Variables			Decision
	LPROD	PGI	LCPS	
LPROD		5.71 ***	5.14 **	PGI → LPROD, LCPS → LPROD No causality between the variables LPROD → LCPS
PGI	4.83		2.87	
LCPS	27.05 ***	4.52		

Note: *** Significant at 1%; ** Significant at 5%. The symbol → represents unidirectional causality.

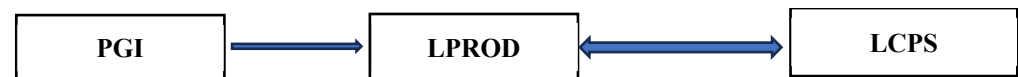


Figure 2. Diagram of the results of the Granger causality test in the sense of Toda–Yamamoto.

4.4. Impulse Response Between Variables

Having identified unidirectional Granger causality from the participatory governance index to sesame production, together with bidirectional Granger causality between sesame production and domestic credit to the private sector, the impulse response function derived from the structural VAR model is analysed to examine the dynamic responses of the variables following a shock. Figure 3 presents the impulse response functions showing the reaction of sesame production to shock in the participatory governance index and to domestic credit to the private sector, the response of the participatory governance index to shock in sesame production and domestic credit, and the response of domestic credit to shocks in sesame production and the participatory governance index. The impulse response functions confirm that participatory governance has a positive and persistent effect on sesame production, while domestic credit acts as a complementary driver. Furthermore, the feedback effects observed between production, governance and credit strengthen the coherence of the system and enhance the transparency of the experimental design by validating the dynamic interactions within the structural VAR model.

4.5. Discussion

Firstly, the observed causality between the variables confirms that the performance of the sesame supply chain does not depend solely on agricultural production capacity. It also stems from how production, collection, marketing and financing activities are organised. This finding is consistent with analyses by [9–11], which suggest that high-performing agricultural value chains rely on effective coordination between stakeholders and a favourable institutional environment.

Although transportation, warehousing and inventory management are not explicitly included in the econometric model, the empirical results have direct implications for these logistics dimensions. Improved participatory governance may facilitate coordination among supply-chain actors, improve public investment in rural logistics infrastructure and strengthen market organization. Likewise, greater access to private credit enables producers and traders to invest in storage facilities, transport equipment and commercialization activities, thereby improving the efficiency and resilience of the sesame supply chain.

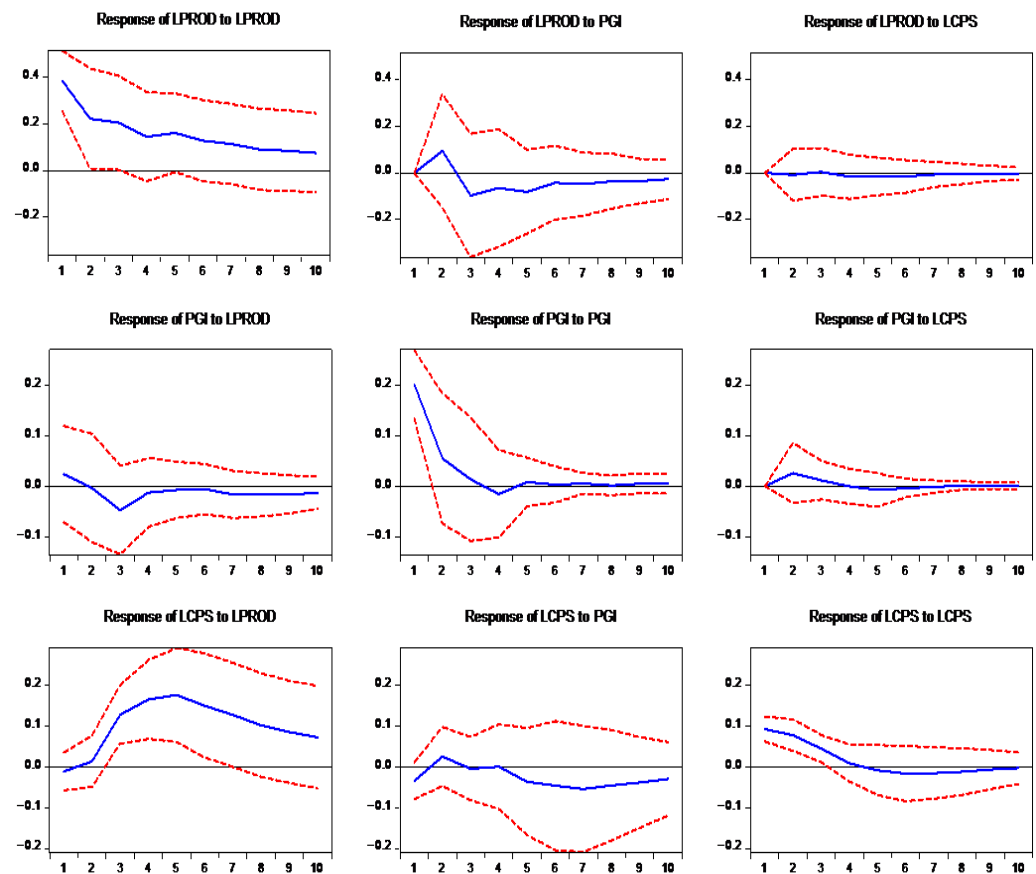


Figure 3. Structural functions of impulse responses between variables.

In Chad, sesame production is used as an indicator of performance and reflects not only the agricultural dynamics of the sector but also the productive system's capacity to mobilise inputs, organise distribution channels and meet market demand. Thus, the results suggest that improving sesame performance requires broader modernisation of the value chain, including storage, logistics, access to market information, and structuring rural markets.

The main institutional finding of this study is the existence of a unidirectional Granger causality relationship running from participatory governance to sesame production. This indicates that a more inclusive institutional environment characterised by greater citizen participation, more effective public action and higher regulatory quality promotes the sector's performance. This conclusion aligns with the work of [16–18], which demonstrates that participatory approaches enhance territorial coordination, ownership of public policies, and sustainable resource management. In Chad, better local governance could help identify producers' needs, improve the allocation of rural infrastructure and strengthen cooperation between public authorities, farmers' organisations and private operators. These findings are also consistent with literature on the governance of agricultural value chains. Studies [14,15] demonstrate that improved coordination of governance enhances the flow of information, product quality, and market integration. Therefore, participatory governance appears to be an effective means of structuring the sesame sector economically.

Conversely, the absence of a reverse causal relationship between sesame production and participatory governance indicates that productive growth alone cannot improve local institutions. Institutional progress appears to require specific reforms, which are independent of agricultural expansion. This finding is consistent with analyses by [19,20], which emphasise the importance of targeted public policies in strengthening institutional capacity sustainably.

A second major finding concerns the bidirectional Granger causality between domestic credit to the private sector and sesame production. This relationship highlights the existence of a virtuous circle between financial development and agricultural performance. Access to credit enables producers and agricultural enterprises to invest in inputs, equipment, storage, transport and marketing, for example. Conversely, a more productive sector improves incomes, strengthens the creditworthiness of stakeholders, and stimulates demand for financial services. These findings corroborate the work of [21,22,26], which emphasises the pivotal role of finance in enhancing agricultural productivity. In the Chadian context, these findings suggest that rural financial inclusion policies could have a significant impact on the entire sesame supply chain. Developing financial products that are tailored to agricultural cycles, such as seasonal credit, partial guarantees and rural digital solutions, could encourage productive investment and improve the sector's competitiveness.

Furthermore, the absence of a direct causal link between participatory governance and domestic credit to the private sector indicates that the impact of institutions on the financial sphere is not immediate. It seems that governance acts on the sector's actual performance first, before indirectly influencing access to finance. This interpretation is consistent with the findings of [9], which demonstrate that the interactions between institutions, economic organisation and finance are typically gradual rather than instantaneous.

Finally, impulse response functions confirm that the effects of participatory governance and credit on sesame production are gradual. This reflects the timeframes specific to the agricultural sector, where institutional reforms and financial investments typically require several production cycles before their full effects are realised.

The Chadian sesame sector is characterized by fragmented markets, insufficient storage facilities, weak transport infrastructure and limited access to formal financial services. Under these conditions, improvements in participatory governance may facilitate collective action among producers, improve public investment priorities and strengthen coordination between market actors. Likewise, greater access to credit may encourage investments that reduce post-harvest losses and improve market integration.

Although several relationships are statistically significant, statistical significance should not be interpreted as evidence of large economic effects. The Toda–Yamamoto framework identifies predictive causal relationships (in the Granger sense) between variables but does not directly quantify the magnitude of their economic impact. Consequently, the results should be interpreted primarily in terms of their direction and temporal dynamics rather than their economic magnitude.

Overall, the results demonstrate that the performance of the sesame supply chain in Chad depends on a balance between production organisation, institutional quality, and private financing. The sustainable development of this sector therefore requires an integrated strategy combining improved local governance, enhanced access to agricultural credit, and modernised logistics and commercial infrastructure.

5. Conclusions

This study analyses the predictive causal relationships between sesame supply chain performance, participatory governance, and domestic credit to the private sector in Chad between 2002 and 2021. Using the Toda–Yamamoto approach, which has been adapted for time series with mixed integration orders, the analysis identified the direction of interaction between these three strategic dimensions of agricultural development. The results highlight three key findings. Firstly, the existence of unidirectional Granger causality from participatory governance to sesame production shows that institutional quality is a key driver of agricultural performance. Greater citizen participation, more effective public action, and a more favourable regulatory environment strengthen coordination

between stakeholders, reduce organisational inefficiencies, and improve sector performance. Secondly, the bidirectional Granger causality observed between domestic credit to the private sector and sesame production reveals a positive feedback loop between financial development and productive performance. Access to finance encourages investment in inputs, equipment, storage and marketing, while a more dynamic sector improves stakeholders' creditworthiness and stimulates demand for financial services. Thirdly, the absence of a direct causal relationship between participatory governance and domestic credit to the private sector suggests that the effects of institutions on the financial sphere are mainly indirect, exerted through prior improvements in productive performance. Overall, the findings answer the research questions by demonstrating that participatory governance is a causal determinant of sesame supply chain performance, that domestic credit and supply chain performance reinforce each other through bidirectional causality, and that participatory governance influences private credit only indirectly through improvements in productive performance. In the Chadian context, therefore, institutional quality appears to affect the real economy first, before gradually filtering through to the financial system. These results confirm that the performance of the sesame supply chain depends on a complementary interaction between productive organisation, public institutions and access to finance, rather than a single factor.

From a managerial perspective, the findings of this study provide practical implications for the main stakeholders involved in the sesame supply chain in Chad. The findings suggest that policymakers could consider strengthening participatory governance mechanisms to improve coordination among public institutions, producer organisations and private actors. Financial institutions are encouraged to develop agricultural credit products adapted to the production cycle of sesame producers in order to facilitate productive investment. Likewise, producer organisations and other supply chain actors should strengthen collaboration and information sharing to improve market access, logistics coordination and the overall competitiveness of the sesame value chain.

These managerial implications translate into three main policy priorities for the sustainable development of the sesame sector. Firstly, participatory local governance should be strengthened through greater involvement of local authorities, producer organisations and private actors in defining agricultural priorities. Secondly, financial instruments tailored to rural realities, such as seasonal credit, portfolio guarantees, agricultural microfinance and digital financing solutions, should be promoted to improve access to productive finance. Thirdly, the sesame supply chain should be modernised through targeted investments in storage, transport, processing and market access infrastructure.

Nevertheless, this study has certain limitations. The small size of the time sample requires caution when interpreting the results. Future research based on longer time series or higher-frequency data would be useful in confirming the robustness of our findings. Furthermore, the relatively small sample size inevitably limits the statistical power of the estimations and the possibility of incorporating additional explanatory variables without over-parameterizing the VAR model. Although the Toda–Yamamoto procedure is particularly appropriate for small samples with mixed orders of integration, the empirical findings should nevertheless be interpreted with appropriate caution until they are confirmed using larger datasets or alternative empirical approaches.

Furthermore, sesame production was used as an indicator of supply chain performance in the absence of more detailed data on the logistical, commercial or industrial aspects of the supply chain in this sector. Future studies should use multidimensional indicators combining production, storage capacity, processing volumes, transport efficiency, export performance and market access whenever these data become available. The present study should be interpreted as analysing the institutional and financial determinants of

supply chain performance rather than operational logistics efficiency. Future research should combine macroeconomic analysis with logistics indicators describing transportation, warehousing, inventory management, processing efficiency and export logistics. It would also be relevant to extend the study to other countries in Central Africa and the Sahel, in order to compare the institutional and financial dynamics of agricultural export value chains. The empirical model does not explicitly include additional control variables such as rainfall variability, international sesame prices, fertilizer use, rural infrastructure or trade openness. Their omission is mainly explained by the limited sample size, which would considerably reduce the degrees of freedom of the VAR specification. Future research should investigate these factors using larger datasets.

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