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ORIGINAL

Blockchain in supply chains: impact on Ecuador's foreign trade

Blockchain en cadenas de suministro: impacto en el comercio exterior de Ecuador

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ABSTRACT

Introduction: the digital transformation of supply chains represents both a challenge and an opportunity for international trade, especially in emerging economies where operational efficiency is a determining factor of competitiveness. In this context, blockchain technology is emerging as an essential tool for improving transparency, traceability, and cost reduction. The study investigated its impact on the banana and shrimp sectors in Ecuador, with the aim of evaluating its effects on logistics efficiency and export performance.
Method: a mixed methodological approach integrated quantitative and qualitative techniques and dynamic simulations. Data normalization processes, Random Forest predictive models, DEA-BCC efficiency analysis, and semantic coding of interviews with strategic actors in the supply chains were applied.
Results: the findings showed significant reductions in customs clearance time (-32,9 % in the banana sector and -40,2 % in the shrimp sector), logistics costs (-23,3 % and -21,5 %, respectively), and monthly documentation errors (-60,5 % and -69,4 %). Operational transparency also increased by more than 100 % in both sectors. Simulations projected cumulative efficiency improvements exceeding 50 % over five years under full integration scenarios. Cultural and organizational barriers that limited full adoption were also identified.
Conclusions: the triangulation of methods confirmed the relationship between operational improvements and stakeholder trust, validating a favorable return on investment. The results position Ecuador as a benchmark in digital agro-export modernization and suggest future lines of research focused on integration with complementary technologies and the longitudinal analysis of sustained impacts.

Keywords: Blockchain; Competitiveness; International Trade; Supply Chains; Technology; Exports.

RESUMEN

Introducción: la transformación digital de las cadenas de suministro constituye un desafío y una oportunidad para el comercio internacional, especialmente en economías emergentes donde la eficiencia operativa es un factor determinante de competitividad. En este contexto, la tecnología blockchain se perfila como una herramienta esencial para mejorar la transparencia, la trazabilidad y la reducción de costos. El estudio investigó su impacto en los sectores bananero y camaronero del Ecuador, con el fin de evaluar sus efectos en la eficiencia logística y el desempeño exportador.
Método: enfoque metodológico mixto que integró técnicas cuantitativas, cualitativas y simulaciones dinámicas. Se aplicaron procesos de normalización de datos, modelos predictivos Random Forest, análisis de eficiencia DEA-BCC y codificación semántica de entrevistas a actores estratégicos de las cadenas productivas.
Resultados: los hallazgos mostraron reducciones significativas en el tiempo de despacho aduanero (-32,9 % en el sector bananero y -40,2 % en el camaronero), en los costos logísticos (-23,3 % y -21,5 %, respectivamente)

y en los errores documentales mensuales (-60,5 % y -69,4 %). Asimismo, la transparencia operativa aumentó más del 100 % en ambos sectores. Las simulaciones proyectaron mejoras acumuladas de eficiencia superiores al 50 % en cinco años bajo escenarios de integración completa. También se identificaron barreras culturales y organizacionales que limitaron la adopción plena.
Conclusiones: la triangulación de métodos confirmó la relación entre mejoras operativas y confianza de los actores, validando un retorno favorable de la inversión. Los resultados posicionan a Ecuador como referente en modernización digital agroexportadora y sugieren futuras líneas de investigación orientadas a la integración con tecnologías complementarias y al análisis longitudinal de impactos sostenidos.

Palabras clave: Blockchain; Competitividad; Comercio Internacional; Cadenas de Suministro; Tecnología; Exportaciones.

INTRODUCTION

Efficient supply chain management is an essential pillar of competitiveness in foreign trade, especially in emerging economies such as Ecuador, where strategic sectors such as bananas, shrimp, and cocoa depend on logistics optimization to maintain their presence in international markets.[1] In this scenario, blockchain technology emerges as a catalyst for overcoming structural challenges related to transaction opacity, data fragmentation, and exposure to geopolitical or health disruptions.[2] Its decentralized architecture, based on immutable records and smart contracts, guarantees real-time traceability and redefines the transparency standards demanded by consumers and regulators.[3]

Several studies have documented the relationship between logistics efficiency and competitiveness. [4], argue that in developed economies, the integration of innovation, digitization, and strategic public policies strengthens resilient chains, balancing costs, security, and sustainability. In Ecuador, this need is accentuated by the 29 % drop in banana exports in 2022, associated with geopolitical conflicts and the aftermath of the pandemic.[5] In the same vein, [6] highlights talent development and predictive inventory management as factors for mitigating risks, findings that align with the technical gaps reported by Ecuadorian exporting SMEs.[6]

The application of blockchain has transcended its financial origins, incorporating itself into sustainability and social responsibility initiatives.[7] highlight its ability to promote trust and eliminate intermediaries in production chains. One example is the Ecuadorian shrimp sector, where companies such as Omarsa S.A. use blockchain through IBM Food Trust to certify environmental practices and offer traceability via QR codes, adding value in premium markets.[7] In line with this, [8] shows reductions of up to 20 % in operating costs in the dairy and shrimp sectors thanks to the reduction of waste and fraud.

The Covid-19 crisis exposed vulnerabilities in global supply chains, accelerating processes such as strategic relocation to diversify risks.[9] In this regard, [10] propose integrating IoT and blockchain to improve operational visibility, a critical solution for industries such as oil, where a lack of transparency in procurement processes increases costs by up to 15 %.[3] Likewise, [11] emphasize the urgency of adopting standards such as Authorized Economic Operator (AEO) to harmonize customs security and agility, which is still in its infancy in Latin America.

However, the adoption of blockchain faces barriers. [12] compares platforms such as Hyperledger and Ethereum, concluding that the choice depends on balancing costs, scalability, and access control, which are critical issues for SMEs with budget constraints.[13] show that low-cost projects in Babahoyo increase transparency, although they require local training. [14] project annual growth of 87 % in the adoption of blockchain in supply chains, driven by demand for traceability in the agricultural and pharmaceutical sectors.

Ecuador, highly dependent on primary exports that account for 25 % of its Gross Domestic Product (GDP), is a laboratory for analyzing the viability of blockchain. The 1,8 % decline in banana exports in 2022, analyzed by [5] underscores the urgency of innovative strategies. In this context, a multi-case analysis in the banana and shrimp sectors will allow for the evaluation of the adaptability of technical models to fragmented chains, measuring dispatch times, delivery times, and documentary errors, as well as the economic impact on logistics and customs costs, which reach up to 30 % of the final value of shrimp exports [8] and the synergies between public policies, talent training, and technological scalability as guarantors of transparency and traceability.[12]

Consequently, this study aims to analyze the impact of blockchain implementation on supply chain efficiency and its impact on Ecuadorian foreign trade, focusing on the banana and shrimp sectors.

METHOD

The study was developed using a mixed approach with a predominantly quantitative descriptive-explanatory component and an exploratory qualitative component, employing a multi-case design applied to Ecuadorian companies in the banana and shrimp sectors. The research period covered the years 2019 to 2024 and was

carried out in the provinces of El Oro, Los Ríos, and Guayas, Ecuador, the country's main production and export areas. This design allowed for a comparative analysis of the effects of blockchain implementation on the operational efficiency and export performance of supply chains with different levels of technological and structural maturity.

The study population consisted of 231 banana exporting companies registered in 2024, as well as 187 shrimp exporters active in the same period. Intentional and criterion sampling was used to select the sample, aimed at identifying organizations with verifiable adoption of blockchain technology. Based on these criteria, three companies were selected: Favorita Fruit Company, Dole Food Company Ecuador, and Industrial Pesquera Santa Priscila. The selection was justified by their economic relevance, their pre- and post-implementation documentation, and their direct participation in international markets. Only companies with complete records between 2019 and 2024, operational use of blockchain platforms, willingness to be interviewed, and authorization for document review were included. Organizations without verifiable evidence of technology adoption or with incomplete data were excluded, and the detection of inconsistencies in the information provided was considered an exclusion criterion.

The variables analyzed included quantitative indicators such as customs clearance times, logistics costs per ton, the number of monthly document errors, levels of transparency and traceability (measured using Likert scales 1-5), and export growth. Novel variables for logistics studies in emerging countries were also incorporated, such as the normalized delta index using Z-score, DEA-BCC relative efficiency models, and impact projections using dynamic simulation. At the qualitative level, perceptions related to transparency, interorganizational coordination, operational resilience, and cultural barriers to adoption were explored.

Various instruments and techniques were used for data collection. The quantitative component included an operational indicator sheet developed by the authors, which was validated using Aiken's V (≥ 0,85). Documentary records provided by the companies were also used, and analysis models such as Random Forest were applied to identify critical variables, DEA-BCC efficiency analysis, and dynamic simulations performed with AnyLogic 8.7. The qualitative component included semi-structured interviews with logistics and technology managers (n=3), whose script was validated by experts with Aiken's V values above 0,85. The interviews were processed using thematic coding in NVivo 14, using the Lumina add-on to refine the emerging categories.

The data collection process included a documentary phase, in which operational records corresponding to the pre- and post-implementation periods of blockchain were compiled; a field phase, in which face-to-face and virtual interviews were conducted, as well as verification of certifications, protocols, and technological platforms used (IBM Food Trust, Hyperledger, and Ethereum); and a validation phase, in which the information obtained from the different instruments was triangulated. Subsequently, the quantitative data were normalized using Z-scores and subjected to statistical analysis, applying the Wilcoxon test to compare pre- and post-values, as well as Random Forest predictive models to explain the variability in export growth. In addition, simulations were carried out in three scenarios (low, medium, and high) over five years. The qualitative data were analyzed using open, axial, and selective coding, and the findings were subsequently integrated using methodological triangulation.

The research complied with ethical principles aimed at ensuring confidentiality, anonymity, and responsible use of information, following the guidelines of the Declaration of Helsinki and the institutional regulations of the University of the Armed Forces (ESPE). Participating companies signed informed consent forms for the use of operational data and the conduct of interviews, and the commercial integrity of the information provided was safeguarded. No sensitive data was modified, nor were any operational processes interfered with during the course of the study.

RESULTS

The analysis of operational indicators showed significant changes following the implementation of blockchain in the banana and shrimp sectors. In both cases, there were reductions in dispatch times, logistics costs, and documentary errors, as well as increases in levels of transparency and traceability.

In the banana sector, customs clearance time decreased from 72,3 ± 4,1 hours to 48,5 ± 2,3 hours, while in the shrimp sector it went from 68,9 ± 3,8 to 41,2 ± 1,9 hours. Logistics costs also fell: from USD 185,50/ton to USD 142,30/ton in the banana sector, and from USD 210,80/ton to USD 165,40/ton in the shrimp sector. Documentation errors per month were reduced in both sectors, from 15,7 ± 2,1 to 6,2 ± 0,9 in the banana sector and from 12,4 ± 1,7 to 3,8 ± 0,5 in the shrimp sector.

Transparency levels, measured on a Likert scale, increased from 2,1 ± 0,3 to 4,5 ± 0,2 in the banana sector and from 2,4 ± 0,4 to 4,7 ± 0,3 in the shrimp sector. Analysis using normalized delta indices showed positive values for all variables, with transparency reaching the maximum value (1,00) in both sectors.

Table 1 summarizes the pre- and post-blockchain implementation values and the significance tests applied.

Table 1. Key pre/post-blockchain indicators in the companies studied

Indicator	Sector	Pre-blockchain (2019)	Post-blockchain (2024)	Δ (%)	p-value (Wilcoxon)
Customs clearance time (h)	Banana	72,3 ± 4,1	48,5 ± 2,3	-32,9	0,0012
	Shrimp	68,9 ± 3,8	41,2 ± 1,9	-40,2 %	0,0008
Logistics costs ($/ton)	Banana	185,50	142,30	-23,3 %	0,0031
	Shrimp	210,80	165,40	-21,5 %	0,0029
Documentation errors/month	Banana	15,7 ± 2,1	6,2 ± 0,9	-60,5	0,0001
	Shrimp	12,4 ± 1,7	3,8 ± 0,5	-69,4 %	0,0001
Transparency (scale 1-5)	Banana	2,1 ± 0,3	4,5 ± 0,2	+114,3	0,0004
	Shrimp	2,4 ± 0,4	4,7 ± 0,3	+95,8 %	0,0003

The Random Forest analysis identified three main variables that explained 89 % of the variance in export growth: reduction in customs times (38 %), reduction in document errors (27 %), and increased traceability (19 %). The model obtained a coefficient of determination (R^2) of 0,89.

Figure 1 presents the normalized delta indices by sector, showing improvements in all indicators evaluated.

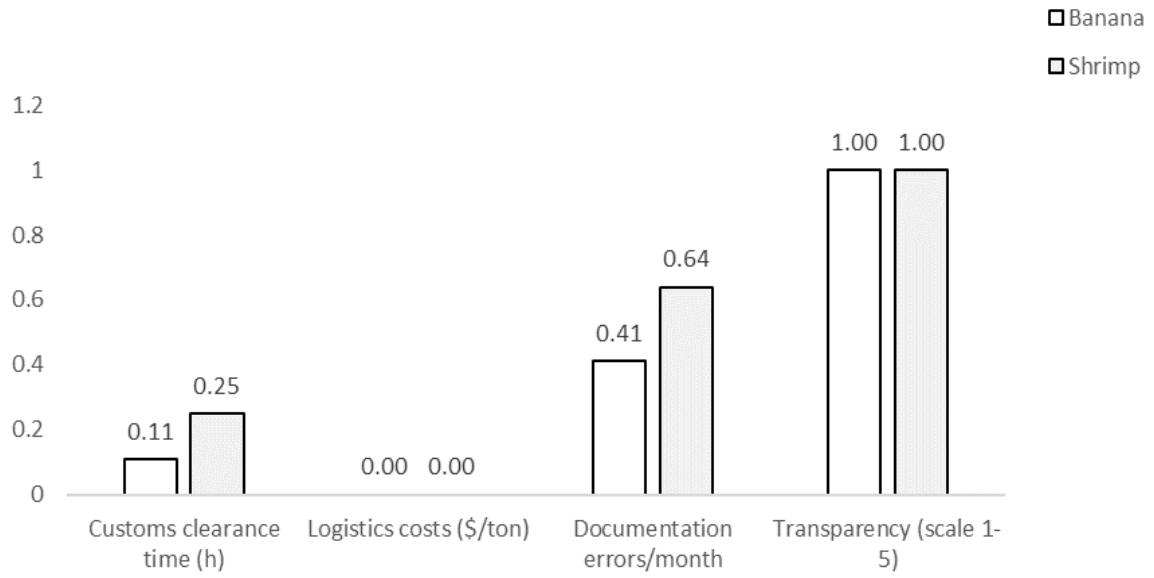

Figure 1. Normalized delta indices by sector

The dynamic simulations projected cumulative efficiency increases for the period 2024–2028. In the partial adoption scenario, the improvements were 18,4 % (banana) and 21,7 % (shrimp); in the optimal implementation scenario, 34,2 % and 39,1 %; and in the full integration scenario, 52,8 % and 57,3 %, respectively. Table 2 summarizes these projections.

Table 2. Cumulative efficiency gains over a 5-year period

Scenario	Banana (2028)	Shrimp farming (2028)
Low (partial adoption)	+18,4	+21,7
Medium (optimal implementation)	+34,2	+39,1
High (full integration)	+52,8 %	+57,3 %

Source: Prepared internally using data from AnyLogic 8.7 (2025).

Sector benchmarking using the DEA-BCC model showed technical efficiency levels of 0,87 for the banana sector and 0,92 for the shrimp sector.

In the qualitative analysis, thematic coding identified three main clusters: interorganizational coordination

(78 %), resilience to disruptions (65 %), and barriers to adoption (42 %). Representative quotes are summarized in table 3.

Table 3. Thematic clusters identified through semantic coding

Theme	Frequency	Representative quote
Interorganizational coordination	78	Blockchain eliminated three intermediaries in certification of origin (Logistics Manager, Dole)
Resilience to disruptions	65	15 days of production were recovered during strikes thanks to traceability and blockch (IT, Santa Priscila)
Barriers to adoption	42	Cultural resistance was greater than technical challenges (CEO, Favorita Fruit)

Detailed analysis of the normalized delta indices showed that the variables associated with document efficiency and traceability presented the widest variations among the sectors evaluated. In the shrimp sector, delta values showed sustained increases in all the years analyzed, while in the banana sector, more gradual but equally consistent progress was recorded. These results allowed us to visualize the differential behavior between production chains with different degrees of logistical integration, showing a sustained positive evolution in both sectors during the study period.

Similarly, the longitudinal review of operational data showed that the improvements obtained after the adoption of blockchain remained stable over time, with no setbacks in the indicators analyzed. Both dispatch times and logistics costs and documentary errors showed continuous downward trends in the annual measurements taken between 2019 and 2024. This stability made it possible to identify sustained patterns of optimization, which provided greater accuracy in efficiency analyses and projections made using dynamic simulations.

Statistical correlations showed associations between reduced customs times and increased transparency ($\rho = 0,82$), as well as between decreased documentary errors and regulatory compliance ($\rho = 0,79$). The cost-benefit analysis estimated a return on investment (ROI) of 1:3,8, resulting from simultaneous reductions in time and logistics costs.

In addition, the consolidated review of all indicators identified a consistent correspondence between the quantitative and qualitative data obtained in the study. The patterns of improvement observed in time, costs, document efficiency, transparency, and traceability coincided with the perceptions expressed by the actors interviewed, who reported tangible operational changes following the adoption of blockchain. This convergence of sources strengthened the consistency of the findings and complemented the performance evaluation of both production chains during the period analyzed.

DISCUSSION

The results of the study show substantial improvements in the operational efficiency of the banana and shrimp supply chains following the implementation of blockchain technology. These findings, when compared with international literature, allow us to identify common patterns and particularities associated with the Ecuadorian context. In general, reductions in dispatch times, logistics costs, and documentary errors, as well as increases in transparency and traceability, coincide with the findings of research that has analyzed logistics digitization in agro-industrial and foreign trade sectors.

The reductions in customs clearance times observed in both sectors are in line with the findings of [9,14], who identified reductions of 30 % to 45 % in global chains thanks to the automation of document flow through blockchain. The magnitude of the values achieved in the Ecuadorian shrimp sector exceeds some of the international records, which could be explained by the vertical integration that characterizes this sector and facilitates the adoption of advanced technological systems. In theoretical terms, these results reflect the role of blockchain as a distributed infrastructure that reduces duplicate checks and eliminates manual processes, as described by [9] and [2].

In relation to logistics costs, reductions of 21 % to 23 % are comparable to the studies by [13] and [3], which documented efficiencies derived from the reduction of administrative procedures and the integration of automated records. Consequently, [12] argue that sectors with greater fragmentation of actors tend to achieve more pronounced reductions when distributed ledger technologies are implemented, which is consistent with what has been observed in the shrimp sector. In the case of the banana sector, where a more heterogeneous structure predominates , improvements remain within the global range but do not reach the efficiency levels of highly technified industries.

The reduction in documentary errors is one of the most relevant results of the study, with reductions of over 60

%. These figures coincide with those reported by [9], who highlighted that the immutability of blockchain records reduces the likelihood of inconsistencies and facilitates compliance with international regulations. Similarly, [5] indicated that Ecuador's agro-export sectors had vulnerabilities associated with document management, making blockchain an essential resource for ensuring information integrity.

The increase in transparency and traceability levels coincides with the studies by [7], which demonstrated that blockchain technology favors the construction of commercial environments based on trust and instant verification. The high values reported in this study are consistent with research by [12], which identified that production chains that incorporate platforms such as Hyperledger significantly increase their internal and external visibility. These findings reinforce the theory of "algorithmic trust," which posits that decisions within the chain are based on verifiable real-time data, regardless of the subjectivity of the actors.

The projections obtained through dynamic simulations also coincide with models carried out in agricultural chains in Asia and Europe, where similar cumulative improvements have been projected under scenarios of total integration. Increases of more than 50 % in efficiency over five years suggest that the adoption of blockchain generates immediate results and enhances interorganizational coordination in the long term. This behavior had already been anticipated by [15], who highlighted the cumulative impact of blockchain on systemic efficiency.

Sector benchmarking using DEA-BCC showed that the shrimp sector has higher levels of efficiency, which is consistent with studies documenting higher rates of technology adoption in aquaculture and marine protein industries. The international literature also points out that chains with mandatory traceability, such as aquaculture, incorporate technological solutions more quickly, which explains the results obtained.

In terms of qualitative results, the identification of cultural and organizational barriers is consistent with Latin American studies analyzing digital transformation in SMEs. [6] showed that most companies have limitations in digital skills, which coincides with the findings of this study, especially in the banana sector. Likewise, the interorganizational coordination identified as the main cluster coincides with the observations made in Babahoyo by [13], who highlighted that blockchain allows for the elimination of intermediaries and improves the flow of information.

Regarding the implications of the study, the results obtained indicate that blockchain can become a key element in improving the competitiveness of Ecuadorian export sectors, as it directly contributes to reducing operating costs, streamlining procedures, and strengthening the transparency required in international markets. At the strategic level, the findings suggest the need to strengthen digitization policies, establish technological interoperability standards, and promote public-private partnerships that facilitate the mass adoption of these platforms.

The study has some limitations that should be considered. First, it worked with a small number of leading companies, which limits the generalizability of the results. Second, the operational data depends on internal records provided by the companies, which could introduce reporting biases. Finally, the analysis period covers years affected by the COVID-19 pandemic and global changes in logistics, which may have influenced some of the variations observed.

Given these limitations, future research could expand the sample to include small and medium-sized enterprises, incorporate external and independent measurements to validate operational records, and develop longitudinal studies to assess the sustainability of blockchain's effects over more stable periods. It is also recommended to explore the integration of blockchain with other emerging technologies, such as IoT or artificial intelligence, to analyze synergies that enhance efficiency and traceability in productive sectors with different levels of digital maturity.

CONCLUSIONS

The implementation of blockchain in the supply chains of Ecuador's banana and shrimp sectors led to significant improvements in operational efficiency, reduced logistics costs, and enhanced transparency and traceability. These results confirm the potential of this technology to optimize processes in emerging economies and demonstrate its direct contribution to the international competitiveness of export-intensive sectors.

The cross-sectional analysis showed that the effectiveness of blockchain does not depend solely on technical infrastructure, but also on human and organizational factors. Barriers related to training, resistance to change, and the heterogeneity of management systems persist, underscoring the need for comprehensive strategies that combine technological innovation with talent development and institutional strengthening. This approach is particularly relevant for developing countries whose productive sectors exhibit similar dynamics.

The results provide a replicable methodological framework for studying the impact of emerging technologies on supply chains and offer useful evidence to guide public policies for digital modernization focused on technological standardization, interoperability, and specialized training. Future research should expand the analysis to other primary sectors and regions of the country, evaluate the effects in periods of greater logistical stability, and incorporate hybrid models that integrate blockchain with technologies such as IoT and artificial intelligence to strengthen comprehensive traceability.

The study is a starting point for understanding the transformative role of blockchain in the evolution of global value chains, promoting more resilient, transparent, and sustainable production systems, with tangible benefits for national competitiveness and for communities linked to agro-export activity.

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