# HOW AI-ENABLED BLOCKCHAIN TECHNOLOGY FACILITATES U.S. SANCTIONS ON FOREIGN BUSINESSES: AN ANALYSIS BASED ON INTERNATIONAL REGULATORY HARMONIZATION

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**Abstract**: This article investigates the critical role of blockchain technology in promoting the integration of international regulatory harmonization within American global supply chains to facilitate U.S. sanctions on foreign businesses. While the convergence of artificial intelligence (AI) and blockchain offers a transformative path toward enhanced transparency, efficiency, and security in supply chain management, its adoption is hampered by intricate legal landscapes and inconsistencies in international regulations. This analysis dissects the key legal roadblocks, including data privacy concerns, jurisdictional conflicts, and ensuring compliance with diverse international standards. More importantly, it explores the opportunities presented by establishing a harmonized regulatory framework. Such a framework would enable the seamless integration of artificial intelligence (AI) and blockchain technologies across global supply chains. By addressing these legal hurdles and capitalizing on the opportunities for international regulatory harmonization, this article explores how blockchain technology can catalyze achieving this objective. Specifically, it examines how blockchain can foster transparency, streamline compliance processes, and mitigate the challenges associated with imposing sanctions on foreign businesses, particularly those from China.

**Keywords**: Blockchain Technology; U.S. Sanctions; Global Supply Chain; International Regulatory Harmonization

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## INTRODUCTION

The intricate network of global supply chains forms the backbone of the American economy, facilitating the movement of goods, materials, and information across continents.[1] However, this complex system is susceptible to disruptions, inefficiencies, and even fraudulent activities, making it vulnerable to exploitation by foreign businesses that do not comply with American sanctions.[2] Innovative technologies like blockchain and Artificial Intelligence (AI) offer a potential solution, promising to revolutionize the management and security of these vital commercial arteries while simultaneously enhancing enforcement capabilities for American sanctions.[3]

Blockchain technology represents a paradigm shift in data management for global supply chains. Imagine a shared digital ledger accessible only to authorized participants, where every transaction is meticulously recorded and secured using cryptography.[4] Each entry, or "block," is chronologically linked to the previous one, creating an immutable chain of events. This inherent transparency makes data tampering or transaction fabrication nearly impossible, thereby strengthening the ability to identify and hold accountable foreign businesses that violate American sanctions.

The potential benefits extend far beyond the American context. Real-time tracking of goods across their entire journey, from raw materials in remote locations to finished products on store shelves, becomes a reality for all stakeholders involved in the global supply chain. This increased transparency can significantly improve the enforcement of American sanctions by providing clear visibility into the movement of goods and identifying potential attempts to circumvent restrictions. Disputes over origin and ownership are minimized, and counterfeiting is significantly hindered. Additionally, smart contracts and self-executing agreements embedded within the blockchain can automate processes and reduce administrative burdens across international borders, streamlining the enforcement of American sanctions compliance.

While robust and efficient supply chains are undoubtedly crucial for the American economy, their reach extends far beyond national borders. However, the widespread adoption of AI-enabled blockchain technology within these global networks faces significant legal hurdles. The legal landscape surrounding this nascent technology is still evolving, presenting a complex web of considerations, particularly with the added layer of complexity introduced by AI integration.[5] Data privacy regulations, intellectual property rights, and the inherently international nature of supply chains raise critical questions that demand international legal solutions –

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[1] Jeffrey Neilson, et al., *Global value chains and global production networks in the changing international political economy: An introduction*. REVIEW OF INTERNATIONAL POLITICAL ECONOMY 21.1, 1-8(2014).

[2] Hoda Davarzani, et al. *Understanding econo-political risks: impact of sanctions on an automotive supply chain*. INTERNATIONAL JOURNAL OF OPERATIONS & PRODUCTION MANAGEMENT 35.11, 1567-1591 (2015).

[3] Fabio Cozzi. *Will blockchain technologies strengthen or undermine the effectiveness of global trade control regulations and financial sanctions?*. GLOBAL JURIST 20.2, 20190047 (2020).

[4] Michael Nofer, et al. *Blockchain*. BUSINESS & INFORMATION SYSTEMS ENGINEERING 59 183-187 (2017).

[5] John Babikian, *Navigating the Legal Landscape: Regulations for Artificial Intelligence, Quantum Computing, and Blockchain*. INTERNATIONAL JOURNAL OF ADVANCED ENGINEERING TECHNOLOGIES AND INNOVATIONS 1.1, 1-16 (2017).

solutions that go beyond national frameworks and specifically address the challenges of enforcing American sanctions on foreign businesses.

This article examines the potential roadblocks that could hinder blockchain technology's implementation, with particular attention to areas such as data security and ownership across international jurisdictions. The investigation will explore how intellectual property rights can be protected for AI algorithms embedded within the blockchain, emphasizing the need for harmonized legal frameworks to facilitate seamless global supply chain operations and empower the enforcement of American sanctions.

The core argument of this article is that while the potential benefits of AI-enabled blockchain for American global supply chains are undeniable, a thorough understanding of the legal challenges, particularly the need for international harmonization to enforce American sanctions, is paramount. By proactively addressing these challenges and fostering a collaborative approach among stakeholders across the globe, policymakers and stakeholders, by working closely together, can pave the way for a future where this transformative technology strengthens not just America but all global supply chains while simultaneously safeguarding American interests through enhanced enforcement of sanctions.

## I. AI-ENABLED BLOCKCHAIN TECHNOLOGY IN GLOBAL SUPPLY CHAINS

The integration of artificial intelligence (AI) with blockchain technology heralds a transformative era for American global supply chains. However, comprehending this advancement requires a nuanced understanding of the foundational technological principles and their corresponding legal ramifications.

### A. Blockchains and Global Supply Chains

Blockchain acts like a shared and secure record-keeping system for all participants in a supply chain.[6] At its essence, blockchain technology operates as a distributed ledger—a secure, decentralized database maintained across a network of computers.[7] This architecture obviates the necessity for a central authority, thereby promoting decentralization. Within this network, each transaction is cryptographically hashed and sequentially linked to its predecessor, forming an immutable record resistant to tampering. This intrinsic transparency and reliability engender trust within the supply chain ecosystem.

Moreover, blockchain technology enables the deployment of smart contracts.[8] These self-executing contracts are embedded within the blockchain and automatically activate predefined actions upon the satisfaction of specific conditions.[9] For instance,

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[6] Razatulshima Ghazali, et al. *Blockchain for record-keeping and data verifying: proof of concept*. MULTIMEDIA TOOLS AND APPLICATIONS 81.25, 36587-36605 (2022).

[7] Advait Deshpande, et al. *Distributed Ledger Technologies/Blockchain: Challenges, opportunities and the prospects for standards*. OVERVIEW REPORT THE BRITISH STANDARDS INSTITUTION (BSI) 40.40, 1-34 (2017).

[8] Shuai Wang, et al. *Blockchain-enabled smart contracts: architecture, applications, and future trends*. IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS: SYSTEMS 49.11, 2266-2277 (2019).

[9] *Id.*

a smart contract might release payment to a supplier only upon verification of successful delivery. This automation not only streamlines processes but also mitigates the risk of human error or fraudulent activity.

Additionally, blockchain technology employs cryptographic techniques to ensure the security and transparency of data stored on the ledger.[10] Cryptographic hashing functions produce unique identifiers for each transaction, rendering them virtually unalterable without detection. Furthermore, all network participants can access the ledger, depending on the specific blockchain's permission structure, thus fostering information visibility and accountability throughout the supply chain.

Unlike traditional, isolated data systems, blockchain facilitates the creation of a unified, shared ledger that meticulously tracks the movement of goods throughout the entire supply chain. This distributed ledger provides an immutable and verifiable record of every touchpoint, from raw material extraction to final product delivery.

This enhanced traceability offers myriad benefits. In the context of food safety, blockchain can monitor the origin, processing, and transportation of food products. This enables regulatory bodies to accurately identify the source of contamination during outbreaks, thereby facilitating targeted recalls and safeguarding consumer health. Similarly, within the pharmaceutical industry, blockchain ensures the authenticity and provenance of drugs, effectively combating the proliferation of counterfeit medications.

The advantages of blockchain technology extend beyond health-related sectors. For instance, the luxury goods industry can utilize blockchain to verify the origin and history of high-value items, address concerns about counterfeiting, and foster consumer trust in the legitimacy of products.

Real-world applications further illustrate the transformative power of blockchain in supply chain management. Walmart, for example, has partnered with IBM to implement a blockchain-based system for tracking mangoes.[11] This system allows them to trace the fruit from farm to store shelves, ensuring freshness and compliance with food safety regulations. Similarly, British Petroleum (B.P.) employs blockchain technology to track the provenance of oil and gas, promoting transparency in their supply chain and demonstrating responsible sourcing practices.[12]

Nevertheless, the legal implications of implementing such transformative technologies warrant careful consideration. The subsequent section will explore the intricate legal landscape surrounding AI-based blockchain technology within American global supply chains.

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[10] Sheping Zhai, et al. *Research on the Application of Cryptography on the Blockchain*, JOURNAL OF PHYSICS: CONFERENCE SERIES. Vol. 1168. IOP Publishing, 2019.

[11] Mohamed Awwad, et al. *Blockchain technology for efficient management of supply chain*. Proceedings of the international conference on industrial engineering and operations management. 2018.

[12] Hongfang Lu, et al. *Blockchain technology in the oil and gas industry: A review of applications, opportunities, challenges, and risks*. IEEE ACCESS 7, 41426-41444 (2019).

## B. Adopting AI for Blockchains

AI-enabled autonomy refers to the capability of machines, whether platforms or software, to function independently within set constraints to achieve goals or solve problems.[13] By learning from prior training and experiences, such systems can rapidly process vast amounts of data, adapting to dynamic scenarios and making swift, accurate decisions even with sparse data. This adaptability is crucial across civilian, industrial, and military applications. In defense, however, the complexity and stakes are higher, requiring superior standards in situational analysis, decision-making, and response. The U.S. advances these technologies primarily through federal research agencies like DARPA, ensuring their reliability and adaptability for military purposes.[14]

AI enhances data analysis and enables the extraction of profound insights from the vast amounts of data generated at each stage of the supply chain. Through machine learning algorithms, AI can discern patterns, trends, and anomalies that might elude human analysis. This facilitates predictive analytics, enabling the anticipation of demand fluctuations and potential disruptions, such as adverse weather conditions or labor strikes, thereby optimizing inventory levels to avoid both shortages and surpluses. Additionally, AI's analytical prowess can enhance supplier management by evaluating performance data recorded on the blockchain, aiding in the identification of reliable partners and foreseeing potential issues.

AI also excels in automating supply chain processes based on data extracted from blockchain systems. One significant application is the automation of smart contracts, which are self-executing contracts with terms directly embedded in code.[15] AI can automatically trigger these contracts when predefined conditions are met, streamlining operations such as payments and approvals. Furthermore, AI-driven automated re-ordering systems can monitor inventory levels and initiate re-orders as needed, ensuring a consistent flow of goods and reducing manual intervention.

Advanced tracking and visibility are other areas where AI significantly contributes to blockchain-based supply chain management. By analyzing real-time data points on the blockchain, AI provides comprehensive insights into a product's journey from origin to destination. This level of transparency enhances customer confidence by allowing them to trace the movement and provenance of their products, while AI's capabilities in fraud detection help identify inconsistencies or suspicious activities, thereby mitigating the risk of counterfeit goods.

The synergy between AI and blockchain fosters a sophisticated supply chain ecosystem characterized by heightened efficiency, transparency, and cost savings.[16] AI can predict equipment failures and maintenance needs by analyzing sensor data and information from Internet of Things (IoT) devices linked to the blockchain, facilitating

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[13] This is based on the article "*AI-enabled Autonomy*". Retrievable from https://www.baesystems.com/en-us/definition/what-is-ai-enabled-autonomy.

[14] William B Bonvillian, and Richard Van Atta. *ARPA-E and DARPA: Applying the DARPA model to energy innovation*. THE JOURNAL OF TECHNOLOGY TRANSFER 36.5 469-513. (2011).

[15] Lennart Ante, *Smart contracts on the blockchain–A bibliometric analysis and review*. TELEMATICS AND INFORMATICS 57, 101519. (2021).

[16] Reyes-González Juan Pablo, et al. *Big data in the healthcare system: a synergy with artificial intelligence and blockchain technology*. JOURNAL OF INTEGRATIVE BIOINFORMATICS 19.1, 20200035. (2022).

predictive maintenance that reduces downtime and prolongs machinery life. AI's ability to optimize routing and logistics further reduces transportation costs and delivery times, enhancing overall supply chain performance.

Risk management is another domain where AI demonstrates significant potential. By analyzing historical and real-time blockchain data, AI can identify potential disruptions, assess supplier reliability, and predict the impact of external factors such as geopolitical events or natural disasters. This proactive approach enables companies to prepare for and respond to unforeseen events more effectively, enhancing supply chain resilience.

AI's role in bolstering the security of blockchain networks is also critical. Machine learning algorithms can detect and respond to cyber threats in real-time, identifying unusual patterns or activities indicative of security breaches and facilitating immediate action to prevent data loss or tampering.[17]

Moreover, AI assists in supplier and partner selection by evaluating performance, reliability, and compliance data recorded on the blockchain.[18] This data-driven approach ensures that companies engage with the most reliable and efficient partners, thereby enhancing overall supply chain efficiency. AI can also monitor and ensure compliance with environmental regulations and sustainability standards, tracking the carbon footprint of products, adherence to labor laws, and ethical sourcing of materials.[19]

## C. Illustrative Cases Related to the Adoption of Blockchain Technology in Supply Chains

The potential of blockchain technology to revolutionize supply chains is undeniable. This section explores its real-world impact through two compelling cases: Walmart's implementation for enhanced food safety and traceability and the collaboration between Maersk and IBM to digitize global trade. These examples showcase the transformative power of blockchain in ensuring transparency, efficiency, and trust across complex supply networks.

### 1. Walmart: Food Safety and Traceability

Walmart has leveraged blockchain technology in partnership with IBM to revolutionize the traceability and safety of its food products.[20] The traditional methods for tracing the provenance of food items were plagued by inefficiencies and delays, making it challenging to pinpoint the source of contamination during foodborne illness outbreaks swiftly. To address these shortcomings, Walmart adopted IBM's Food Trust

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[17] Varun Shah, *Machine Learning Algorithms for Cybersecurity: Detecting and Preventing Threats.* REVISTA ESPANOLA DE DOCUMENTACION CIENTIFICA 15.4, 42-66 (2021).

[18] Naoum Tsolakis, et al. Artificial intelligence and blockchain implementation in supply chains: a pathway to sustainability and data monetisation?. ANNALS OF OPERATIONS RESEARCH 327.1, 157-210 (2023).

[19] *See, for example,* Baran Ada,. *Eco-Innovation and Regulation: Evaluating the Impact of AI Policies on the Ecological Footprint of the IT Sector*. BS thesis. University of Twente, 2024.

[20] Reshma Kamath, *Food traceability on blockchain: Walmart's pork and mango pilots with IBM*. THE JOURNAL OF THE BRITISH BLOCKCHAIN ASSOCIATION 1.1 (2018).

blockchain platform, which meticulously records each stage of a product's journey from farm to store.[21]

By implementing this blockchain solution, Walmart can now trace the origin of products such as mangoes and pork within seconds, a dramatic improvement from the previous timeframe of days or weeks.[22] This enhanced traceability not only ensures greater food safety but also enables a much faster response to contamination issues, significantly mitigating the risk to public health. The blockchain's immutable ledger provides a transparent and secure record, offering a reliable means to track and verify the entire supply chain process. Consequently, this technological advancement positions Walmart at the forefront of food safety and supply chain innovation, demonstrating the profound impact of blockchain in enhancing operational efficiency and consumer protection.

### 2. Maersk and IBM: Global Trade Digitization

Maersk, a leading shipping company, has collaborated with IBM to develop TradeLens, a pioneering blockchain-based platform aimed at transforming global trade.[23] The traditional international shipping landscape is riddled with inefficiencies and a lack of transparency due to the involvement of numerous stakeholders, including shippers, customs officials, ports, and carriers. This complexity often results in delays and redundant paperwork, hampering the overall efficiency of the trade process.

TradeLens addresses these challenges by recording all shipping events and documentation on a shared ledger, accessible to all parties involved.[24] Through the use of smart contracts, the platform automates the exchange of information and approvals, thus streamlining operations. This innovative approach has markedly reduced the reliance on paperwork, expedited customs procedures, and enhanced the transparency and efficiency of global trade operations. For example, the time required to send shipping documents has been reduced by up to 40%, illustrating the profound impact of TradeLens in optimizing the global trade ecosystem. By integrating blockchain technology, Maersk and IBM have set a new standard in the digitization of international shipping, fostering greater collaboration and efficiency across the supply chain.

## D. Advantages and Limitations of AI-Enabled Blockchain Technology in Supply Chains

The combination of AI and blockchain has great potential to improve the efficiency of various industries.[25] In finance, for example, AI can analyze data stored on blockchain to detect fraud, while in healthcare, AI and blockchain can create a secure

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[21] Bowen Tan, et al. *The impact of blockchain on food supply chain: The case of Walmart*. Smart Blockchain: First International Conference, SmartBlock 2018, Tokyo, Japan, December 10–12, 2018, Proceedings 1. Springer International Publishing, 2018.

[22] Reshma Kamath, *Food traceability on blockchain: Walmart's pork and mango pilots with IBM*. THE JOURNAL OF THE BRITISH BLOCKCHAIN ASSOCIATION 1.1 (2018).

[23] Thomas Jense, et al."Delivering business value with blockchain technology: The long journey of TradeLens. MIS QUARTERLY EXECUTIVE 18.4, 221-243 (2019).

[24] Wafaa A.H. Ahmed, and Alexa Rios. *Digitalization of the international shipping and maritime logistics industry: a case study of TradeLens*. THE DIGITAL SUPPLY CHAIN. Elsevier, 309-323 (2022).

[25] Satish Kumar, et al. *Artificial intelligence and blockchain integration in business: trends from a bibliometric-content* analysis. INFORMATION SYSTEMS FRONTIERS 25.2, 871-896 (2023).

system for patients to control their medical records.[26] Furthermore, this convergence can benefit areas like supply chain management, marketing, and social media by making processes more efficient and secure.[27] On one hand, it offers undeniable advantages, such as enhanced traceability and transparency, which foster greater trust and collaboration among stakeholders. By creating an immutable record of every step a product takes, from raw materials to finished goods, blockchain ensures that critical data points are accessible and verifiable by all participants.[28] This level of transparency allows consumers to see a product's journey and enables regulators to enforce quality standards more effectively. Moreover, blockchain empowers companies to differentiate themselves by providing consumers with verifiable information about product sourcing and sustainability practices.[29]

AI integration further unlocks the potential for intelligent automation within the supply chain.[30] AI algorithms can analyze vast datasets stored on the blockchain, identifying inefficiencies and optimizing processes. This can lead to significant cost reductions and overall improved supply chain efficiency. The use of AI can also streamline operations through automation and data-driven insights, resulting in faster product recalls, optimized inventory management, and better resource allocation.[31]

However, the limitations inherent to blockchain technology cannot be ignored. Scalability remains a significant challenge, as current blockchain implementations often struggle to handle the massive data volumes associated with complex global supply chains.[32] This can result in network congestion and transaction delays, potentially hindering real-time applications. Additionally, integrating blockchain technology with existing IT infrastructure is a major hurdle, as many companies rely on legacy systems that may not be readily compatible with the distributed nature of blockchains. This necessitates substantial investments in system upgrades and data migration strategies to achieve seamless integration.

To navigate these challenges, stakeholders must work together to address legal obstacles and ensure responsible innovation within a clear legal framework. Collaboration from policymakers, industry leaders, and legal scholars is essential to harness the potential of AI-enabled blockchain technology for a more efficient, transparent, and ethical global trade ecosystem. Overcoming resistance to change and incentivizing all supply chain participants, along with standardizing data formats and implementing robust cybersecurity measures, are crucial steps toward widespread adoption. Thus, while AI-enabled blockchain presents transformative opportunities for

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[26] *Id.*
[27] *Id.*
[28] Santhi Raja Abirami, and Padmakumar Muthuswamy. *Influence of blockchain technology in manufacturing supply chain and logistic*s. LOGISTICS 6.1, 15 (2022).
[29] Nir Kshetri, Blockchain and sustainable supply chain management in developing countries. INTERNATIONAL JOURNAL OF INFORMATION MANAGEMENT 60, 102376 (2021).
[30] Olubunmi Adeolu Adenekan, et al. *Enhancing manufacturing productivity: A review of AI-Driven supply chain management optimization and ERP systems integration*. INTERNATIONAL JOURNAL OF MANAGEMENT & ENTREPRENEURSHIP RESEARCH 6.5, 1607-1624 (2024).
[31] Rafsan Mahi, *Optimizing supply chain efficiency in the manufacturing sector through ai-powered analytics.* INTERNATIONAL JOURNAL OF MANAGEMENT INFORMATION SYSTEMS AND DATA SCIENCE 1.1, 41-50 (2024).
[32] Weichao Gao, et al. *A survey of blockchain: Techniques, applications, and challenges*. 2018 27th international conference on computer communication and networks (ICCCN). IEEE, 2018.

supply chains, careful consideration of both opportunities and challenges is required to realize its full potential.

## II. U.S. LAWS RELATED TO BLOCKCHAIN TECHNOLOGY IN SUPPLY CHAINS

The adoption of blockchain technology in global supply chains is regulated by a variety of U.S. laws and regulations that span across technology, data privacy, security, financial transactions, and international trade. In the realm of blockchain and distributed ledger technology (DLT), while there is no singular federal law specifically targeting blockchain, several federal agencies provide essential guidelines. These laws affect how blockchain is implemented, ensuring compliance with legal standards. Here are key relevant laws and their impact on blockchain in supply chain management, illustrated with real-life examples:

There is no single overarching federal law governing blockchain in supply chains. Cybersecurity laws, such as the Cybersecurity Information Sharing Act (CISA), promote the sharing of cyber threat information between the government and the private sector, addressing cybersecurity concerns in blockchain implementations.[33] Guidelines and standards provided by the National Institute of Standards and Technology (NIST) ensure data security and integrity in blockchain applications. Other federal and state agencies also provide crucial guidelines depending on how the technology is used. These agencies include the Securities and Exchange Commission (SEC) for financial transactions involving blockchain-based tokens, the Commodity Futures Trading Commission (CFTC) for tokens classified as commodities, and the Federal Trade Commission (FTC) for consumer protection concerns related to potential misuse of the technology.

### A. Cybersecurity Law

Cybersecurity is a critical area governed by laws such as the Cybersecurity Information Sharing Act (CISA), which promotes the sharing of cyber threat information between the government and the private sector. Blockchain implementations in supply chains must address cybersecurity concerns by adhering to guidelines and standards provided by the National Institute of Standards and Technology (NIST) to ensure data security and integrity.[34]

Navigating the legal landscape for adopting blockchain technology in global supply chains requires understanding and adhering to a complex array of laws and regulations across various domains. Companies must stay updated on legal developments and work closely with legal experts to ensure that their blockchain applications comply with all relevant regulatory requirements. This includes addressing data privacy laws such as the European Union's General Data Protection Regulation (GDPR), which requires companies to implement robust data security measures such

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[33] John Heidenreich. *The privacy issues presented by the Cybersecurity Information Sharing Act*. NDL REV. 91, 395. (2015).

[34] Craig Schlenoff, et al.. *Performance evaluation of intelligent systems at the national institute of standards and technology (NIST).* INTERNATIONAL TEST AND EVALUATION ASSOCIATION (ITEA) JOURNAL 32.1, 59-67 (2011).

as anonymization techniques, and procedures for handling data subject rights requests.[35]

## B. Securities and Exchange Commission (SEC) Regulations

The Securities and Exchange Commission (SEC) and the Commodity Futures Trading Commission (CFTC) are crucial in regulating blockchain applications within the U.S. financial system. The SEC oversees blockchain applications related to securities, guiding initial coin offerings (ICOs) and digital asset transactions,[36] while the CFTC regulates blockchain applications in commodities and derivatives markets. This regulatory oversight is particularly relevant for supply chain management systems that utilize tokenization, the process of creating digital tokens representing ownership or rights associated with an asset. In supply chains, these tokens can represent ownership of physical goods or commodities, and if classified as securities by the SEC, they are subject to stringent registration and disclosure requirements. These requirements ensure investor protection by providing accurate and comprehensive information about the tokenized asset and associated risks. Non-compliance with SEC regulations can lead to significant legal penalties for issuing companies. Thus, companies integrating blockchain technology and considering tokenization in their supply chains must carefully evaluate the classification of these tokens under SEC regulations. Additionally, data privacy regulations such as the Health Insurance Portability and Accountability Act (HIPAA) for medical data and the General Data Protection Regulation (GDPR) for European users must be considered depending on the information stored on the blockchain. Ensuring compliance with these regulatory frameworks can help mitigate legal risks and foster a secure, transparent environment within the tokenized supply chain ecosystem.

## C. General Data Protection Regulation (GDPR) of the European Union (EU)

The European Union's General Data Protection Regulation (GDPR) is a landmark piece of legislation in data privacy that extends beyond the EU, affecting any organization, including U.S. companies, that processes the personal data of EU citizens. This has significant implications for blockchain-enabled supply chains involving European suppliers, customers, or any data pertaining to EU individuals. Companies operating such blockchain-based supply chains must comply with GDPR's stringent data protection principles, which mandate robust safeguards for personal data, ensuring data security, accuracy, and minimization of data collection.[37] The GDPR also empowers individuals with various rights concerning their personal data, such as the "right to be forgotten," allowing EU citizens to request the erasure of their personal data under certain conditions.

Data privacy and security laws significantly impact blockchain technology, especially when storing and transmitting personal data. Despite being a European

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[35] Chris Jay Hoofnagle, et al. *The European Union general data protection regulation: what it is and what it means.* INFORMATION & COMMUNICATIONS TECHNOLOGY LAW 28.1, 65-98 (2019).

[36] Saman Adhami, and Giancarlo Giudici. *Initial coin offerings: Tokens as innovative financial assets*. Blockchain economics and financial market innovation: Financial innovations in the digital age 61-81, (2019).

[37] Abdulah M. Aseri, *The implication of the European union's general data protection regulation (GDPR) on the global data privacy*. JOURNAL OF THEORETICAL AND APPLIED INFORMATION TECHNOLOGY 98.04 (2020).

Union regulation, the GDPR affects U.S. companies that handle EU citizens' data, requiring blockchain implementations to adhere to its stringent data privacy requirements. Additionally, the California Consumer Privacy Act (CCPA) enhances privacy rights and consumer protections for Californians, impacting blockchain applications that process personal data from this state. Companies must ensure compliance with these regulatory frameworks to mitigate legal risks and foster a secure, transparent environment in blockchain-enabled supply chains.

## D. Federal Trade Commission (FTC) Regulations

The Federal Trade Commission (FTC) plays a critical role in ensuring consumer protection in the United States by enforcing fair business practices, including regulations on advertising and data privacy.[38] As blockchain technology is increasingly integrated into supply chain traceability systems, compliance with FTC regulations becomes essential.[39] The FTC focuses on deceptive marketing practices, particularly related to product provenance and authenticity. Companies leveraging blockchain to track the origin of consumer goods must ensure that their marketing claims about traceability and authenticity are accurate and verifiable. Misleading consumers with inflated claims about blockchain capabilities, such as asserting 100% traceability when the system falls short, could result in FTC penalties for false advertising.

Moreover, the FTC has authority over data privacy practices. Companies using blockchain within their supply chains must carefully manage how consumer data is collected, stored, and used. The FTC scrutinizes these practices to ensure they comply with data privacy regulations, especially when the blockchain system involves sensitive consumer information. Adhering to FTC regulations is crucial for fostering consumer trust and transparency within blockchain-enabled supply chains, thereby creating a secure and ethical environment for all participants.

Additionally, supply chain operations utilizing blockchain technology must comply with regulations enforced by the U.S. Customs and Border Protection (CBP), which includes documentation and traceability requirements for importing and exporting goods. Ensuring compliance with both FTC and CBP regulations allows companies to effectively integrate blockchain technology into their supply chains, promoting legal adherence and operational efficiency.

## E. Intellectual Property Laws

Intellectual property laws play a critical role in the implementation of blockchain technology, with the U.S. Patent and Trademark Office (USPTO) overseeing the patenting of blockchain innovations and the registration of trademarks.[40] Companies must ensure that their blockchain technology does not infringe on existing patents to avoid legal disputes and potential penalties. The USPTO's management of patenting processes involves a thorough examination to verify the originality and novelty of blockchain-related inventions, thereby safeguarding the intellectual property rights of innovators. Additionally, the registration of trademarks protects brands and

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[38] Richard A. Posner, *The Federal Trade Commission*. THE UNIVERSITY OF CHICAGO LAW REVIEW 37.1, 47-89 (1969).

[39] *Id.*

[40] Birgit Clark, and Ruth Burstall. *Crypto-pie in the sky? How blockchain technology is impacting intellectual property law*. STAN. J. BLOCKCHAIN L. & POL'Y 2, 252. (2019).

ensures that companies can maintain a unique identity in the marketplace.[41] Compliance with intellectual property laws is essential for fostering innovation and maintaining competitive advantage, as it prevents unauthorized use of patented technologies and protects the proprietary interests of companies developing blockchain solutions. By navigating the complexities of patent law and securing necessary protections through the USPTO, companies can advance their blockchain technologies with confidence, contributing to a robust and legally sound technological landscape.

## F. Uniform Commercial Code (UCC)

The Uniform Commercial Code (UCC) plays a crucial role in facilitating commercial transactions within the United States by establishing a standardized legal framework governing contracts and sales, which are fundamental to supply chains.[42] As blockchain technology introduces smart contracts that automate various supply chain processes, such as triggering payments upon delivery of goods, ensuring these contracts align with the UCC is essential. Smart contracts must adhere to the UCC's regulations on contract formation, enforceability, and performance, which include requirements for offer, acceptance, consideration, and legality of terms.[43] Compliance with these stipulations is critical to avoid legal challenges and disputes that could arise from deviations from established legal principles. The integration of smart contracts into blockchain-enabled supply chains necessitates a thorough understanding of the UCC to ensure legal certainty and streamline operations. By programming smart contracts to meet UCC standards, companies can promote trust and efficiency within their supply chain ecosystems, thereby fostering a more reliable and legally sound operational environment. Ensuring that blockchain-based smart contracts comply with the UCC is vital for their enforceability and the smooth functioning of modern supply chains.

## G. Electronic Signatures in Global and National Commerce Act (E-SIGN Act)

The Electronic Signatures in Global and National Commerce Act (E-SIGN Act) establishes the legal validity of electronic transactions within the United States, granting legal recognition to electronic signatures and records.[44] This promotes trust and facilitates the adoption of digital commerce practices. In blockchain-enabled supply chains, the E-SIGN Act is particularly relevant for the use of smart contracts in contract management. Smart contracts, which are self-executing agreements stored on a blockchain, often depend on electronic signatures to authenticate the involved parties. The E-SIGN Act ensures that these electronically signed smart contracts are legally binding and enforceable within the U.S. court system, providing legal certainty that

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[41] Beth Simone Noveck, *Trademark law and the social construction of trust: Creating the legal framework for online identity*. WASH. ULQ 83, 1733 (2005).
[42] Robert A Hillman,. *Construction of the Uniform Commercial Code: UCC Section 1-103 and Code Methodology.* BC INDUS. & COM. L. REV. 18, 655 (1976).
[43] G. Marcus Cole, *The long convergence: Smart contracts and the customization of commercial law*. S. CAL. L. REV. 92, 851 (2018).
[44] Jonathan E. Stern, *The electronic signatures in global and national commerce act.* BERK. TECH. LJ 16, 391 (2001).

fosters trust and streamlines digital transactions within the supply chain ecosystem.[45] By adhering to the E-SIGN Act's provisions on electronic signatures, companies can effectively utilize the efficiency and security advantages of smart contracts in their blockchain-based supply chains. Additionally, compliance with the Uniform Commercial Code (UCC) is necessary to ensure the enforceability of these smart contracts, as the UCC outlines the essential elements for contract formation, enforceability, and performance. By ensuring adherence to both the E-SIGN Act and the UCC, companies can promote a legally sound, efficient, and trustworthy operational environment for their blockchain-enabled supply chains.

## H. Drug Supply Chain Security Act (DSCSA)

The Drug Supply Chain Security Act (DSCSA) mandates the creation of an electronic, interoperable system to trace prescription drugs throughout the U.S. supply chain, aiming to enhance security and integrity by preventing counterfeit drugs from infiltrating the market.[46] Pharmaceutical companies are leveraging blockchain technology to meet DSCSA requirements, ensuring comprehensive data interoperability and adherence to traceability standards. Blockchain provides an immutable and transparent ledger that can effectively track the movement of drugs from manufacturers to consumers. This technology facilitates compliance with the stringent standards set forth by the DSCSA, thereby safeguarding public health.[47] An illustrative parallel can be seen in the collaboration between IBM and Walmart on the IBM Food Trust blockchain, which significantly enhanced traceability in the food supply chain. Similarly, the application of blockchain in the pharmaceutical supply chain ensures that all stakeholders, from manufacturers to end consumers, have access to a secure and transparent record of drug movements. By adopting blockchain, pharmaceutical companies not only comply with DSCSA regulations but also enhance the overall integrity and safety of the drug supply chain, protecting consumers from counterfeit and substandard medications.

## I. Food Safety and International Trade

In specific industries, regulatory bodies such as the Food and Drug Administration (FDA) and the Federal Motor Carrier Safety Administration (FMCSA) impose additional requirements on blockchain implementations.[48] The FDA mandates that blockchain systems in pharmaceuticals and food products adhere to stringent regulations, ensuring safety, traceability, and transparency. This ensures that products are safe for consumption and that their origins and journey through the supply chain are meticulously documented.[49] Similarly, the FMCSA sets standards for tracking and safety in logistics and transportation, which blockchain technology must meet to ensure

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[45] Jennifer L. Koger, *You Sign, E-SIGN, We All Fall Down: Why the United States Should Not Crown the Marketplace as Primary Legislator of Electronic Signatures*. TRANSNAT'L L. & CONTEMP. PROBS. 11, 491 (2001).

[46] Shambhu Sarkar, *Why Pharmaceutical Drug Traceability in the US Needs a Centralized Cloud-Based Platform.* CURRENT JOURNAL OF APPLIED SCIENCE AND TECHNOLOGY 42.21, 1-11 (2023).

[47] Girish Babu Botta, *Pharmaceutical medicine traceability: An overview of global compliance*. WORLD JOURNAL OF BIOLOGY PHARMACY AND HEALTH SCIENCES 15.2 245-252. (2023)

[48] Mark J. Andrews, and Henry E. Seaton. *Safety fitness determinations: what is FMCSA measuring?*. JOURNAL OF TRANSPORTATION MANAGEMENT 29.1, 8 (2018).

[49] John Mangan, and Chandra Lalwani. *Global logistics and supply chain management*. John Wiley & Sons, 2016.

compliance. These industry-specific regulations are crucial for maintaining the integrity and safety of supply chains.

Moreover, existing laws and international trade regulations are essential when implementing blockchain technology. The FDA's involvement is significant when blockchain is used to track food products, ensuring adherence to established safety standards. Blockchain can also facilitate smoother customs clearances and document verification in international trade, streamlining processes and reducing delays. By meeting these regulatory requirements, blockchain technology enhances the reliability and efficiency of supply chains across various industries, ensuring that safety, traceability, and compliance are upheld from production to final delivery.

In conclusion, by proactively addressing these legal considerations, companies can avoid hefty fines and penalties while fostering trust with trading partners within the globalized supply chain ecosystem. Compliance with cybersecurity standards and data privacy regulations ensures that blockchain applications are not only legally sound but also secure and trustworthy, enhancing their reliability and efficiency in the supply chain. In the process of adopting blockchain technology in global supply chains, companies must remain updated on legal developments and work closely with legal experts to ensure their blockchain applications comply with all relevant regulatory requirements. This comprehensive regulatory framework ensures that blockchain technology is implemented in a legally compliant and secure manner, harnessing its transformative potential in supply chain management.

## III. U.S. SANCTIONS AND INTERNATIONAL REGULATORY HARMONIZATION

As the international community grapples with the complexities of economic sanctions and the imperative for regulatory harmonization, the integration of artificial intelligence and blockchain emerges as a pivotal strategy. This confluence of technologies offers a sophisticated means to enhance transparency, efficiency, and compliance in a globally interconnected financial system. Through the deployment of AI's analytical prowess and blockchain's immutable ledger capabilities, regulatory bodies can achieve a cohesive and robust mechanism for sanctions enforcement. This section explores how these advanced technological tools facilitate international regulatory harmonization, ensuring that sanctions are applied consistently and effectively across diverse jurisdictions. The discussion delves into the operational synergies between AI and blockchain, examining their potential to transform the landscape of international regulatory compliance and fortify the enforcement of economic sanctions against non-compliant entities.

### A. Cross-Border Trade and Jurisdiction

The existence of trade agreements and tariffs can significantly impact the feasibility and cost-effectiveness of utilizing AI-enabled blockchain across borders.[50] For example, trade agreements that streamline customs procedures and reduce tariffs on technology imports can incentivize the adoption of blockchain solutions within

[50] Dhruv Patel, et al;. *Security in modern manufacturing systems: integrating blockchain in artificial intelligence-assisted manufacturing*. INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH 62.3, 1041-1071 (2024).

global supply chains. Conversely, protectionist trade policies that impose high tariffs on technology components can hinder the widespread adoption of this technology. Understanding the specific provisions of relevant trade agreements is crucial for businesses contemplating the implementation of AI-enabled blockchain across international borders.

The distributed nature of blockchain networks, where data can be stored across multiple jurisdictions, raises complex questions regarding the applicable laws governing these systems.[51] Determining which country's laws govern a particular smart contract or data point within the blockchain can be challenging. This ambiguity creates uncertainty for businesses operating within these ecosystems, potentially hindering innovation and investment.

Blockchain transactions frequently span multiple jurisdictions, creating significant complexities in determining the applicable legal framework in the event of disputes. In cross-border trade, the challenge is exacerbated by the varying laws across different countries regarding contract enforcement, data privacy, and financial transactions. This legal fragmentation presents a substantial hurdle for international business operations.

For instance, consider a U.S. exporter utilizing blockchain technology for supply chain management with partners in Asia and Europe. This scenario necessitates navigating a labyrinthine web of international laws. The differing regulations on contract enforcement mean that a dispute over a transaction could require resolution in multiple jurisdictions. This not only complicates the legal process but also increases costs and uncertainty for the involved parties. The exporter must contend with diverse legal standards, procedural rules, and enforcement mechanisms, which can significantly delay dispute resolution and inflate associated legal expenses.

The global nature of blockchain transactions calls for a harmonized legal approach to ensure clarity and consistency in the application of law. Without international consensus and standardized regulations, companies operating across borders face ongoing challenges in legal compliance and contract enforcement. Addressing these issues requires a coordinated effort to develop unified legal frameworks that can accommodate the decentralized and borderless nature of blockchain technology. This would facilitate smoother international transactions and provide greater legal certainty for businesses engaged in global trade, ultimately enhancing the efficiency and reliability of blockchain-enabled supply chain management.

## B. The Need for International Regulatory Harmonization

It is noted that there are ongoing efforts to establish unified international standards for cross-border trade and their corresponding rules and regulations. Organizations such as the International Organization for Standardization (ISO) are actively developing standards for blockchain technology, addressing issues like terminology, security, and interoperability. Additionally, industry consortiums and

[51] Yang Xiao, et al. *A survey of distributed consensus protocols for blockchain networks*. IEEE COMMUNICATIONS SURVEYS & TUTORIALS 22.2, 1432-1465 (2020).

international trade organizations are playing a crucial role in fostering collaboration and harmonization efforts.

Existing international frameworks and agreements, while not specifically designed for AI-enabled blockchain, can offer a foundation for future regulatory harmonization. For instance, the United Nations Commission on International Trade Law (UNCITRAL) Model Law on Electronic Commerce provides a framework for legal recognition of electronic transactions, which can be extrapolated to smart contracts within blockchain ecosystems.[52] Similarly, the Hague Convention on Contracts for the International Sale of Goods (CISG) offers a framework for resolving cross-border sales disputes, which can be adapted to the context of AI-enabled blockchain supply chains.

Regulatory harmonization represents a process where regulatory authorities align technical requirements for the development and marketing of pharmaceutical products.53 Harmonization of regulatory requirements has many benefits, such as ensuring favorable marketing conditions to support early access to medicinal products, promoting competition and efficiency, and reducing unnecessary duplication of clinical testing. For example, the FDA engages with stakeholders globally through international venues to respond to the increasingly complex and global nature of pharmaceutical industry operations and related regulatory oversight. This work progresses the FDA's mission of ensuring pharmaceutical safety and effectiveness. It is accomplished through the FDA's involvement in several international organizations, including the International Council for Harmonisation (ICH), the International Pharmaceutical Regulators Programme (IPRP), the Pharmaceutical Inspection Cooperation Scheme (PIC/S), Asia-Pacific Economic Cooperation (APEC), and International Coalition of Medicines Regulatory Authorities (ICMRA).

However, the limitations of these existing frameworks become apparent when considering the unique characteristics of AI-enabled blockchain technology. The distributed nature of blockchain networks and the potential for autonomous decision-making by AI algorithms necessitate a reevaluation of traditional legal concepts like jurisdiction and liability.

Achieving international regulatory harmonization for AI-enabled blockchain technology requires a multi-pronged approach. Collaboration between governments, industry leaders, and legal scholars remains paramount. International organizations like ISO and UNCITRAL can play a vital role in facilitating dialogues and fostering the development of comprehensive regulatory frameworks. Furthermore, learning from existing regional initiatives can offer valuable insights. The European Union's efforts to regulate crypto assets through frameworks like MiCA (Markets in Crypto Assets) can serve as a case study for broader international harmonization efforts.[54]

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[52] Vesna Zivkovic, *Work of the United Nations Commission on International Trade Law (UNICTRAL) on the Regulation of Electronic Commerce*. STRANI PRAVNI ZIVOT 281, (2004).

[53] See *International Regulatory Harmonization,* US Food and Drug Administration, 03/26/2020. Available at: https://www.fda.gov/drugs/cder-international-program/international-regulatory-harmonization.

[54] Oliver Read, and Carolin Diefenbach. *The Path to the EU Regulation Markets in Crypto-assets (MiCA)*. No. 13/2022. WIFIN Working Paper, 2022.

By acknowledging the challenges and opportunities presented by the current regulatory landscape, stakeholders can work towards a future where a harmonized international approach fosters innovation and facilitates the responsible and secure integration of AI-enabled blockchain technology within global supply chains.

## C. U.S. Sanctions on Foreign Businesses

The U.S. enforces sanctions on foreign businesses for a myriad of reasons, predominantly anchored in national security interests or broader foreign policy objectives. Among the various types of sanctions imposed are those related to terrorism financing and proliferation, targeting businesses that support terrorist organizations or countries engaged in the development of weapons of mass destruction. For example, Iranian entities associated with their nuclear program or businesses funneling resources to designated terrorist groups frequently face such sanctions. Additionally, human rights sanctions are directed at businesses implicated in egregious human rights violations, including forced labor and other severe abuses. Cybersecurity sanctions, on the other hand, focus on entities involved in malicious cyber activities such as cyberattacks or intellectual property theft. Furthermore, regional sanctions encompass entire nations or regions, as seen in the comprehensive sanctions imposed on countries like Cuba, Myanmar, and North Korea, aimed at pressuring these regimes to alter their behaviors.[55]

The specific restrictions within U.S. sanctions programs can vary widely, tailored to the targeted entity and the nature of the violation. These restrictions may include the freezing of financial assets within U.S. jurisdiction, thereby blocking the sanctioned businesses from accessing their resources. Trade restrictions often accompany these measures, prohibiting or severely limiting commercial exchanges with the sanctioned entities, including import and export bans. Investment restrictions may be imposed, preventing or limiting investments in these businesses, thereby cutting off potential financial support. Visa restrictions are also a common tool, denying entry to individuals associated with the sanctioned entities.

A salient illustration of these measures can be seen in the sanctions imposed on various foreign businesses. For instance, Huawei Technologies Co., Ltd., a major Chinese telecommunications company, was added to the U.S. Department of Commerce's Entity List in 2019,[56] significantly restricting its access to American technology and software due to national security concerns regarding espionage and surveillance.[57] Similarly, Rosneft Trading S.A., a subsidiary of the Russian state-controlled oil company Rosneft, was sanctioned in 2020 for its involvement in the Venezuelan oil sector, specifically aiding the Maduro regime by facilitating the sale and transport of Venezuelan crude oil.[58] The China National Petroleum Corporation (CNPC) and its subsidiaries have been sanctioned multiple times, particularly for their involvement in Iran's energy sector amidst concerns over Iran's nuclear program and

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[55] Yesun Yoon. *Assessment of the effectiveness of economic sanctions: The cases of Iran, North Korea, Myanmar, and Cuba*. Diss. Monterey, California: Naval Postgraduate School, 2017.

[56] Halil Deligöz, *US Technological Sanctions: The Huawei Case*. GLOBAL TRADE AND CUSTOMS JOURNAL 19.5 (2024).

[57] E. K. Jaisal, The US, China and Huawei debate on 5G telecom technology: Global apprehensions and the Indian scenario. OPEN POLITICAL SCIENCE 3.1, 66-72. (2020).

[58] Meiramkul Saiymova, et al. *Russia's petroleum industry in the period of sanctions and COVID-19 Pandemic: a review and analysis.* INTERNATIONAL JOURNAL OF ENERGY ECONOMICS AND POLICY 11.5, 483-489 (2021).

other destabilizing activities.[59] In 2019, the U.S. sanctioned subsidiaries of Dalian Ocean Shipping Company (COSCO), a major Chinese shipping company, for transporting Iranian oil in violation of U.S. sanctions aimed at curbing Iran's nuclear ambitions.[60] Another notable case is ZTE Corporation, which faced severe sanctions in 2018 for violating U.S. export controls related to Iran and North Korea, resulting in a prohibition on receiving U.S.-made components and causing significant operational disruptions.[61] Lastly, Nord Stream 2 A.G., the Swiss-based entity responsible for constructing the Nord Stream 2 gas pipeline from Russia to Germany, faced U.S. sanctions due to concerns that the pipeline would increase European dependence on Russian energy while reducing Ukraine's transit revenue.[62]

These examples underscore the U.S. government's strategic deployment of economic sanctions to address a diverse array of international challenges, leveraging its substantial influence over global financial and trade systems to enforce compliance and achieve its foreign policy objectives.

## D. U.S. Sanctions and International Regulatory Harmonization

Imposing sanctions on foreign businesses, such as those in China, through the process of international regulatory harmonization in the American global supply chains presents several significant challenges. These challenges can be broadly categorized into issues of compliance verification, geopolitical complexities, economic interdependencies, legal and regulatory discrepancies, technological limitations, and enforcement mechanisms.

One of the primary challenges is the verification of compliance with sanctions.[63] Ensuring that foreign businesses adhere to the imposed restrictions requires robust mechanisms for monitoring and verification. This is particularly difficult given the complexity and opacity of global supply chains, where products and materials often pass through multiple intermediaries and jurisdictions. The lack of transparency in certain regions, coupled with the potential for deliberate concealment or falsification of information, complicates the task of verifying whether businesses comply with the sanctions.

Geopolitical complexities further exacerbate the challenge of imposing sanctions. The relationship between the sanctioning country and the targeted foreign business's home country can influence the effectiveness of the sanctions. For instance, if China perceives the sanctions as politically motivated or economically damaging, it may take countermeasures that undermine the sanctions' impact. Diplomatic tensions

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[59] Erica Downs, *High anxiety: The trade war and China'S oil and gas supply security*. COLUMBIA| SIPA CENTER ON GLOBAL ENERGY POLICY (2019).
[60] Liying Zhang, and Sizhuo Chen. *Amendments to the Ocean Shipping Reform Act of 2022 and Its Impact and Enlightenment*. MARINE L. & POL'Y 36 (2023).
[61] Xin Wang. *The Impact and Response of Trade Sanctions*. ASIA PACIFIC JOURNAL OF SOCIETY AND LAW· 1.1 (2024).
[62] Moniek de Jong, *Too little, too late? US sanctions against Nord Stream 2 and the transatlantic relationship*. JOURNAL OF TRANSATLANTIC STUDIES 20.2, 213-229 (2022).
[63] Richard Nephew, *Implementation of Sanctions: United* States. ECONOMIC SANCTIONS IN INTERNATIONAL LAW AND PRACTICE. Routledge, 93-115 (2019).

can lead to a lack of cooperation or even active resistance from the foreign government, making it difficult to enforce the sanctions effectively.

Economic interdependencies between countries also pose a significant challenge. The global nature of supply chains means that businesses in the United States are often reliant on foreign suppliers for critical components and materials. Imposing sanctions can disrupt these supply chains, leading to economic consequences for American businesses and consumers. The interlinked nature of the global economy means that sanctions can have unintended ripple effects, potentially harming the sanctioning country's economic interests.

Legal and regulatory discrepancies across jurisdictions present another layer of complexity. Different countries have varying legal frameworks and regulatory standards, which can hinder the harmonization of sanctions enforcement. For example, what constitutes a violation in one country may not be recognized as such in another, leading to inconsistent application and enforcement of sanctions. This inconsistency can be exploited by foreign businesses to circumvent restrictions, further complicating the regulatory landscape.

Technological limitations also pose a challenge in the implementation of sanctions.[64] While technologies like blockchain can enhance transparency and traceability, their adoption is not yet universal. The integration of such technologies into existing supply chains and regulatory frameworks requires significant investment and coordination. Additionally, technological disparities between countries and regions can lead to uneven implementation and effectiveness of sanctions.

Enforcement mechanisms are crucial to the success of sanctions, yet they are often difficult to implement and maintain.[65] Effective enforcement requires a combination of regulatory oversight, international cooperation, and punitive measures. However, coordinating these efforts on a global scale is inherently challenging. Enforcement agencies must have the capacity to monitor compliance, investigate violations, and impose penalties, all of which require substantial resources and international collaboration. The lack of a unified global regulatory body to oversee and enforce sanctions further complicates these efforts.

In summary, imposing sanctions on foreign businesses through international regulatory harmonization in American global supply chains involves a multifaceted set of challenges. These include ensuring compliance verification, navigating geopolitical complexities, managing economic interdependencies, reconciling legal and regulatory discrepancies, overcoming technological limitations, and establishing effective enforcement mechanisms. Each of these challenges requires careful consideration and coordinated efforts to achieve the desired outcomes of the sanctions while minimizing unintended consequences.

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[64] Tim Beal, *Sanctions as instrument of coercion: Characteristics, limitations, and consequences*. Sanctions as War. Brill, 27-50 (2021).

[65] Bryan R. Early and Timothy M. Peterson. *Does punishing sanctions busters work? Sanctions enforcement and US trade with sanctioned state*s. POLITICAL RESEARCH QUARTERLY 75.3, 782-796. (2022).

## E. How AI-enabled Blockchain Technology Can Help the Imposition of U.S. Sanctions

AI-enabled blockchain technology can significantly enhance the enforcement of U.S. sanctions on foreign businesses through a multifaceted approach to international regulatory harmonization. This synthesis of advanced technologies enables a more seamless, efficient, and transparent global regulatory framework, thereby reinforcing the efficacy of sanctions.

At the core of this synergy, AI's capability to analyze vast amounts of data and identify patterns plays a crucial role. Through machine learning algorithms, AI can scrutinize complex financial transactions, trade flows, and corporate networks to detect evasive maneuvers employed by sanctioned entities.[66] By integrating AI with blockchain's decentralized ledger technology, these analyses gain a layer of verifiability and immutability, ensuring that detected anomalies are recorded in an incorruptible manner. This convergence allows regulatory bodies worldwide to access and trust the data, thereby facilitating a unified response to sanctions enforcement.

Moreover, blockchain's intrinsic characteristics of transparency and traceability are instrumental in achieving regulatory harmonization. Every transaction recorded on a blockchain is time-stamped and immutable, creating an auditable trail that authorized stakeholders can access. This transparency ensures that any attempts by foreign businesses to circumvent sanctions through complex and opaque financial structures can be promptly identified and addressed. AI can enhance this process by providing real-time monitoring and analysis, flagging suspicious activities for further investigation.

The decentralized nature of blockchain also supports international cooperation by eliminating the need for a centralized authority to manage compliance data. This decentralization is pivotal in fostering trust among different jurisdictions with varying degrees of regulatory rigor. By ensuring that all participants in the global financial system operate from a common, tamper-proof ledger, blockchain reduces the potential for discrepancies and inconsistencies that can arise from disparate regulatory practices. AI can further streamline this process by automating the verification of compliance with sanctions, reducing the administrative burden on regulatory bodies, and enhancing the speed and accuracy of enforcement actions.

In addition, AI-enabled blockchain technology can facilitate the standardization of regulatory frameworks.[67] AI can analyze the regulatory requirements of various countries, identify commonalities and discrepancies, and propose standardized protocols that harmonize these regulations. Blockchain can then implement these protocols across the international financial system, ensuring consistent application and compliance. This standardization is crucial for mitigating the risks associated with regulatory arbitrage, where businesses exploit differences between national regulations to circumvent sanctions.

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[66] Iris H-Y., Chiu, and Ernest WK Lim. *Technology vs ideology: how far will artificial intelligence and distributed ledger technology transform corporate governance and business?*." BERKELEY BUS. LJ 18 1 (2021).

[67] Ritik Kumar, et al. *AI-powered blockchain technology for public health: A contemporary review, open challenges, and future research directions*. HEALTHCARE. 11. 1. MDPI, (2022).

Furthermore, AI-driven predictive analytics can forecast potential compliance risks and suggest preemptive measures to mitigate them.[68] By leveraging historical data and machine learning models, AI can predict which entities are likely to engage in sanctionable activities, allowing regulators to take proactive steps. Blockchain can then be used to share these insights securely and transparently with relevant stakeholders, ensuring a coordinated and timely response.

In conclusion, the AI-enabled blockchain technology offers a robust framework for enhancing the enforcement of U.S. sanctions on foreign businesses. By providing real-time, transparent, and immutable data, these technologies facilitate international regulatory harmonization, ensuring a cohesive and effective global response. This innovative approach not only enhances the detection and prevention of sanctions evasion but also streamlines regulatory processes, fostering a more resilient and cooperative international financial system.

## IV. FUTURE TRENDS AND RECOMMENDATIONS

By examining the technological horizon and outlining recommendations, this section aims to equip companies and policymakers with the knowledge necessary to thrive in the years to come. This proactive approach will ensure that American global supply chains can harness the full potential of AI-enabled blockchain technology for a secure, efficient, and sustainable future.

### A. Emerging Legal Trends in Blockchain Technology

AI-enabled blockchain technology presents a transformative force for global supply chains. This innovation necessitates navigating a rapidly evolving legal landscape. This section explores some key emerging legal trends shaping the adoption of AI-enabled blockchain within American global supply chains.

#### 1. Regulatory Uncertainty

A primary challenge lies in the nascent nature of AI-enabled blockchain technology. Existing legal frameworks often struggle to keep pace with technological advancements, leading to a period of regulatory uncertainty.[69] This ambiguity can hinder investment and innovation as businesses grapple with unclear legal parameters. However, this also presents an opportunity for stakeholders to proactively engage with policymakers in shaping a future-proof regulatory environment.

#### 2. Focus on Data Privacy and Security

The integration of AI algorithms within blockchain networks raises significant data privacy concerns.[70] The increased potential for data collection and the inherent transparency of blockchain necessitate robust data governance frameworks. Emerging

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[68] Sakthiswaran Rangaraju, *Secure by intelligence: enhancing products with AI-driven security measures*. EPH-INTERNATIONAL JOURNAL OF SCIENCE AND ENGINEERING 9.3, 36-41 (2023).

[69] Arjan J. Frederiks, et al. *The early bird catches the worm: The role of regulatory uncertainty in early adoption of blockchain's cryptocurrency by fintech ventures*. JOURNAL OF SMALL BUSINESS MANAGEMENT 62.2, 790-823 (2024).

[70] Oumaima Fadi, et al. *A survey on blockchain and artificial intelligence technologies for enhancing security and privacy in smart environments*. IEEE ACCESS 10, 93168-93186, (2022).

legal trends highlight a growing emphasis on user consent mechanisms, data anonymization techniques, and adherence to data privacy regulations like GDPR and CCPA. Furthermore, ensuring the security of sensitive data through encryption and vulnerability assessments is paramount.

### 3. Rethinking Product Liability

Traditional product liability models may struggle to adapt to the complex, interconnected nature of AI-enabled blockchain supply chains. Assigning liability for product defects becomes particularly challenging when multiple actors, including manufacturers, distributors, retailers, and even the AI platform itself, are involved. New legal doctrines tailored to this ecosystem may be required to establish clear lines of responsibility while fostering innovation and consumer safety.

### 4. Evolving Dispute Resolution Mechanisms

Cross-border trade disputes within AI-enabled blockchain supply chains necessitate a reevaluation of traditional dispute resolution methods.[71] While litigation remains an option, its time-consuming and expensive nature underscores the potential of blockchain-based solutions. Smart contracts offer the possibility of automated dispute resolution mechanisms encoded within the contract itself. However, the enforceability of such clauses and the need for human intervention in complex cases necessitate a hybrid approach that leverages both blockchain efficiencies and established arbitration frameworks.

### 5. New Trends of International Regulatory Harmonization

International regulatory harmonization for adopting AI-enabled blockchain technology in global supply chains is an evolving field marked by several key trends.[72] One significant trend is the standardization of data formats and communication protocols, which ensures interoperability among different blockchain systems and AI algorithms. [73] Organizations like ISO and IEEE are actively working on setting these standards. Cross-border regulatory collaboration is also increasing, with governments and regulatory bodies forming bilateral and multilateral agreements to reduce regulatory fragmentation and streamline international trade.

Emphasis on data privacy and security is heightened, with international regulations like GDPR setting stringent data handling requirements that are being adopted globally to foster trust among international partners.[74] Additionally, global certification programs are being developed to validate compliance with international

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[71] Anthony Amunátegui Abad, *Artificial Intelligence and the Future of International Trade Law and Dispute Settlement.* CONTEMPORARY ASIA ARBITRATION JOURNAL 17.1, 35-68 (2024).
[72] Louise Manning, et al. *Artificial intelligence and ethics within the food sector: Developing a common language for technology adoption across the supply chain*. TRENDS IN FOOD SCIENCE & TECHNOLOGY 125, 33-42 (2022).
[73] Michal S. Gal, and Daniel L. Rubinfeld. *Data standardization*. NYU L REV. 94 737. (2019).
[74] Michael L. Rustad, and Thomas H. Koenig. *Towards a global data privacy standard*. FLA. L. REV. 71, 365. (2019).

standards for AI and blockchain technologies, facilitating smoother cross-border transactions by providing benchmarks for regulatory compliance.[75]

There is also a growing trend to incorporate ethical AI principles, including guidelines for transparency, accountability, and fairness in AI algorithms used in supply chains.[76] This ensures that AI systems operate fairly and without bias across different jurisdictions. Regulatory bodies are promoting the use of blockchain to enhance traceability and transparency in supply chains, particularly in industries where provenance and authenticity are critical.

Public-private partnerships are encouraged to drive innovation and compliance in AI-enabled blockchain adoption. These partnerships foster a collaborative approach to regulatory harmonization by sharing knowledge, resources, and infrastructure. Sustainability is becoming a key focus, with harmonized regulations promoting the use of AI and blockchain technologies to enhance environmental sustainability in supply chains. Lastly, there is an increasing emphasis on developing robust monitoring and enforcement mechanisms, including real-time data analytics and automated compliance checks, to ensure adherence to agreed-upon standards and practices.

These trends reflect a concerted effort to create a cohesive, secure, and efficient global trading environment, addressing the need for standardization, collaboration, ethical considerations, and sustainability, thereby paving the way for the seamless integration of advanced technologies in international commerce.

## B. Regulatory Outlook and Anticipated Changes

The adoption of AI-enabled blockchain technology within American global supply chains necessitates a proactive approach to legal and regulatory frameworks. As this technology becomes more integrated, the legal landscape surrounding it is fluid and constantly evolving. Several key areas are expected to see significant transformations.

One area of focus will be data governance. Regulations are likely to establish clear guidelines for data ownership within AI-enabled blockchain ecosystems. This may involve user consent mechanisms for data collection and utilization alongside robust data anonymization techniques to protect privacy. Additionally, we can expect the development of stringent cybersecurity standards and data breach notification requirements to ensure the security and integrity of data throughout the supply chain.

Product liability doctrines will also need to adapt to this new landscape.[77] New legal doctrines may emerge to delineate liability within the complex networks of AI-enabled blockchain supply chains. These doctrines will need to strike a balance between fostering innovation and ensuring consumer safety. When assigning responsibility for product defects, legal frameworks may consider factors like the role of algorithmic decision-making processes within the AI components of the blockchain system.

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[75] Nusi Drljevic, et al., *Perspectives on risks and standards that affect the requirements engineering of blockchain technology*. COMPUTER STANDARDS & INTERFACES 69, 103409 (2020).

[76] Louise Manning, et al. *Artificial intelligence and ethics within the food sector: Developing a common language for technology adoption across the supply chain*. TRENDS IN FOOD SCIENCE & TECHNOLOGY 125, 33-42 (2022).

[77] Richard W. Wright, *The principles of product liability*. REV. LITIG. 26, 1067 (2007).

Finally, legal frameworks will likely evolve to address the enforceability of dispute resolution clauses embedded within smart contracts across jurisdictions.[78] This may involve establishing standardized legal frameworks for smart contracts, potentially leveraging international cooperation to foster recognition of their legal validity across borders. Such efforts will promote stability and predictability within the global supply chain ecosystem.

## C. Ethical and Social Implications

While the potential of AI-enabled blockchain technology for global supply chains is undeniable, its integration necessitates a nuanced approach that prioritizes not just efficiency but also fairness, transparency, and societal well-being. This section explores these crucial ethical and social considerations.

The very nature of blockchain technology, with its emphasis on immutability and distributed ledgers, can create challenges in ensuring complete transparency throughout the supply chain.[79] Opaque AI algorithms embedded within the system raise concerns about potential bias in decision-making processes, particularly regarding sourcing practices or labor conditions. To mitigate these concerns, fostering explainable AI is crucial. This means developing algorithms that can be audited and understanding their decision-making processes. Additionally, prioritizing human oversight and intervention alongside AI algorithms can help ensure ethical sourcing and responsible labor practices.

The automation potential of AI-enabled blockchain technology presents a double-edged sword. While repetitive and potentially hazardous tasks can be streamlined, concerns regarding job displacement within the supply chain sector require careful consideration. Reskilling and upskilling initiatives can help prepare workers for new roles within the evolving supply chain landscape. Even with increased automation, ensuring fair labor practices and upholding worker rights throughout the global supply chain remains paramount.

The energy consumption associated with some blockchain technologies has raised environmental concerns. Transitioning to energy-efficient blockchain protocols and fostering the use of renewable energy sources can help mitigate this impact. Furthermore, by optimizing logistics and reducing waste within AI-enabled blockchain supply chains, the technology can potentially contribute to a more sustainable global trade ecosystem.

The social responsibility for navigating the ethical and social implications of AI-enabled blockchain technology is shared among stakeholders. Companies utilizing this technology must prioritize ethical sourcing practices, fair labor conditions, and environmental sustainability throughout their supply chains. Policymakers have a role to play in establishing regulations that promote responsible innovation and mitigate potential negative social impacts. Finally, consumers can leverage their purchasing

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[78] Riikka Koulu, *Blockchains and online dispute resolution: smart contracts as an alternative to enforcement*. SCRIPTED 13, 40 (2016).

[79] Marc Pilkington. *Blockchain technology: principles and applications*. Research handbook on digital transformations. Edward Elgar Publishing, 225-253. 2016.

power to support companies that prioritize ethical and sustainable practices within AI-enabled blockchain supply chains.

In conclusion, the ethical and social implications of AI-enabled blockchain technology demand careful consideration alongside its potential benefits. By prioritizing transparency, responsible automation, environmental sustainability, and shared social responsibility, stakeholders can harness this technology to create a more just, equitable, and sustainable global supply chain ecosystem.

## D. Legal Strategies for Blockchain Adoption

As blockchain technology continues to integrate into various industries, navigating the complex legal landscape is crucial for successful adoption. Several key legal strategies can help companies harness the potential of blockchain while mitigating associated risks.

Conducting regular legal audits is a critical first step. These audits assess whether a company's blockchain solutions comply with current laws and regulations.[80] By proactively identifying potential legal issues, companies can take corrective measures to ensure their blockchain initiatives operate within a compliant framework.[81]

Regulatory sandboxes offer a valuable platform for companies to test and refine their blockchain innovations in a controlled environment.[82] These sandboxes, often established by regulatory bodies, provide a safe space for experimentation while ensuring minimal disruption to existing markets. By participating in regulatory sandboxes, companies can gain valuable insights into potential regulatory hurdles and collaborate with regulators to develop compliant solutions.[83]

The global nature of supply chains necessitates international cooperation on blockchain regulations.[84] Companies can collaborate with international regulatory bodies to advocate for harmonized standards. This collaborative approach can help streamline cross-border transactions and reduce regulatory uncertainty for companies operating in a globalized marketplace.

Smart contracts, self-executing agreements stored on a blockchain, offer significant advantages but may not address all aspects of complex business relationships.[85] Drafting traditional legal agreements alongside smart contracts can provide an additional layer of security and address unforeseen contingencies. These

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[80] Daniel Drummer, and Dirk Neumann. *Is code law? Current legal and technical adoption issues and remedies for blockchain-enabled smart contracts*. JOURNAL OF INFORMATION TECHNOLOGY 35.4, 337-360 (2020).

[81] *See* Francis K.T. Wat, et al. *Potential risks to e-commerce development using exploratory factor analysis*. INTERNATIONAL JOURNAL OF SERVICES TECHNOLOGY AND MANAGEMENT 6.1, 55-71. (2005).

[82] Hilary J. Allen, *Regulatory sandboxes*. GEO. WASH. L. REV. 87, 579 (2019).

[83] Walter G. Johnson, Caught in quicksand? Compliance and legitimacy challenges in using regulatory sandboxes to manage emerging technologies. REGULATION & GOVERNANCE 17.3, 709-725 (2023).

[84] Yanling Chang, et al.. *Blockchain in global supply chains and cross border trade: a critical synthesis of the state-of-the-art, challenges and opportunities*. INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH 58.7, 2082-2099 (2020).

[85] Silas Nzuva. *Smart contracts implementation, applications, benefits, and limitations*. JOURNAL OF INFORMATION ENGINEERING AND APPLICATIONS 9.5, 63-75 (2019).

legal agreements can, for instance, outline dispute resolution mechanisms or define the parameters under which a smart contract can be modified.

Building privacy considerations into the design of blockchain solutions from the outset is crucial. This "privacy by design" approach ensures compliance with data protection laws and fosters trust among users.[86] Companies can implement various techniques to achieve this, such as data anonymization or leveraging permissioned blockchains that restrict access to specific participants.

By employing these legal strategies, companies can navigate the complexities of blockchain adoption and unlock the transformative potential of this technology within a legally compliant and responsible framework.

## E. Recommendations for Cross-Border Cooperation

A harmonized legal landscape is critical for fostering innovation, safeguarding consumer interests, and promoting the responsible and secure development of global supply chains. This section outlines key recommendations for achieving this objective.

Regular dialogues between policymakers, industry leaders, legal scholars, and international organizations can serve as a powerful catalyst for crafting comprehensive regulatory frameworks.[87] These dialogues should foster a collaborative environment where stakeholders can share best practices and lessons learned from early adopters. By harnessing the collective knowledge of diverse stakeholders, policymakers can develop regulations that are informed, effective, and adaptable to the evolving nature of AI-enabled blockchain technology.

Building upon existing international frameworks, such as the UNCITRAL Model Law on Electronic Commerce, can provide a robust foundation for future regulatory harmonization.[88] These established frameworks can be adapted to address the specificities of AI-enabled blockchain ecosystems, ensuring consistency and reducing regulatory burdens for businesses operating across borders. Furthermore, supporting the standardization efforts of organizations like ISO is crucial. Standardized terminology, security protocols, and interoperability standards for blockchain technology will facilitate seamless international trade and reduce regulatory uncertainty. By establishing a common language and technical infrastructure, these efforts can promote global collaboration and innovation within the blockchain space.

By proactively shaping the regulatory landscape through these collaborative efforts, stakeholders can ensure that AI-enabled blockchain technology flourishes within a legal framework that prioritizes both innovation and responsible development. This collaborative approach will safeguard consumer interests and promote the secure and ethical development of global supply chains. As the legal and regulatory landscape surrounding AI-enabled blockchain technology continues to evolve, ongoing

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[86] *See* Danezis, George, et al. *Privacy and data protection by design-from policy to engineering*. arXiv preprint arXiv:1501.03726 (2015).

[87] Jeremy Barnett, and Philip Treleaven. *Algorithmic dispute resolution—The automation of professional dispute resolution using AI and blockchain technologies*. THE COMPUTER JOURNAL 61.3, 399-408 (2018).

[88] Gunawan Widjaja, et al. *UNCITRAL Model Law on Electronic Commerce and Model Law on Electronic Signatures*, CROSS-BORDER 1.1, 283-296 (2018).

international cooperation will remain paramount in unlocking the transformative potential of this technology for American global supply chains.

## F. Recommendations for Private Companies and Policymakers

The burgeoning adoption of AI-enabled blockchain technology within American global supply chains necessitates a multifaceted approach to legal and regulatory frameworks. This section explores anticipated changes within these frameworks and outlines recommendations for navigating this evolving environment.

The unique characteristics of AI-enabled blockchain necessitate adjustments to existing legal frameworks. Three key areas likely to undergo significant transformations are data privacy and security, regulatory harmonization, and smart contract enforceability.[89] Regulations are expected to evolve to provide greater clarity on data ownership within these ecosystems, especially in the international context. This may involve establishing user consent mechanisms for data collection and utilization alongside robust data anonymization techniques to protect privacy. Additionally, we can expect the development of stringent cybersecurity standards and data breach notification requirements to ensure the security and integrity of data throughout the supply chain.[90]

New legal doctrines may also emerge to delineate liability within the complex networks of AI-enabled blockchain supply chains.[91] Striking a balance between fostering innovation and ensuring consumer safety will be crucial. When assigning responsibility for product defects, legal frameworks may consider factors like the role of algorithmic decision-making processes within the AI components of the blockchain system.

Finally, legal frameworks will likely need to address the enforceability of dispute resolution clauses embedded within smart contracts across jurisdictions.[92] This may involve establishing standardized legal frameworks for smart contracts, potentially leveraging international cooperation to foster recognition of their legal validity across borders. Such efforts will promote stability and predictability within the global supply chain ecosystem.

Effective international cooperation is paramount in fostering a harmonized legal landscape for AI-enabled blockchain technology.[93] Here, we recommend several key approaches. Regular dialogues between policymakers, industry leaders, legal scholars, and international organizations can serve as a powerful catalyst for crafting comprehensive regulatory frameworks. These dialogues should foster a collaborative

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[89] Georgios I. Zekos, and Georgios I. Zekos. *AI and legal issues*. Economics and Law of Artificial Intelligence: FINANCE, ECONOMIC IMPACTS, RISK MANAGEMENT AND GOVERNANCE 401-460 (2021).
[90] Agnes Clare Odimarha, et al. *Securing the digital supply chain: Cybersecurity best practices for logistics and shipping companies.* WORLD JOURNAL OF ADVANCED SCIENCE AND TECHNOLOGY 5.1, 026-033 (2024).
[91] Жамиля Панабергенова. *Fulfilling fiduciary duties in the ai era: emerging risks and responsibilities in ai-assisted corporate financial oversight*. ОБЩЕСТВО И ИННОВАЦИИ 5.2/S, 222-230 (2024).
[92] Riikka Koulu, *Blockchains and online dispute resolution: smart contracts as an alternative to enforcement*. *S*CRIPTed 13, 40 (2016).
[93] Amy Schmitz, and Colin Rule. *Online dispute resolution for smart contracts*. J. DISP. RESOL. 103 (2019).

environment where stakeholders can share best practices and lessons learned from early adopters. By harnessing the collective knowledge of diverse stakeholders, policymakers can develop regulations that are informed, effective, and adaptable to the evolving nature of AI-enabled blockchain technology.

Building upon existing international frameworks, such as the UNCITRAL Model Law on Electronic Commerce, can provide a robust foundation for future regulatory harmonization.[94] These established frameworks can be adapted to address the specificities of AI-enabled blockchain ecosystems, ensuring consistency and reducing regulatory burdens for businesses operating across borders. Furthermore, supporting the standardization efforts of organizations like ISO is crucial. Standardized terminology, security protocols, and interoperability standards for blockchain technology will facilitate seamless international trade and reduce regulatory uncertainty. By establishing a common language and technical infrastructure, these efforts can promote global collaboration and innovation within the blockchain space.

## G. Future Research Directions

The burgeoning field of AI-enabled blockchain technology within global supply chains presents a compelling opportunity for further academic exploration. This section examines key areas for future research and explores anticipated developments in the technology itself alongside their potential legal implications.

Standardization and interoperability are crucial for fostering seamless information sharing and collaboration within complex AI-enabled blockchain supply chains.[95] Research into standardized protocols and data formats can address legal complexities surrounding data ownership and jurisdiction.[96] By enabling smooth data exchange across different platforms, these efforts can reduce friction and promote efficient supply chain management.

Developing frameworks for explainable AI within blockchain systems is another critical research area.[97] Understanding how AI algorithms make decisions within supply chains is essential for mitigating concerns about algorithmic bias and ensuring fair and ethical practices throughout the network. Research efforts should focus on making AI decision-making processes transparent and auditable.

The legal enforceability of smart contracts across jurisdictions remains an open question.[98] Further research is needed to develop standardized legal frameworks for smart contracts that provide clarity and certainty for businesses operating within AI-enabled blockchain supply chains. This will help establish a predictable legal environment and promote the widespread adoption of this technology.

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[94] Gerold Herrmann, *Establishing a legal framework for electronic commerce: the work of the United Nations Commission on International Trade Law (UNCITRAL)*. WORLD TRADE AND ARBITRATION MATERIALS 11.6 (1999).

[95] Shenle Pan, et al. *Digital interoperability in logistics and supply chain management: state-of-the-art and research avenues towards Physical Internet*. COMPUTERS IN INDUSTRY 128, 103435 (2021).

[96] *Id.*

[97] Prabhat Kumar, et al. *Blockchain and explainable AI for enhanced decision making in cyber threat detection*. Software: Practice and Experience (2024).

[98] Vimal Dwivedi, et al. *Legally enforceable smart-contract languages: A systematic literature review*. ACM COMPUTING SURVEYS (CSUR) 54.5, 1-34 (2021).

Quantum computing harnesses the principles of quantum mechanics to solve complex problems exponentially faster than classical computers,[99]posing both threats and opportunities for blockchain in global supply chains. On one hand, its immense computational power could potentially crack the cryptographic algorithms securing blockchain networks, compromising data integrity and trust[100]. On the other hand, quantum computing could enhance supply chain visibility and efficiency by optimizing complex logistics, predicting disruptions, and enabling new levels of automation.[101] However, realizing these benefits requires developing quantum-resistant cryptographic protocols and integrating quantum technologies seamlessly with existing blockchain infrastructure, presenting significant challenges for the industry.

Decentralized Autonomous Organizations (DAOs), self-governing organizations facilitated by blockchain technology, present intriguing possibilities for supply chain management.[102] Research into the legal and regulatory frameworks governing DAOs, particularly regarding decision-making processes and liability attribution, is necessary to navigate this nascent domain. A clear understanding of the legal landscape surrounding DAOs will be essential for their successful integration into supply chains.

The convergence of AI-enabled blockchain with the Internet of Things (IoT) has the potential to revolutionize data collection and real-time monitoring within supply chains.[103] However, the vast amount of data generated by IoT devices raises new challenges concerning data privacy, security, and ownership.[104] Legal frameworks will need to adapt to address these complexities and ensure responsible data management practices. Research efforts should explore how to balance the benefits of real-time data collection with the need to protect consumer privacy and data security.

By actively pursuing these research avenues and anticipating future technological advancements, stakeholders can stay ahead of the curve and ensure that the legal landscape surrounding AI-enabled blockchain technology evolves alongside the technology itself. This proactive approach can pave the way for a future where this transformative technology facilitates secure, efficient, and ethical global supply chains.

## CONCLUSION

AI-enabled blockchain technology presents a transformative opportunity to revolutionize how goods are sourced, tracked, and delivered across the globe. This technology has the potential to foster a more secure, efficient, and ethical trade

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[99] David Deutsch. *Quantum computation*. PHYSICS WORLD 5.6, 57 (1992).
[100] Noah Kappert, et al. *Quantum Computing-The Impending End for the Blockchain?*. PACIS. 2021.
[101] Eleanor Rieffel and Wolfgang Polak. *An introduction to quantum computing for non-physicists*. ACM COMPUTING SURVEYS (CSUR) 32.3, 300-335 (2000).
[102] Kyung Taeck Minn, *Towards enhanced oversight of" self-governing" decentralized autonomous organizations: case study of the DAO and its shortcomings*. NYU J. INTELL. PROP. & ENT. L. 9, 139 (2019).
[103] Sushil Kumar Singh, et al. *Blockiotintelligence: A blockchain-enabled intelligent IoT architecture with artificial intelligence.* FUTURE GENERATION COMPUTER SYSTEMS 110, 721-743 (2020).
[104] Brian Parker, and Christian Bach. *The synthesis of blockchain, artificial intelligence and internet of things*. EUROPEAN JOURNAL OF ENGINEERING AND TECHNOLOGY RESEARCH 5.5, 588-593 (2020).

ecosystem, but unlocking its full potential hinges on overcoming a critical challenge: the need for international harmonization.[105]

The complex nature of global supply chains, with their interconnected networks spanning diverse jurisdictions, presents an intricate web of legal considerations. Data privacy concerns necessitate a nuanced approach that safeguards consumer information across international borders. Assigning clear liability for product defects and ensuring the enforceability of smart contract dispute resolution mechanisms require novel legal solutions with international applicability. The nascent character of this technology underscores the urgent need to develop legal doctrines and frameworks specifically tailored to the unique characteristics of AI-enabled blockchain ecosystems. These frameworks must be established through a collaborative effort among stakeholders from all corners of the global marketplace.

Despite the challenges, the potential benefits of international harmonization in the context of AI-enabled blockchain are substantial. By fostering collaboration and establishing consistent legal principles across jurisdictions, we can unlock a future where this technology enhances transparency and traceability throughout the entire supply chain. This, in turn, can lead to improved product safety, streamlined logistics, and a more sustainable trade environment. AI algorithms can optimize operations, reduce waste, and generate valuable data for informed decision-making by all stakeholders involved. Increased transparency empowers consumers to make informed choices, while improved traceability facilitates swift product recalls and combats counterfeiting. Streamlined logistics and optimized operations can lead to cost reductions and improved efficiency for businesses across the global supply chain.

In conclusion, the long-term success of AI-enabled blockchain hinges on a commitment to international cooperation. Policymakers, industry leaders, legal scholars, and international organizations must work together to develop robust and adaptable regulatory frameworks that ensure data privacy, consumer protection, and fair competition within the global marketplace. By prioritizing the development of harmonized international legal solutions, we can mitigate legal complexities and harness the transformative potential of this technology. This collaborative approach will pave the way for a more secure, efficient, and ethical global supply chain for the future. The future rests on our collective ability to embrace responsible innovation within a framework of international cooperation, fairness, transparency, and good governance.

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[105] R. Sivarethinamohan, et al., *Unlocking the potential of (AI-powered) blockchain technology in environment sustainability and social good*. APPLIED EDGE AI. Auerbach Publications, 193-213. (2022).