

The Role of Cryptocurrency Activities in Facilitating Iran's Foreign Trade under International Financial Restrictions: Integrating Evidence from the ARDL Model and Expert Thematic Analysis

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ABSTRACT

The present study aimed to investigate the role of cryptocurrency activities in facilitating Iran's foreign trade under international financial restrictions. The primary focus was on identifying the short- and long-run effects of cryptocurrency activity and explaining the mechanisms through which digital assets may reduce transaction costs, as well as the institutional constraints and risks associated with their use. The study employed a mixed-methods approach. In the quantitative phase, 131 monthly observations covering January 2015 to November 2025 were examined. Iran's merchandise trade volume was calculated as the sum of FOB exports and CIF imports, cryptocurrency activity was measured using Bitcoin spot trading volume, and the oil price was obtained from the monthly average Brent crude oil price. Following the application of the augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests, an ARDL(1,1,1) model, the bounds test, and an error correction model were estimated. Heteroskedasticity and autocorrelation consistent (HAC) standard errors were employed to account for conditional heteroskedasticity. In the qualitative phase, data obtained from 18 semi-structured interviews with experts were analyzed using thematic analysis and integrated with the quantitative findings. The findings indicated that the bounds test confirmed the existence of a long-run relationship among the variables. Cryptocurrency activity had a positive and statistically significant short-run effect on foreign trade; specifically, a 1% increase in cryptocurrency activity was associated with a 0.039% increase in trade. However, the long-run cryptocurrency coefficient was positive but statistically insignificant. The full reimposition of sanctions reduced the level of monthly trade by approximately 23.3%, whereas the oil price had a positive and statistically significant long-run effect. The error correction coefficient indicated that 39.5% of disequilibrium was corrected each month. The thematic analysis also identified five themes: payment facilitation, dual macroeconomic consequences, retail investment behavior, institutional challenges, and policy lessons. Based on the findings, cryptocurrencies may serve as a complementary payment channel capable of reducing part of the friction in foreign trade in the short run; however, no evidence was obtained of a persistent long-run effect. Effective utilization of this potential requires risk-based regulation, infrastructure security, and a clear distinction between commercial payments and speculative activity.

Keywords: cryptocurrency; foreign trade; economic sanctions; ARDL model; transaction cost theory.



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Introduction

The architecture of international trade has historically depended on access to banking networks, correspondent relationships, reserve currencies, cross-border messaging systems, and regulated financial intermediaries capable of settling obligations between geographically dispersed buyers and sellers. Although globalization has substantially reduced informational and logistical barriers to international exchange, payment frictions remain a major component of cross-border transaction costs, particularly for firms operating in economies subject to financial restrictions. Digitalization has altered this environment by reducing search, verification, communication, and coordination costs and by enabling economic transactions to be organized through increasingly decentralized technological infrastructures (1). Blockchain technology represents one of the most consequential manifestations of this transformation because it allows economic agents to record, verify, and transfer digitally represented value without relying exclusively on traditional centralized intermediaries. The original Bitcoin protocol demonstrated the technical feasibility of a peer-to-peer electronic cash system in which transactions could be validated through a distributed network rather than a conventional financial institution (2). Subsequent research has therefore increasingly examined cryptocurrencies not merely as speculative assets but also as an alternative technological infrastructure for transferring value, coordinating transactions, and restructuring financial intermediation.

From an economic perspective, the potential relevance of blockchain and cryptocurrencies stems largely from their capacity to alter verification and networking costs. Blockchain-based systems can reduce certain costs associated with establishing trust, validating ownership, and maintaining transaction records, although they simultaneously introduce new governance, scalability, and incentive problems (3). Earlier analyses of Bitcoin similarly emphasized that the system combines technological innovation with a distinctive economic and governance structure in which transaction verification, monetary issuance, and network security are jointly determined by decentralized participants (4). The implications of blockchain extend beyond payments. Distributed ledgers can influence organizational governance by modifying the processes through which ownership, voting rights, contracts, and corporate records are verified (5). They may also affect supply-chain management by improving traceability, coordination, information sharing, and transactional transparency among parties that do not necessarily possess a high degree of mutual trust (6). These characteristics make cryptocurrency-based settlement potentially relevant to international trade, where transactions frequently involve multiple intermediaries, currencies, legal jurisdictions, and settlement stages.

The relevance of digital assets becomes particularly pronounced when conventional financial intermediation is expensive, slow, inaccessible, or politically constrained. Cross-border payments frequently involve correspondent banks, foreign-exchange conversion, regulatory screening, liquidity management, and multiple settlement infrastructures. Such frictions can increase transaction costs and create incentives for economic agents to search for alternative payment mechanisms. Recent evidence suggests that payment frictions can influence the scale and direction of international financial flows and may also interact with exchange-rate dynamics (7). Digital money may modify these mechanisms by changing the cost and speed of international payments and by allowing transactions to take place through infrastructures that differ from conventional banking arrangements (8). Scenario-based research likewise indicates that widespread adoption of digital money could affect the intensive margin of cross-border flows by changing transactional efficiency and the relative attractiveness of alternative settlement

instruments (9). Consequently, cryptocurrencies and stablecoins should be analyzed not only as financial assets but also as potential components of an emerging cross-border payment architecture.

Empirical measurement of cryptocurrency-based international transfers, however, remains difficult. Blockchain transactions are observable at the ledger level, but the economic purpose, geographical origin, geographical destination, and identity of the parties are frequently imperfectly observed. Methodological advances have increasingly attempted to estimate cross-border cryptocurrency activity by combining blockchain data with exchange information and other indicators. Research on international crypto flows demonstrates that cross-border digital-asset movements are economically substantial and respond to macroeconomic, financial, and institutional conditions (10). Stablecoins pose a particularly important measurement challenge because they can circulate across exchanges, wallets, decentralized protocols, and jurisdictions without generating the conventional records associated with international bank transfers. Methods developed to estimate international stablecoin flows indicate that these instruments have become sufficiently important to warrant systematic inclusion in analyses of global financial movements (11). More recent empirical evidence on Bitcoin, Ether, and stablecoin flows also confirms that digital assets possess a distinct cross-border dimension and that their international movements are shaped by economic incentives and differences across jurisdictions (12).

Stablecoins may be especially relevant for international settlement because they seek to combine the transferability of blockchain-based assets with relatively stable values, generally through reference to sovereign currencies such as the U.S. dollar. Unlike highly volatile unbacked cryptocurrencies, dollar-linked stablecoins can potentially be used as transactional instruments, stores of short-term liquidity, and intermediary assets between local currency and international markets. At the same time, their rapid growth raises concerns regarding reserve quality, redemption arrangements, governance, operational resilience, market integrity, and regulatory arbitrage. The regulation of stablecoin arrangements therefore requires attention to both their payment functionality and the financial risks generated by their underlying structures (13). The emergence of decentralized finance further expands the range of blockchain-based financial services by enabling trading, lending, liquidity provision, and other contractual functions through smart contracts rather than traditional intermediaries (14). Nevertheless, decentralized finance does not eliminate intermediation risks entirely; concentration, governance dependencies, oracle vulnerabilities, liquidity mismatches, and interconnectedness may create forms of de facto centralization despite the nominally decentralized architecture (15).

These opportunities and risks become more complex when cryptocurrency use takes place in countries experiencing capital controls, weak institutional environments, or restrictions on access to the international financial system. Cross-country evidence suggests that cryptocurrency adoption is associated with institutional and macrofinancial conditions, including corruption and capital-control environments, although such correlations should not automatically be interpreted as causal relationships (16). Digital assets may provide legitimate users with alternative mechanisms for preserving value or executing payments, while the same technological characteristics can facilitate regulatory circumvention, opacity, illicit transfers, or sanctions evasion. Evidence that privacy-enhancing cryptocurrencies and other digital assets can be associated with activity in less transparent segments of online markets further illustrates the dual-use nature of the cryptocurrency ecosystem (17). Accordingly, the economic evaluation of cryptocurrencies under financial restrictions requires simultaneous consideration of their transaction-cost advantages, compliance risks, market volatility, and institutional consequences.

Economic sanctions provide a particularly important context for such analysis because they alter both the incentives and the constraints faced by firms engaged in international trade. Sanctions can affect trade through restrictions on banking relationships, foreign-exchange access, shipping, insurance, investment, financing, and the willingness of foreign counterparties to transact with sanctioned jurisdictions. They may also increase sovereign financial vulnerability and interact with broader debt and financing conditions (18). In the Iranian case, previous economic research has demonstrated that sanctions can materially change export destinations and encourage the redirection of trade toward alternative markets, producing what has been described as export deflection (19). Analyses of the prospective removal of sanctions have likewise shown that Iran's reintegration into international markets can generate meaningful changes in trade, production, and strategic economic responses, demonstrating the substantial influence of sanctions on the country's external economic relations (20). These findings indicate that sanctions are not merely a binary political condition; rather, they reshape transaction costs, counterpart selection, settlement arrangements, and the structure of foreign trade.

Cryptocurrencies may theoretically mitigate a portion of these frictions because blockchain-based transfers do not inherently require the same correspondent-banking chains used in conventional cross-border settlements. This possibility has generated growing interest in whether digital assets can be employed to circumvent or reduce the effectiveness of financial sanctions. Empirical research investigating Bitcoin activity in relation to sanctions provides evidence that cryptocurrency markets may respond to financial restrictions and that Bitcoin can, under certain conditions, be used as a mechanism for avoiding conventional financial channels (21). Nevertheless, the ability of cryptocurrencies to bypass specific payment restrictions does not imply that they can neutralize the broader economic consequences of sanctions. Digital-asset transactions remain dependent on conversion between fiat and crypto assets, access to exchanges or counterparties, liquidity conditions, technological infrastructure, compliance practices, and the willingness of foreign actors to accept such instruments. Sanctions can therefore generate demand for alternative settlement channels without necessarily making those channels sufficient substitutes for conventional trade finance.

This distinction is particularly relevant to Iran, where the interaction between sanctions, exchange-rate pressures, restricted banking access, and a growing domestic cryptocurrency ecosystem has created a distinctive institutional environment. Iranian scholarship has previously identified cryptocurrencies as potentially facilitating international exchanges under sanctions by reducing dependence on conventional financial intermediaries and creating alternative mechanisms for transferring value (22). Legal research has likewise examined the possible role of cryptocurrencies in reducing the practical effects of unilateral sanctions while emphasizing the unresolved legal and regulatory questions surrounding their use (23). At the policy level, Iranian research has highlighted both the economic opportunities and the security threats arising from cryptocurrency adoption, including questions of capital flight, financial monitoring, monetary sovereignty, illicit finance, and the need for an appropriate regulatory framework (24). These studies establish a strong conceptual basis for examining cryptocurrency use under sanctions but also reveal that its economic consequences cannot be evaluated independently of domestic institutional arrangements.

The scale and political-economic relevance of cryptocurrency activity in Iran have continued to increase. Recent blockchain intelligence estimates characterize Iran as possessing a multibillion-dollar cryptocurrency ecosystem in which household demand, geopolitical pressures, state-linked activity, and efforts to preserve value under domestic economic instability interact in complex ways (25). Such evidence is important because it demonstrates that

cryptocurrency activity in Iran is no longer a marginal technological phenomenon. Nevertheless, aggregate crypto activity may reflect several fundamentally different behaviors: cross-border commercial settlement, portfolio diversification, inflation hedging, capital flight, speculative trading, sanctions-related transfers, or institutional activity. Consequently, observing a rise in cryptocurrency transaction volume does not by itself demonstrate that cryptocurrencies facilitate merchandise trade. Establishing such a relationship requires an empirical design capable of distinguishing temporal association from broad narratives concerning sanctions circumvention.

The theoretical logic underlying a possible trade-facilitation effect is nevertheless compelling. International trade entails transaction costs associated with searching for counterparties, negotiating terms, verifying performance, transferring funds, managing exchange-rate risk, and complying with institutional requirements. Where financial sanctions intensify banking frictions, these costs may increase substantially. Cryptocurrency-based settlement could reduce some of these costs by shortening settlement chains, providing continuous market access, and enabling value transfer without direct reliance on correspondent banks. Yet the same mechanism may generate additional costs through price volatility, exchange fees, cybersecurity threats, wallet management, compliance uncertainty, counterparty risk, and conversion back into fiat currency. The net effect is therefore theoretically ambiguous and likely to differ between short- and long-run horizons. In the short run, digital assets may operate as flexible bridging instruments during periods of payment disruption; over the long run, trade performance may remain more strongly determined by production capacity, oil revenues, logistical conditions, exchange-rate dynamics, trade policy, and the persistence of sanctions.

The distinction between short-run adjustment and long-run equilibrium is central to the empirical investigation of this issue. Cryptocurrency activity, oil prices, and foreign trade are time-series variables that may display trends, persistence, and different orders of integration. Conventional regression models applied to nonstationary variables can generate misleading statistical relationships unless their integration and cointegration properties are properly addressed. The autoregressive distributed lag framework is particularly appropriate when the variables are a combination of $I(0)$ and $I(1)$ processes, provided that none is integrated of order two, and it permits simultaneous estimation of short-run dynamics and long-run relationships. The bounds-testing approach developed by Pesaran, Shin, and Smith provides a formal procedure for evaluating whether a stable level relationship exists among such variables (26). This methodological framework is therefore well suited to determining whether cryptocurrency activity is associated only with temporary changes in Iranian foreign trade or whether its influence persists as part of a longer-run equilibrium relationship.

Nevertheless, econometric evidence alone cannot fully identify the mechanisms through which cryptocurrencies may affect trade. A positive statistical association between global cryptocurrency activity and Iranian foreign trade could result from direct payment facilitation, common responses to global liquidity, changes in risk appetite, macroeconomic shocks, or other omitted mechanisms. Qualitative evidence is therefore necessary to determine whether practitioners actually use digital assets to reduce settlement time, replace unavailable payment channels, manage sanctions-related restrictions, or overcome foreign-exchange constraints. It is equally important to identify the institutional conditions that may weaken these mechanisms, including regulatory uncertainty, cybersecurity risks, exchange restrictions, limited commercial acceptance, and the distinction between transaction-driven and speculative cryptocurrency demand. This need is reinforced by evidence that cross-border crypto flows are heterogeneous and shaped by both payment motivations and broader financial incentives (10, 12).

A further research gap concerns the tendency to discuss cryptocurrency adoption, sanctions circumvention, and trade facilitation as if they were equivalent phenomena. They are analytically distinct. Cryptocurrency adoption may increase because households seek inflation hedges; sanctions circumvention may involve financial transfers unrelated to merchandise trade; and trade facilitation requires that digital assets reduce actual frictions associated with commercial exchange. Moreover, developments in stablecoins and decentralized finance have expanded the technological possibilities for cross-border settlement, but their economic contribution remains conditional on liquidity, convertibility, regulation, network access, and institutional trust (13, 14). The broader digital-finance literature therefore implies that the relevant question is not whether cryptocurrencies are universally beneficial or harmful, but under what conditions, through which mechanisms, and over what time horizon they can alter international transaction costs.

Against this background, an integrated quantitative–qualitative approach can provide a more rigorous account of cryptocurrency activity in Iran’s sanctions-constrained trade environment. Time-series evidence can determine whether changes in cryptocurrency activity are systematically associated with changes in foreign trade after accounting for major macroeconomic factors such as oil prices and the reimposition of sanctions, while expert evidence can clarify the mechanisms, institutional constraints, and risks underlying any observed relationships. Such integration is particularly important because recent international research increasingly recognizes that digital money can alter cross-border financial flows while simultaneously generating new regulatory and financial-stability challenges (8, 9). It also responds to the need to distinguish a short-term payment-bridging function from claims that cryptocurrencies can structurally offset the effects of exclusion from conventional international financial networks.

Accordingly, the aim of this study is to examine the short- and long-run role of cryptocurrency activity in facilitating Iran’s foreign trade under international financial restrictions and to integrate ARDL-based econometric evidence with expert thematic analysis to explain the underlying transaction-cost mechanisms, institutional constraints, and associated risks.

Methods and Materials

The present study is applied in terms of purpose and, in terms of implementation, adopts a mixed-methods approach based on a convergent parallel design with quantitative dominance. The mixed-methods approach was selected because the statistical relationship between cryptocurrency activities and foreign trade, by itself, does not reveal the mechanisms through which cryptocurrencies exert effects under conditions of banking restrictions. Accordingly, the results of the time-series analysis were compared with the experiences and perceptions of economic experts, policymakers, and foreign-trade practitioners, and the two sets of findings were integrated at the final interpretation stage. The unit of analysis in the quantitative phase was “the Iranian economy at monthly time intervals,” whereas in the qualitative phase it was “experts’ experiences and perspectives regarding the role of cryptocurrencies in foreign-trade settlement.”

The quantitative dataset covered monthly time-series data from January 2015 to December 2025, providing a total of 132 observations for each variable. The dependent variable was foreign trade volume (TRADE), calculated as the sum of the monthly value of Iran’s merchandise exports and imports in U.S. dollars. Trade data were extracted from the monthly reports of the Islamic Republic of Iran Customs Administration and cross-checked against statistics from the Central Bank. The main explanatory variables included the trading volume of major

cryptocurrencies (CRYPTO_VOL), the market capitalization of Bitcoin and Ethereum (CRYPTO_MKT), and the total value locked in decentralized finance protocols (DeFi_TVL). Cryptocurrency data were collected from CoinMarketCap and CoinGecko, while DeFi data were obtained from DeFiLlama. The market exchange rate (EXR), Brent crude oil price (OIL_PRICE), and intensity of financial restrictions (SANCTION) were also included as control variables. The sanctions variable was coded according to the implementation dates of official banking, oil, and trade sanctions packages. To assess whether the cryptocurrency effect was conditional on sanctions intensity, an interaction term between cryptocurrency activity and sanctions intensity was also included in supplementary model specifications.

Before estimation, the data were examined for missing values, outliers, and structural breaks. Variables measured in monetary terms were converted to consistent prices and units and transformed using natural logarithms to reduce heteroskedasticity. The stationarity of the series was assessed using the augmented Dickey–Fuller and Phillips–Perron tests. Given the possibility of combining variables that were stationary at level, $I(0)$, and stationary after first differencing, $I(1)$, subject to the absence of any $I(2)$ variable, the autoregressive distributed lag (ARDL) approach was selected. The optimal lag length was determined using the Akaike information criterion, and the existence of a long-run relationship was assessed using the bounds testing procedure developed by Pesaran, Shin, and Smith (2001). The general specification of the model was defined as follows:

$$\ln TRADE_t = \alpha_0 + \sum \phi_i \ln TRADE_{t-i} + \sum \beta_j \ln CRYPTO_VOL_{t-j} + \sum \delta_k \ln CRYPTO_MKT_{t-k} + \sum \theta_l \ln DeFi_TVL_{t-l} + \sum \gamma_m X_{t-m} + \varepsilon_t$$

In this equation, X denotes the vector of control variables, including the exchange rate, oil price, and sanctions intensity. After cointegration was confirmed, the long-run coefficients and the error correction model were estimated to identify short-run dynamics. A negative and statistically significant coefficient for the error correction term was required to confirm convergence toward the long-run equilibrium. The robustness of the results was evaluated using the Breusch–Godfrey serial correlation test, White heteroskedasticity test, Jarque–Bera normality test, Ramsey Regression Equation Specification Error Test (RESET), and CUSUM and CUSUMSQ stability plots. Econometric analyses were conducted using EViews at a 5% significance level.

The qualitative study population consisted of experts in economics and banking, policymakers, academics, managers of cryptocurrency exchanges, and foreign-trade practitioners. Participants were selected purposively based on possessing specialized knowledge or direct experience related to sanctions, international payments, or cryptocurrencies. Sampling continued until theoretical saturation was achieved, resulting in 18 interviews: three managers from the Central Bank's foreign-exchange and international affairs divisions, two experts from the Ministry of Industry, Mine and Trade, one expert from the Ministry of Economic Affairs and Finance, six academics and researchers, four private-sector practitioners, and two independent cryptocurrency market analysts. Data were collected through semi-structured interviews, with questions focusing on settlement methods, changes in payment costs and processing time, legal and security risks, the role of stablecoins, and the impact of regulation.

After informed consent was obtained, the interviews were recorded and transcribed verbatim. Qualitative data analysis followed the thematic analysis procedure proposed by Braun and Clarke (2006), including familiarization with the data, generation of initial codes, development of themes, review of themes, definition and naming of themes, and report production. To enhance credibility, triangulation of interview findings with official documents and

ARDL results, member checking, and documentation of the coding decision trail were employed. At the integration stage, each quantitative result was compared with convergent, complementary, or contradictory qualitative themes. Thus, the qualitative component was not used to statistically establish the relationship but rather to explain the possible mechanisms and boundary conditions underlying the observed association. Participants' identities remained confidential, and quotations were reported using anonymous codes.

Findings and Results

Foreign trade volume was defined as the sum of Iran's FOB merchandise exports and CIF merchandise imports with the rest of the world, obtained from the IMF–IMTS database. Cryptocurrency activity was measured using the monthly total reported Bitcoin spot trading volume from Coin Metrics; this indicator represents the aggregate reported spot trading volume in U.S. dollars. The oil price was measured as the monthly average of daily Brent crude oil prices obtained from FRED/EIA. The sanctions dummy variable was assigned a value of one beginning in November 2018, coinciding with the full reimposition of U.S. sanctions. The common sample period extended from January 2015 to November 2025 and included 131 monthly observations. Variables were entered into the ARDL model in natural logarithmic form. Among 27 specifications with lag lengths ranging from one to three, the Bayesian information criterion (BIC) selected the ARDL(1,1,1) specification. Monthly seasonal effects were also controlled for, and because an ARCH effect was detected, HAC standard errors with a 12-month lag were reported.

Table 1. Descriptive Statistics of the Variables

Variable	Unit	N	Mean	Median	Standard Deviation	Minimum	Maximum
Iran's foreign trade volume	USD billion	131	6.584	5.918	1.971	3.325	13.110
Bitcoin spot trading volume	USD billion per month	131	216.953	146.538	213.455	0.252	874.240
Brent crude oil price	USD per barrel	131	66.472	65.410	18.672	18.379	122.711
Sanctions dummy variable	0/1	131	0.649	1	0.479	0	1

The descriptive statistics indicate substantial volatility in cryptocurrency activity, as the standard deviation of Bitcoin trading volume is approximately equal to its mean. Iran's foreign trade also varied from USD 3.32 billion to USD 13.11 billion per month. The mean of the sanctions dummy indicates that approximately 65% of the observations belong to the period following the full reimposition of sanctions.

Table 2. Results of Stationarity Tests

Variable	Form	ADF	ADF p Value	PP	PP p Value	Conclusion
LNTRADE	Level	-1.599	.4841	-3.025	.0326	Mixed evidence
LNTRADE	First difference	-7.009	< .001	-16.111	< .001	Stationary
LNCRYPTO	Level	-1.728	.4165	-1.735	.4130	Nonstationary
LNCRYPTO	First difference	-11.272	< .001	-11.385	< .001	Stationary
LNOIL	Level	-2.267	.1828	-2.369	.1507	Nonstationary
LNOIL	First difference	-9.142	< .001	-8.657	< .001	Stationary

For foreign trade, the ADF and PP tests do not yield identical conclusions at level; however, both tests confirm stationarity after first differencing at a probability level below .001. Cryptocurrency activity and the oil price are likewise stationary after first differencing. Therefore, none of the variables is $I(2)$, satisfying the fundamental requirement for application of the ARDL approach.

Table 3. Results of the Bounds Test

Specification	Value
Selected model	ARDL(1,1,1)
F statistic	4.573
5% lower bound	3.229
5% upper bound	4.322
p value corresponding to the upper bound	.0363
Conclusion	Long-run relationship confirmed at the 5% level

Because the F statistic of 4.573 exceeds the 5% upper bound of 4.322, the null hypothesis of no level relationship is rejected. Consequently, a long-run equilibrium relationship exists among foreign trade, cryptocurrency activity, and the oil price. This finding only confirms the existence of a long-run relationship among the set of variables and does not, by itself, imply that each individual long-run coefficient is statistically significant.

Table 4. Short-Run Results of the ARDL Model

Variable	Coefficient	HAC Standard Error	t Statistic	p Value
$\Delta \text{LNCRYPTO}$	0.0390	0.0175	2.234	.0275
ΔLNOIL	0.2937	0.1029	2.855	.0051
SANCTION	-0.2651	0.0649	-4.082	< .001

The short-run coefficient of cryptocurrency activity is positive and statistically significant at the 5% level. Specifically, a 1% increase in Bitcoin spot trading volume is associated with an approximately 0.039% increase in Iran's foreign trade in the same month. This result is consistent with a short-run role for cryptocurrencies in increasing liquidity and providing alternative settlement channels; however, because the cryptocurrency indicator is global, it should not be interpreted directly as the volume of cryptocurrency payments made by Iranian traders. The oil-price coefficient is likewise positive and statistically significant; a 1% increase in the Brent crude oil price is associated with an approximately 0.294% increase in Iran's merchandise trade. The coefficient of the sanctions dummy is -0.265. Exact transformation of the logarithmic coefficient indicates that the full reimposition of sanctions was associated with an approximately 23.3% reduction in the level of monthly trade; however, this coefficient represents the conditional net effect after controlling for oil prices, cryptocurrency activity, and monthly seasonal effects.

Table 5. Long-Run Results of the ARDL Model

Variable	Long-Run Coefficient	HAC Standard Error	t Statistic	p Value
LNCRYPTO	0.0334	0.0254	1.316	.1910
LNOIL	0.3691	0.0433	8.523	< .001

The long-run coefficient of cryptocurrency activity is positive but statistically insignificant. Thus, the empirical data support a positive short-run effect but do not provide sufficient evidence to claim a persistent long-run effect of cryptocurrencies on Iran's foreign trade. This difference likely indicates that cryptocurrencies primarily function as flexible instruments for occasional or short-term settlement, whereas factors such as oil export capacity, logistical constraints, regulation, and sanctions intensity become more influential over the long run. The long-run oil-price coefficient is 0.369 and highly statistically significant; therefore, a 1% increase in the oil price is associated with an approximately 0.369% increase in Iran's merchandise trade in the long run.

Table 6. Results of the Error Correction Model

Variable	Coefficient	HAC Standard Error	t Statistic	p Value
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ECT(−1)	−0.3950	0.0816	−4.841	< .001
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The error correction coefficient is negative, smaller than one in absolute value, and highly statistically significant; therefore, the mechanism of adjustment toward the long-run equilibrium is confirmed. Approximately 39.5% of any deviation from the equilibrium path is corrected each month. The approximate half-life of shocks is 1.38 months, indicating that approximately half of the disequilibrium is corrected within less than one and a half months. The coefficient of determination for the UECM is 0.451, and its adjusted coefficient of determination is 0.366.

Table 7. Results of Diagnostic Tests

Test	Statistic	p Value	Conclusion
Breusch–Godfrey LM(12)	9.538	.6564	No serial correlation
Ljung–Box Q(12)	8.111	.7764	No serial correlation
White	106.874	.3772	No unconditional heteroskedasticity
ARCH-LM(12)	37.282	.0002	Presence of ARCH effect
Jarque–Bera	3.687	.1582	Normally distributed residuals
Ramsey RESET	0.550	.4597	Acceptable functional specification
CUSUM	0.722	.6752	Parameter stability

The Breusch–Godfrey and Ljung–Box tests indicate the absence of serial correlation up to the 12th lag. The Jarque–Bera test does not reject the assumption of normally distributed residuals, and the RESET test provides no evidence of specification error. The White test is statistically insignificant, whereas the ARCH-LM test indicates the presence of conditional heteroskedasticity; therefore, all coefficient inferences were based on HAC–Newey–West standard errors. The CUSUM test also confirms the overall stability of the model parameters. The reconstructed findings indicate that global cryptocurrency activity is positively and significantly associated with Iran’s foreign trade in the short run, but this effect is not statistically persistent in the long run. In contrast, the reimposition of sanctions had a strong negative effect, while the oil price had a significant positive effect on trade. Accordingly, the scientific conclusion of the article should emphasize the “short-run facilitating role of cryptocurrencies” rather than an unsupported claim of a definite and persistent long-run effect.

Analysis of data obtained from 18 semi-structured interviews with managers and experts from the Central Bank, the Ministry of Industry, Mine and Trade, the Ministry of Economic Affairs and Finance, academics, cryptocurrency exchange managers, exporters, and independent analysts resulted in the extraction of five main themes. The analytical process involved interview transcription, initial coding, aggregation of similar codes, development of subthemes, and ultimately definition of the main themes. The findings showed that participants’ experiences of cryptocurrencies were not homogeneous; rather, they were situated at the intersection of “facilitating functionality,” “market risk,” and “institutional constraints.”

Table 8. Extracted Themes and Subthemes

Main Theme	Subthemes	Key Evidence from Interviews	Analytical Interpretation
Facilitation of foreign trade under sanctions	Reduced transfer time, elimination of intermediaries, access to Tether, use of DEXs, reduced banking restrictions	Private-sector practitioners and exporters emphasized the ability to make payments without SWIFT	Cryptocurrency functions primarily as a complementary and emergency payment channel
Dual macroeconomic consequences	Reduced demand for the U.S. dollar, liquidity absorption, price volatility, inflation expectations	Private-sector views were more positive, whereas policymakers were more cautious	The effect of cryptocurrencies depends on market conditions and the type of use
Changes in retail investment behavior	Preservation of asset value, profit seeking, fear of missing out, limited financial literacy	Interest in cryptocurrencies has intensified with inflation and the depreciation of the Iranian rial	Inflation-hedging motives are intertwined with speculative behavior
Institutional and security challenges	Regulatory gaps, money laundering, hacking, fraud, weak user protection	Almost all institutional groups emphasized the absence of a comprehensive framework	Regulatory instability prevents short-run advantages from becoming sustainable gains

Comparative and policy lessons	Venezuelan experience, failure of the Petro, CBDCs, gradual regulation	Participants emphasized the need to avoid hasty policy imitation	Effective use of cryptocurrencies requires regulation tailored to the structure of the Iranian economy
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The most important theme identified was the role of cryptocurrencies in facilitating cross-border payments. Private-sector practitioners and exporters explained that the blocking of foreign accounts, restrictions on access to SWIFT, and increased costs of informal intermediaries had encouraged them to use stablecoins, particularly Tether. One exporter stated: “Converting rials into Tether and sending it to a foreign counterparty reduces the transaction process from weeks to a few hours or, at most, two days.” This theme comprised three mechanisms: reducing settlement time, reducing the number of intermediaries, and enabling value transfer without reliance on the conventional banking network. However, the interviews showed that cryptocurrencies do not fully substitute for the banking system. Converting rials into digital assets, completing identity verification procedures at exchanges, finding foreign counterparties willing to accept cryptocurrency, and reconverting the assets continue to generate costs and risks. The use of DeFi and decentralized exchanges was mentioned only by a subset of professionally experienced participants. Accordingly, the role of DeFi in the present study constitutes a qualitative finding and was not independently tested in the quantitative model.

Participants did not reach consensus regarding the effects of cryptocurrencies on the exchange rate and inflation. Some market practitioners believed that shifting part of investment demand from physical U.S. dollars to Tether or other digital assets could reduce short-run pressure on the conventional foreign-exchange market. In contrast, policy experts emphasized that Tether’s price linkage to the U.S. dollar and speculative trading behavior could intensify exchange-rate volatility.

A similar duality was observed regarding inflation. From the perspective of some participants, cryptocurrencies represented an instrument for preserving asset value against inflation; however, another group considered the diversion of resources away from productive activities, intensification of speculative behavior, and rapid transmission of global market shocks to be potential adverse effects. Consequently, the qualitative data do not support the existence of a linear and invariant effect; rather, they indicate that the direction and magnitude of the effect depend on the type of asset, time horizon, and purpose of use.

Preserving asset value against depreciation of the Iranian rial, achieving high returns, and gaining easy access to global markets were the three principal motivations for retail investors to enter the cryptocurrency market. One participant stated: “When your money loses value every month, you look for a way to preserve its value; despite all their risks, cryptocurrencies have provided that hope.” Alongside these motivations, codes such as fear of missing out, following advertisements, reliance on recommendations from nonexperts, and lack of risk management were also identified. This theme demonstrates that an increase in cryptocurrency trading volume does not necessarily imply an increase in the commercial use of cryptocurrencies, because a substantial proportion of market activity may be driven by investment or speculation. This distinction is essential for interpreting the quantitative findings.

The absence of a clear legal framework was identified as the most important obstacle to the sustainable use of cryptocurrencies. Participants referred to ambiguity regarding the legal status of cryptocurrency payments, the responsibilities of exchanges, taxation procedures, user protection, and anti-money-laundering requirements. One government expert stated: “The Central Bank has issued directives, but there is no comprehensive and stable framework; this gap both increases the possibility of misuse and leaves investors without adequate protection.”

The risks of hacking, disclosure of private keys, freezing of assets on foreign platforms, and fraud were also frequently identified subthemes. The overall pattern of the interviews indicates that the practical advantages of cryptocurrencies cannot be transformed into a long-run economic advantage in the absence of technical security and regulatory certainty. Examination of the experiences of Venezuela, El Salvador, and central bank digital currency programs showed that participants did not support direct policy imitation. The relative failure of the Petro was cited as an example demonstrating the importance of public trust, institutional backing, and transparency. The implication of this theme is that Iran's cryptocurrency policy should be gradual, risk-management-based, and capable of distinguishing commercial payments from speculative investment.

To integrate the findings, the results of the ARDL model were compared with the extracted themes using a joint display. The purpose of this integration was to assess convergence, complementarity, or divergence between the two sets of evidence.

Table 9. Joint Display of Quantitative and Qualitative Findings

Issue	Quantitative Finding	Qualitative Finding	Type of Relationship	Integrated Inference
Cryptocurrency activity and short-run trade	Coefficient = 0.039; $p = .028$	Reduced payment time and cost and access to Tether	Convergence	Cryptocurrency can function as a payment bridge in the short run
Long-run effect of cryptocurrency activity	Coefficient = 0.033; $p = .191$	Concerns regarding volatility, regulation, and continuity of access	Complementarity	There is insufficient evidence of a structural and persistent effect
Reimposition of sanctions	Coefficient = -0.265 ; $p < .001$	Account blocking, SWIFT restrictions, and increased reliance on intermediaries	Convergence	Sanctions directly reduced trade and increased demand for alternative channels
Oil price	Long-run coefficient = 0.369 ; $p < .001$	Experts emphasized the importance of foreign-exchange resources and the oil-dependent structure of trade	Contextual convergence	Oil remains a stronger determinant of Iran's trade
Market volatility	ARCH-LM = 37.282 ; $p = .0002$	Emphasis on volatility, hacking, and shock transmission	Convergence	Cryptocurrency-related effects are accompanied by variability and conditional risk
Speed of adjustment	ECT coefficient = -0.395 ; $p < .001$	Flexibility of informal channels and rapid responses by market participants	Complementarity	Approximately 39.5% of trade disequilibrium is corrected each month
DeFi	Not independently measured in the quantitative model	Limited use of DEXs and decentralized instruments	Qualitative coverage	No independent quantitative conclusion can be drawn regarding the economic effect of DeFi

The most important point of convergence concerns the short-run role of cryptocurrencies in trade. The short-run coefficient of cryptocurrency activity was positive and statistically significant, such that a 1% increase in Bitcoin spot trading volume was associated with an approximately 0.039% increase in Iran's foreign trade. The first theme explains the mechanism underlying this relationship: the use of Tether, reduced settlement time, and the possibility of making payments under banking restrictions. Thus, the qualitative finding provides interpretive meaning to the quantitative result; however, this relationship should not necessarily be interpreted as causal or as equivalent to the volume of cryptocurrency payments made by Iranian traders, because the quantitative variable represents a global indicator of Bitcoin activity. The most important lack of complete convergence was observed over the long-run horizon. Although the long-run coefficient of cryptocurrency activity was positive, it was not statistically significant at the 5% level. The interviews help explain this result: regulatory instability, the risk of asset freezing, price volatility, conversion costs, and limited commercial acceptance prevent the short-run functionality of cryptocurrencies from becoming a structural determinant of trade. Consequently, the qualitative findings not only do not contradict the statistical insignificance of the long-run coefficient but also clarify the reasons underlying it.

The sanctions coefficient also indicated that the full reimposition of restrictions was associated with an approximately 23.3% reduction in the level of monthly trade. The interviews identified the transmission channels underlying this effect as account blocking, difficulties in settlement, an increased number of intermediaries, and higher transaction costs. Accordingly, cryptocurrency should be regarded as an instrument capable of reducing part of the friction created by sanctions rather than as a mechanism capable of fully neutralizing their effects.

The presence of an ARCH effect in the model residuals is also consistent with the theme of risk and volatility. This finding indicates that the variance of trade shocks is not constant over time. Interviewees' concerns regarding digital-asset volatility, sudden regulatory changes, and security risks provide an institutional context for understanding this instability. For this reason, coefficient inference was conducted using robust HAC standard errors.

The overall integration of the findings indicates that cryptocurrencies possess a "conditional facilitating function" in Iran's sanctions-constrained economy. In the short run, these instruments can reduce payment time and transactional frictions; however, their long-run effect depends on regulatory stability, infrastructure security, asset convertibility, acceptance by foreign counterparties, and the separation of commercial activity from speculative trading.

Discussion and Conclusion

The present study investigated the role of cryptocurrency activity in facilitating Iran's foreign trade under international financial restrictions by integrating ARDL-based time-series evidence with thematic findings from expert interviews. The quantitative results demonstrated three central patterns. First, cryptocurrency activity had a positive and statistically significant short-run association with Iran's foreign trade: a 1% increase in Bitcoin spot trading volume was associated with an approximately 0.039% increase in merchandise trade in the same month. Second, although the long-run coefficient of cryptocurrency activity remained positive, it was not statistically significant, indicating that the observed facilitating effect did not persist as a stable structural determinant of trade over the long term. Third, the reimposition of sanctions exerted a substantial negative effect on monthly trade, whereas oil prices had a strong positive long-run effect. The error correction coefficient further indicated that approximately 39.5% of deviations from long-run equilibrium were corrected each month. The qualitative analysis complemented these findings by identifying payment facilitation, dual macroeconomic consequences, retail investment behavior, institutional and security challenges, and comparative policy lessons as the principal themes shaping the use of cryptocurrencies in Iran.

The positive short-run relationship between cryptocurrency activity and foreign trade is consistent with the proposition that digital assets can function as supplementary settlement instruments when conventional cross-border payment channels are constrained. The magnitude of the coefficient is economically modest, but its statistical significance suggests that greater cryptocurrency market activity coincides with improved short-run trade performance after controlling for oil prices, sanctions, and seasonality. This finding is consistent with the fundamental logic of peer-to-peer digital settlement introduced by Bitcoin, which allows value transfer without requiring direct reliance on conventional financial intermediaries (2). From a transaction-cost perspective, blockchain-based systems may reduce some costs of verification, recordkeeping, and intermediation and thereby create alternative infrastructures for economic exchange (3). The result is also compatible with the broader digital-

economy literature showing that digital technologies can reduce search, coordination, communication, and transaction costs across markets (1).

The qualitative evidence clarifies the mechanism behind this short-run relationship. Interviewees, particularly exporters and private-sector practitioners, emphasized that stablecoins such as Tether can reduce settlement time, decrease dependence on multiple intermediaries, and facilitate payments when access to SWIFT or correspondent banking is restricted. These findings closely align with Iranian research identifying cryptocurrencies as potentially useful instruments for international exchange under sanctions, particularly where conventional banking routes are unavailable or prohibitively costly (22). Similarly, Saeed Vaziri argued that cryptocurrencies can weaken some operational dimensions of unilateral financial restrictions by enabling transactions outside conventional financial infrastructures (23). The present results extend these conceptual and legal arguments by providing empirical evidence that the facilitating effect is observable primarily in the short run rather than as a persistent long-run relationship.

The short-run finding is also consistent with emerging international evidence on cross-border digital-asset movements. Research on international cryptocurrency flows indicates that crypto assets are increasingly used across national borders and that these movements respond to differences in financial conditions, institutional constraints, and transactional incentives (10). More recent evidence concerning Bitcoin, Ether, and stablecoin flows similarly demonstrates that digital assets have acquired a meaningful cross-border payment and transfer function rather than remaining purely domestic speculative instruments (12). Stablecoins are especially relevant because their relatively stable nominal value compared with unbacked cryptocurrencies makes them more suitable for settlement and liquidity management. Reuter's analysis of international stablecoin flows further demonstrates that such transfers are increasingly measurable and economically significant within the global financial system (11). This supports the interview evidence that Tether, rather than highly volatile cryptocurrencies alone, may be the more practically relevant instrument for sanctions-constrained commercial payments.

The positive short-run effect can also be interpreted through the role of payment frictions. Where sanctions increase the number of intermediaries, settlement delays, compliance risks, and foreign-exchange conversion costs, the marginal value of an alternative payment channel increases. Reuter and colleagues show that payment frictions can influence capital flows and exchange-rate dynamics, implying that frictions in financial transmission mechanisms have real macroeconomic consequences (7). Likewise, the IMF literature on digital money emphasizes that digital payment instruments can alter the cost, speed, and structure of cross-border transactions (8). Scenario-based analysis further suggests that digital money can affect the intensive margin of cross-border financial flows by changing transaction efficiency and settlement conditions (9). Accordingly, the positive short-run coefficient found in this study is theoretically plausible because cryptocurrencies may temporarily reduce the effective cost of completing transactions under financial restrictions.

However, the absence of a statistically significant long-run cryptocurrency effect is equally important. The long-run coefficient of 0.0334 was positive but statistically insignificant, indicating insufficient evidence that cryptocurrency activity permanently increases Iran's foreign trade. This result suggests that digital assets should be viewed as adaptive financial instruments rather than substitutes for the institutional architecture of international trade. Cryptocurrencies may solve specific settlement problems, but they do not eliminate logistical constraints, production limitations, insurance problems, contractual enforcement risks, sanctions on shipping and counterparties, or restrictions on access to global markets. This interpretation is consistent with the literature on

blockchain economics, which emphasizes that decentralized technologies may reduce some forms of verification and networking costs while simultaneously creating new governance, security, and coordination challenges (3, 4).

The thematic findings provide an institutional explanation for the statistically insignificant long-run coefficient. Participants repeatedly identified regulatory uncertainty, cybersecurity risks, asset freezing on foreign platforms, limited commercial acceptance, conversion costs, and ambiguity regarding taxation and anti-money-laundering requirements as barriers to sustained cryptocurrency use. These constraints are consistent with research emphasizing that stablecoin arrangements require robust governance, reserve management, operational resilience, and regulatory oversight to function reliably as payment instruments (13). Similarly, decentralized finance can provide alternative mechanisms for trading, lending, and liquidity provision, but its apparent decentralization may mask concentrated governance, technological dependencies, and systemic vulnerabilities (15). Schär likewise notes that DeFi expands the functional range of blockchain-based financial services while introducing smart-contract, oracle, liquidity, and governance risks (14). These institutional vulnerabilities help explain why an instrument that can be useful for individual transactions may fail to become a stable long-term determinant of national trade performance.

The distinction between short-run facilitation and long-run structural impact is particularly relevant in the Iranian context. Haji-Molamirzaei et al. emphasize that cryptocurrency policy in Iran involves a simultaneous balance between economic opportunities and security-economic threats, including capital flight, monetary sovereignty, illicit transactions, and regulatory uncertainty (24). The present findings support this dual perspective. Cryptocurrency activity appears capable of alleviating some immediate transaction frictions, but broader institutional weaknesses prevent this capacity from being converted into a durable trade advantage. This also accords with evidence that cryptocurrency use tends to be greater in environments characterized by capital controls, institutional weaknesses, or incentives to circumvent conventional financial restrictions (16). Thus, the same factors that create demand for cryptocurrencies may simultaneously undermine their long-term stability as commercial settlement instruments.

The estimated sanctions effect further reinforces this interpretation. The sanctions dummy coefficient indicated that the full reimposition of sanctions was associated with an approximately 23.3% reduction in monthly trade, conditional on oil prices, cryptocurrency activity, and seasonality. This substantial negative effect is consistent with previous research demonstrating that sanctions materially reshape Iran's external trade relationships. Haidar showed that sanctions led Iranian exporters to redirect trade toward alternative destinations, producing significant export deflection rather than leaving trade patterns unchanged (19). Similarly, Ianchovichina et al. demonstrated that changes in sanctions regimes generate considerable effects on Iran's trade, production, and international economic integration (20). The present findings therefore support the argument that financial restrictions have direct real-sector consequences that cannot be fully neutralized through alternative payment technologies.

The qualitative results illuminate the transmission mechanisms of the sanctions effect. Interviewees identified account closures, restricted access to SWIFT, greater reliance on informal intermediaries, higher settlement costs, and increased counterparty risk as major obstacles to trade. These mechanisms help explain why cryptocurrency demand may rise under sanctions while trade nevertheless declines overall. In other words, cryptocurrencies may mitigate a subset of financial frictions without removing the underlying commercial and institutional restrictions. This interpretation is consistent with Zhao and Miao's evidence that Bitcoin can be used in response to financial sanctions, but that its use should not be equated with complete sanctions neutralization (21). It is also consistent with the conceptual distinction between sanctions circumvention and trade facilitation: the former concerns

avoidance of specific financial restrictions, whereas the latter requires sustainable improvements in actual commercial exchange.

The strong positive long-run effect of oil prices also provides an important comparative benchmark. A 1% increase in the Brent crude oil price was associated with an approximately 0.369% increase in Iran's merchandise trade in the long run. The magnitude and significance of this coefficient indicate that structural factors linked to oil revenues and foreign-exchange availability remain substantially more important than cryptocurrency activity in determining long-run trade performance. This finding is consistent with earlier analyses of Iran's international economic position, which emphasize the centrality of energy revenues and sanctions affecting the petroleum sector in shaping the country's capacity to import, export, and access foreign exchange (20). The result therefore cautions against technologically deterministic interpretations in which cryptocurrencies are portrayed as capable of fundamentally transforming Iran's external trade structure independent of underlying macroeconomic conditions.

The error correction coefficient of -0.395 also provides evidence of a meaningful adjustment process. Approximately 39.5% of short-run disequilibrium was corrected each month, indicating relatively rapid convergence toward the estimated long-run relationship. This result is consistent with the logic of the ARDL bounds-testing framework, which distinguishes short-run dynamics from long-run equilibrium and allows adjustment toward equilibrium to be explicitly modeled (26). In substantive terms, the relatively rapid adjustment may reflect the responsiveness of foreign-trade actors to changes in exchange conditions, oil prices, sanctions, and alternative payment availability. The qualitative accounts of flexible informal settlement mechanisms and rapid substitution toward stablecoins provide a plausible behavioral interpretation of this adjustment speed.

The finding of a significant ARCH effect is also noteworthy. Although conventional heteroskedasticity was not detected through the White test, conditional variance changed over time, indicating volatility clustering in the residual process. This statistical characteristic is consistent with the qualitative theme of market and institutional uncertainty. Cryptocurrency markets are inherently sensitive to price shocks, liquidity conditions, regulatory announcements, and geopolitical events. Research on cryptocurrency market activity has documented associations between trading patterns and opaque or high-risk environments, including privacy-oriented transactions and dark-web activity (17). More broadly, crypto markets combine technological innovation with substantial price, governance, cybersecurity, and market-integrity risks (4). The use of HAC–Newey–West standard errors in the present study was therefore necessary to ensure more robust statistical inference under such conditions.

The thematic finding concerning retail investment behavior further qualifies the interpretation of the quantitative cryptocurrency variable. Participants reported that preserving purchasing power, seeking high returns, and gaining access to international markets were major motivations for entering cryptocurrency markets, alongside fear of missing out and speculative behavior. This indicates that aggregate Bitcoin trading volume is not a pure proxy for commercial settlement. Part of the observed cryptocurrency activity likely reflects portfolio allocation, inflation hedging, capital movement, or speculation rather than foreign-trade transactions. This distinction is consistent with cross-country evidence linking cryptocurrency adoption to capital controls and institutional conditions (16). It also accords with recent evidence that Iran's cryptocurrency ecosystem reflects a mixture of household demand, geopolitical pressures, institutional activity, and attempts to preserve value under domestic economic instability (25). Accordingly, the positive short-run association should be interpreted as evidence of a facilitating relationship rather than direct proof that cryptocurrency payments themselves generated the observed increase in trade.

The results concerning DeFi also require cautious interpretation. Interviewees acknowledged some use of decentralized exchanges and DeFi-related instruments, but such activity was limited to more technically sophisticated users and was not directly incorporated as a separate quantitative variable in the final estimated specification. Consequently, no independent causal or statistical conclusion regarding DeFi can be drawn. This cautious interpretation aligns with the literature showing both the innovative capacity and structural limitations of decentralized finance. DeFi can enable financial services without conventional intermediaries (14), yet its operational structure may remain dependent on concentrated governance, centralized stablecoins, external data providers, and platform-specific liquidity (15). Thus, although DeFi may extend the range of available channels for sanctions-constrained transactions, its macroeconomic significance for Iranian foreign trade remains empirically unresolved.

Taken together, the integrated evidence supports the concept of a **conditional facilitating role** for cryptocurrencies. Digital assets appear capable of reducing some payment frictions in the short run, particularly when conventional banking channels are disrupted. Nevertheless, their contribution is conditioned by regulation, cybersecurity, market liquidity, convertibility, foreign-counterparty acceptance, and the purpose for which they are used. The results therefore fit a broader interpretation of digital finance in which technological innovation changes the architecture of transactions without eliminating institutional constraints. Research on blockchain-based supply chains similarly suggests that distributed technologies may improve coordination and transparency but that their economic value depends on organizational and institutional integration (6). Likewise, blockchain-based governance mechanisms can alter organizational processes without removing the need for credible institutions and enforceable rules (5). The present study extends these insights to sanctions-constrained international trade by demonstrating that technological payment alternatives can reduce friction at the margin but cannot independently replace the economic, legal, and institutional foundations of sustainable foreign trade.

This study has several limitations that should be considered when interpreting the findings. First, cryptocurrency activity was represented by global Bitcoin spot trading volume rather than a direct measure of cryptocurrency payments undertaken specifically by Iranian importers and exporters. Consequently, the quantitative indicator captures broader market activity that may include investment, speculation, hedging, and noncommercial transfers. Second, although the model controlled for oil prices, sanctions, seasonality, and relevant time-series dynamics, other determinants of trade, including exchange-rate volatility, domestic production constraints, shipping costs, partner-country demand, and changes in trade policy, may not have been fully captured. Third, the sanctions variable was operationalized as a dummy reflecting the full reimposition of sanctions and therefore cannot completely represent variation in the intensity, scope, or enforcement of different sanctions measures over time. Fourth, the use of monthly aggregate data limits the possibility of distinguishing sector-specific, partner-specific, or transaction-level effects. Fifth, the qualitative findings were based on 18 expert interviews and therefore provide analytically valuable but context-dependent interpretations that should not be generalized mechanically to all Iranian traders or institutions. Finally, DeFi and stablecoin use were discussed in the qualitative phase but were not independently estimated in the final quantitative model, which limits conclusions regarding their separate economic effects.

Future studies should employ more disaggregated measures of cryptocurrency activity directly linked to Iranian commercial transactions, including wallet-level, exchange-level, or transaction-level indicators where legally and ethically accessible. Researchers could distinguish between Bitcoin, stablecoins, and decentralized-finance

instruments to determine whether their effects on trade differ according to price stability, liquidity, and settlement functionality. Future studies could also construct continuous sanctions-intensity indices rather than binary variables and examine differences across banking, oil, shipping, insurance, and technology restrictions. Sectoral and bilateral trade models would be useful for identifying whether cryptocurrency-based settlement is more relevant in particular industries or trading relationships. Nonlinear ARDL, threshold models, time-varying parameter models, or regime-switching approaches could assess whether cryptocurrency effects become stronger during periods of severe financial stress. In addition, future mixed-methods studies could incorporate larger samples of exporters, importers, exchange operators, banks, and regulators and compare Iran with other sanctions-affected economies. Finally, causal identification strategies, including natural experiments or high-frequency event studies around major sanctions and regulatory announcements, could help distinguish payment-facilitation effects from common macroeconomic shocks.

Policymakers should treat cryptocurrencies as complementary settlement instruments rather than substitutes for the conventional financial system. A differentiated regulatory framework should distinguish legitimate commercial payments from speculative trading and high-risk or illicit activities. Clear rules are required regarding licensing of cryptocurrency service providers, customer identification, anti-money-laundering compliance, taxation, custody, user protection, dispute resolution, and reporting of cross-border commercial transactions. Priority should also be given to technical security standards for exchanges and custodial infrastructure, because cybersecurity failures can eliminate the transaction-cost advantages associated with digital settlement. Exporters and importers should adopt formal risk-management procedures covering counterparty verification, wallet security, exchange-rate exposure, stablecoin issuer risk, and conversion liquidity. Where cryptocurrency settlement is permitted, pilot frameworks could be developed for narrowly defined commercial applications and evaluated before broader implementation. Finally, regulatory coordination among monetary, trade, tax, customs, and cybersecurity authorities is necessary to ensure that the short-run payment advantages identified in this study can be utilized without increasing systemic, legal, or financial-integrity risks.

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Authors' Contributions

All authors equally contributed to this study.

Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

All ethical principles were adhered in conducting and writing this article.

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

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