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Stablecoins, Risk Transmission and Systemic Reconfiguration in a Fragmented USD Access System: Evidence from Quantile Time-Frequency Analysis

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Abstract

In high-inflation economies, stablecoins are increasingly becoming infrastructural channels through which households and firms access U.S.-dollar value outside traditional financial arrangements. We study Argentina as a fragmented USD access system composed of a regulated official channel, an informal parallel channel (the Blue Dollar), and platform-based USDT channels on Binance and Bitso. Using a quantile time-frequency connectedness framework, we estimate reduced-form dynamic dependence and spillover patterns across these interdependent subsystems under normal and extreme market states and across short- and long-term horizons. Four main findings emerge. First, system-wide connectedness is dominated by short-term transmission and rises sharply during policy regime transitions, particularly around the relaxation of capital controls. Second, under normal conditions, stablecoin markets behave as early-moving net spillover transmitters, whereas the Blue Dollar and the official rate primarily absorb shocks. Third, connectedness exhibits a symmetric U-shaped pattern across quantiles, indicating that tail events intensify cross-channel dependence regardless of shock direction. Fourth, under upper-tail extreme market states, the official rate becomes a net transmitter in the long-term frequency band, implying that major devaluation episodes can temporarily reconfigure the system's transmission architecture, even though stablecoin channels remain important in overall connectedness. These findings should be interpreted as evidence of dynamic dependence rather than structural causality. They suggest that digital dollarization does not simply add another trading venue; it increases boundary permeability, reshapes information hierarchy, and changes the monitoring problem faced by authorities in fragmented financial systems.

Keywords: systemic connectedness; dynamic dependence; financial resilience; quantile connectedness; stablecoins; USD access system; digital dollarization

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1. Introduction

The rapid expansion of cryptocurrency adoption has intensified the complexity of modern financial systems. This expansion is economically significant: Latin America received nearly USD 415 billion in cryptocurrency value between July 2023 and June 2024, with year-over-year growth of approximately 42.5%, and Argentina alone received an estimated USD 91.1 billion [1]. New financial instruments and digital trading platforms have widened access to capital and improved the speed of financial intermediation, but they have also deepened interdependence across markets and increased the potential for rapid shock transmission. Stablecoins illustrate this duality particularly clearly. By combining the transactional flexibility of digital assets with price anchoring to the U.S. dollar, stablecoins now serve not only as crypto-market instruments but also as alternative channels for liquidity management, wealth preservation, and cross-market arbitrage in inflationary and financially constrained environments [2–4].

These dynamics are especially salient in high-inflation emerging market economies (EMEs). In such settings, households and firms often seek protection from domestic currency instability through unofficial dollarization and parallel-market finance [5,6]. Stablecoins add a new, digitally mediated layer to this process. Their platform-based, continuously traded architecture can reduce frictions in access to dollar-linked value, but it can also intensify dynamic dependence across formal and informal segments of the financial system. From a systems perspective, stablecoins therefore matter not only because they affect one specific market but because they alter the organization, coupling structure, and resilience of broader financial arrangements under stress [7–10].

These concerns are particularly acute for EMEs. In recent years, crypto assets have introduced an additional dimension to capital flight, a phenomenon termed "cryptoization" that involves the adoption of cryptocurrencies in hyperinflationary environments [11]. Contemporary evidence underscores this trend: approximately one-third of Latin American households have utilized stablecoins for retail payments.[1] The Bank for International Settlements (BIS) cautions that this "digital dollarization" may reinforce unofficial dollarization dynamics and increase financial stability risks [9,12]. Argentina offers a particularly informative setting because residents do not access USD through a single market. Instead, they navigate a fragmented USD access system composed of a regulated official channel, an informal parallel channel, and platform-based stablecoin channels. These channels serve overlapping functions of payment, hedging, wealth preservation, and arbitrage, yet they differ sharply in governance, transparency, trading frictions, and exposure to policy intervention. The Argentine case therefore provides a natural setting for examining how financial innovation, policy discontinuities, and digital infrastructures jointly reshape systemic connectedness.

Against this background, this paper asks three questions. First, what functional role do stablecoin channels play within a fragmented and interconnected financial system in a high-inflation economy? Second, how does the coupling structure among official, parallel, and digital-dollar channels vary across short-term and long-term horizons and across normal versus stressed market states? Third, how do policy regime transitions, especially the relaxation of capital controls, reconfigure information flows, subsystem roles, and the resilience of the overall system? Addressing these questions requires moving beyond a narrow market-by-market perspective toward a system-level analysis of contagion, hierarchy, and resilience.

To answer these questions, we employ a quantile time-frequency connectedness framework that enables us to trace spillovers simultaneously across market states, time horizons, and dynamic evolution [13–15]. This paper contributes to the literature in four ways. First, it provides an integrated empirical analysis of Argentina's official rate, Blue Dollar, and ARS-denominated USDT channels within a single system-level framework, treating them as interdependent subsystems rather than isolated markets. Second, it shows how quantile and frequency decompositions can identify not only spillover intensity but also the changing architecture of dynamic dependence across normal and extreme market conditions. Third, it documents that stablecoin platforms behave as early-moving net spillover transmitters whose role remains robust across market states, while the official rate becomes a long-run transmitter only under upper-tail extreme market states, indicating that major devaluation episodes can temporarily reconfigure the system's transmission structure. Fourth, it offers a data-driven approach for monitoring interconnected vulnerabilities in fragmented financial systems, while explicitly treating connectedness as a reduced-form measure rather than proof of structural causality.

The remainder of the paper is organized as follows. Section 2 reviews the related literature and develops the paper's systems and systemic-risk framing. Section 3 presents the institutional background and the architecture of Argentina's USD access system. Section 4 describes the data and preliminary evidence. Section 5 introduces the methodology. Section 6 reports the empirical results, discusses systemic vulnerabilities and resilience, and presents robustness checks. Finally, Section 7 concludes the paper.

2. Related Literature, Systemic Risk, and Systems Framing

This section reviews three primary strands of literature relevant to our study: the evolving role of stablecoins in financial systems and their implications for financial stability, the empirical analysis of connectedness and spillover effects within and across cryptocurrency markets, and recent research on financial network reconfiguration and structural evolution. It then develops the article's systems and connectedness-based framing.

The first strand of literature extensively investigates the growing adoption of stablecoins as a potential substitute for fiat currency and the associated challenges to financial stability. Researchers observe that as fiat-collateralized stablecoins gain traction, economic agents increasingly prefer assets like USDT for transactions, remittances, and investments over local fiat currencies [16,17]. This currency substitution trend poses a threat to monetary sovereignty by potentially diminishing the local currency's role in both international trade and domestic circulation [12,18,19]. Such dynamics are particularly pronounced in high-inflation economies, where stablecoins offer a critical hedge against purchasing power erosion. Historical accounts document that residents in EMEs traditionally sought unofficial dollarization through foreign cash or offshore deposits during crises [6,20,21]. The advent of digital assets has extended this behavior, leading to cryptoization [11,17,19,22], where traditional foreign exchange is increasingly replaced by crypto assets for wealth preservation [23]. Furthermore, the decentralized and pseudo-anonymous nature often associated with stablecoins can complicate regulatory oversight, potentially facilitating capital flight and regulatory arbitrage in jurisdictions with stringent capital controls [24,25]. This informal circulation may weaken monetary policy transmission as financial disintermediation occurs, shifting balance sheets from traditional bank deposits to stablecoin issuers and thus affecting the central bank's capacity to manage liquidity and interest rates [26–29]. Despite these discussions on digital dollarization and its potential implications, the literature remains sparse in providing granular empirical evidence on how these substitution and destabilization dynamics manifest within specific EME foreign exchange markets under varying conditions.

The second strand of literature employs quantitative frameworks to analyze connectedness and spillover effects involving digital assets. A substantial body of work has concentrated on internal linkages within cryptocurrency markets and their interdependencies with traditional financial markets [30–36]. However, much of this research predominantly views cryptocurrencies as global investment assets, often focusing on the interplay between major crypto assets like Bitcoin and broader financial markets. Consequently, there is a notable absence of studies that specifically examine the dynamic connectedness between stablecoin markets and distinct foreign exchange mechanisms prevalent in EMEs. Crucially, the interaction and spillover effects between fiat-collateralized stablecoins, such as USDT, and specific parallel-market exchange rates like the Blue Dollar remain largely unexplored.

The third strand examines financial systems as evolving networks whose topology can be reconfigured by crises, policy shocks, and other rare events. Network-based studies show that market stress can alter centrality, clustering, and the relative importance of nodes, meaning that the system's structure is itself an object of empirical interest rather than a fixed background condition [14,37]. Recent work by Siudak and Swietlik [38], for example, combines complex-network tools with self-organizing maps to show that Black Swan events such as COVID-19 and the Russia–Ukraine war materially reconfigure stock-return correlation networks. This literature is directly relevant to our setting because Argentina's USD access system is also a multi-node financial network exposed to policy discontinuities. Our contribution is to extend this reconfiguration perspective from equity-market correlation networks to a fragmented foreign-exchange and stablecoin system, using quantile and frequency decompositions to show when, and over what horizons, reconfiguration is most pronounced.

Taken together, the existing literature provides important insights into stablecoin adoption, financial connectedness, and network reconfiguration, but it remains underdeveloped in three respects that are central to the study of complex financial systems. First, it insufficiently theorizes how official, informal, and digital-dollar channels jointly constitute an interconnected financial system rather than a collection of separate markets. Second, it offers limited evidence on how policy shocks alter the architecture of dynamic dependence, segmentation, and reintegration across such channels. Third, it has not yet developed sufficiently granular empirical tools for identifying connectedness-based vulnerabilities under different states of market stress. In settings such as Argentina, stablecoins should therefore be understood not only as alternative instruments of currency substitution but also as nodes within a broader socio-technical financial system whose resilience depends on the interaction of households, firms, platforms, intermediaries, and policy boundaries.

3. Institutional Background and the Architecture of the Fragmented USD Access System

3.1. Evolution of Argentina's Foreign Exchange Policies

Argentina's foreign exchange policies have shifted markedly in recent years, with important implications for exchange rate formation and cross market dynamics. For exposition, we summarize these developments in two broad stages: (i) a period dominated by foreign exchange controls and (ii) a transition toward a managed float accompanied by liberalization.

Stage 1: Foreign exchange controls. Beginning on 1 September 2019, the Argentine government imposed stringent foreign exchange controls under *Official Gazette Decree 609/2019*.[2] The Central Bank of Argentina (BCRA) subsequently reinforced these restrictions through *Communiqué A 6770*,[3] tightening access to USD and contributing to a persistent divergence between the official rate and the parallel market rate (the "peso gap").[4] Within this control-heavy environment, a major adjustment took place on 13 December 2023, when the government implemented a sharp devaluation, setting the official rate at 800 pesos per dollar (a depreciation of more than 50%).[5] A crawling peg arrangement was introduced thereafter, implying a pre-announced monthly devaluation rate of 2% for the peso.[6]

Stage 2: Managed float and liberalization. On 14 April 2025, Argentina began dismantling key elements of the currency controls ("cepo cambiario"),[7] easing access to foreign currency for households and firms. Following an IMF agreement, the exchange-rate regime moved toward a managed float within a band of 1000–1400 pesos per dollar, with the band limits expanding at a monthly rate of 1%.[8]

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3.2. The Architecture of Argentina's USD Access System

In systems terms, Argentina's USD access system comprises three interdependent subsystems. The official market is a rule-bound channel administered through formal regulation and recurrent capital controls. The Blue Dollar market is an informal subsystem that expands when households and firms face binding constraints in official channels.[9] Stablecoin trading on centralized exchanges constitutes a digital subsystem that provides platform-based, continuously available access to USD-pegged value [39]. These subsystems are linked by common user demands for hedging, wealth preservation, payments, and arbitrage, but they differ in institutional legitimacy, trading frictions, transparency, and regulatory visibility. The Argentine case is therefore well suited to examining how policy shocks and digital innovation reshape the coupling structure of a fragmented foreign exchange system.

To gauge the scale of stablecoin activity, Table 1 reports descriptive statistics for daily trading volumes (in million ARS) of USDT/ARS and USDC/ARS across major centralized exchanges. The figures indicate sizable and persistent trading, concentrated predominantly in USDT and largely facilitated by major centralized exchanges such as Binance and Bitso. The sharp concentration in USDT is substantively important for interpretation: our price-based connectedness system uses the two most liquid USDT/ARS venues as separate platform nodes rather than aggregating all stablecoins into a single synthetic index. This avoids mixing assets with very different trading depth and data availability, but it also means that our conclusions are strongest for the dominant USDT channel and should not be read as equally representative of thinner USDC or minor stablecoin markets.

Table 1. Daily trading volume of stablecoin trading pairs against ARS by ticker and exchange (in million ARS).

Category	Ticker/Exchange	Obs	Mean	SD	Min	Max
Panel A: Daily trading volumes by Ticker						
	USDT	1595	1354.75	1392.09	0.01	9404.47
	USDC	292	0.28	0.75	0.00	9.34
Panel B: Daily trading volumes by Exchange						
	Binance	2130	517.33	774.39	0.18	6078.07
	Bitso	6653	253.28	778.21	0.00	9404.47
	Bitex.la	179	15.57	77.33	0.03	1035.11
	Buda	2285	0.20	0.40	0.00	9.34
	C-Patex	4	0.00	0.00	0.00	0.00
	CryptoMKT	2015	7.88	10.20	0.00	106.21

Notes: Data are obtained from CoinAPI. Obs denotes the number of exchange-pair-day observations. Mean, SD, Min, and Max are daily trading volumes measured in million ARS. The sample covers USDT/ARS and USDC/ARS spot transactions executed on major centralized exchanges, spanning the period from 1 January 2021 through 30 June 2025.

4. Data Description and Preliminary Analysis

This paper investigates the quantile time-frequency spillovers among Argentina's USD markets: the official exchange rate, the parallel (blue dollar) market, and the stablecoin market. We choose the official exchange rate series, denoted as USD/ARS (Official), as a proxy for the official foreign exchange market, and the informal "blue dollar" price series, USD/ARS (Blue), as a proxy for the parallel market. The data for both series are obtained from Investing.com,[10] a platform providing a wide array of financial market data. For the stablecoin market, we utilize the daily closing spot prices of the USDT/ARS trading pairs from two major exchanges, denoted as USDT/ARS (Binance) and USDT/ARS (Bitso). The selection of these specific pairs is grounded in two key considerations. First, Binance is the largest cryptocurrency exchange globally, while Bitso is the largest exchange in Latin America. Second, Table 1 reveals that the average daily trading volume of these two pairs collectively accounts for over 97% of the total turnover among all stablecoin/ARS trading pairs across centralized exchanges. This overwhelming market share underscores their representativeness in capturing Argentina's dominant stablecoin-dollar channel.

We do not aggregate USDT/ARS with USDC/ARS or other stablecoin pairs in the return connectedness model. USDC/ARS activity is sparse in our CoinAPI records and has substantially lower average turnover than USDT/ARS, which would make an aggregated stablecoin price series sensitive to missing observations, stale prices, and exchange-specific liquidity gaps. Treating Binance USDT/ARS and Bitso USDT/ARS as separate nodes also allows us to preserve platform fragmentation: both pairs reference the same dollar-pegged token, but they trade on venues with different client bases, fee schedules, liquidity conditions, and operating infrastructures. Because stablecoin markets trade continuously while the official and blue-dollar indicators are observed as daily closing series, we use daily frequency to align all channels on a common calendar. This choice sacrifices intraday price-discovery information but avoids imposing an artificial high-frequency structure on the official and informal series. We employ daily data covering the period from 28 April 2023 to 25 November 2025. The sample period is primarily determined by data availability, with the specific start date dictated by the official launch of the USDT/ARS trading pair on the Binance exchange.[11] Table 2 provides detailed definitions and sources for all variables.

Table 2. Definition of Variables.

Market Type	Variable Name	Description of Variables	Source
Official Market	USD/ARS (Official)	Daily official closing exchange rate of the Argentine peso against the US Dollar.	Investing.com
Informal Market	USD/ARS (Blue)	Daily closing exchange rate of the informal "Blue Dollar" parallel market.	Investing.com
Stablecoin Market	USDT/ARS (Binance)	Daily closing price of the USDT (Tether) to ARS trading pair on the Binance exchange.	Binance
	USDT/ARS (Bitso)	Daily closing price of the USDT (Tether) to ARS trading pair on the Bitso exchange.	Bitso

Notes: The dataset covers the period from 28 April 2023 to 25 November 2025. Price variables are measured as ARS per USD or USDT. The starting date corresponds to the official launch of the USDT/ARS spot trading pair on the Binance exchange.

As illustrated in Figure 1, all USD/ARS price series exhibit a persistent upward trend throughout the sample period, reflecting the continuous depreciation of the Argentine peso. Notably, at the beginning of the sample, a substantial price gap is observed between the official exchange rate and the three market-determined rates, a direct consequence of Argentina's stringent capital controls (cepo cambiario) that artificially suppressed the official rate well below its market-clearing level. The December 2023 devaluation sharply narrowed this gap by realigning the official rate upward. Subsequently, following the formal dismantlement of the cepo cambiario in April 2025, the four price series exhibit a clear tendency toward mutual convergence, as the newly liberalized official rate rises while the parallel and stablecoin premiums diminish.

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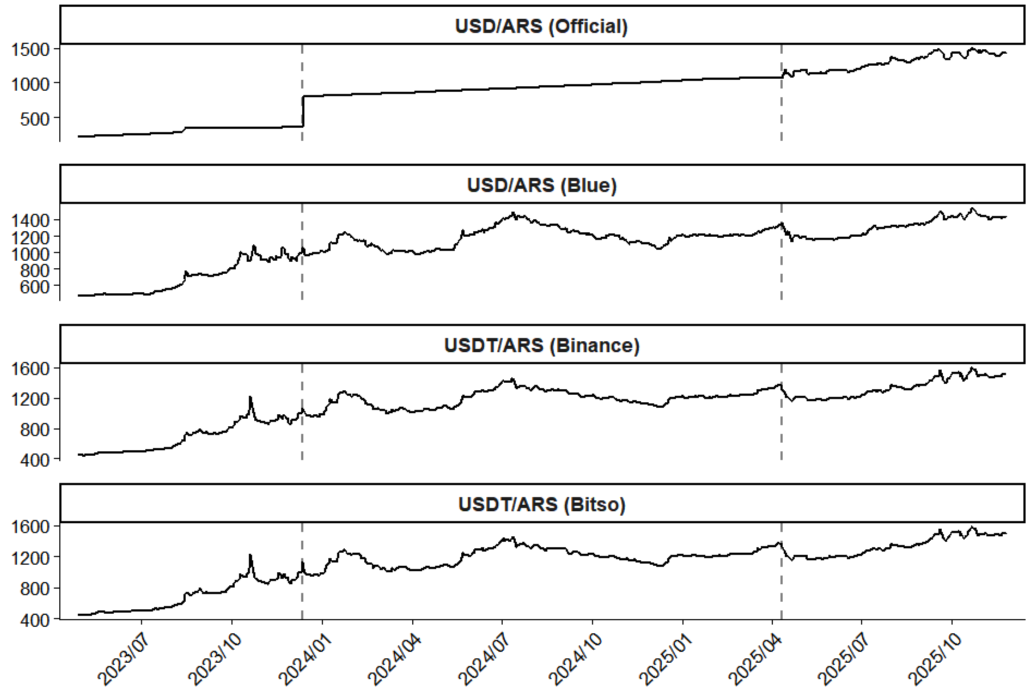

Figure 1. Time series plots of prices. *Notes:* The figure displays the daily price series for each of the four USD/ARS markets over the sample period. The two vertical dashed lines demarcate key structural events. The first dashed line (13 December 2023) marks the Argentine government's sharp devaluation of the official exchange rate by over 50%. The second dashed line (14 April 2025) marks the dismantlement of Argentina's longstanding currency controls (cepo cambiario).

Figure 2 plots the daily return series, computed as the log-difference of the price series multiplied by 100 ($r_t = 100 \times (\ln P_t - \ln P_{t-1})$), where positive values indicate ARS depreciation. We find that all series exhibit pronounced volatility clustering and experience dramatic fluctuations around key policy interventions. Specifically, the official market displays an isolated, extreme positive spike exceeding 80 percentage points, corresponding to the government's sharp devaluation in December 2023. Interestingly, the blue dollar and stablecoin markets exhibit notable negative spikes around the same event, as the abrupt realignment of the official rate compressed the parallel market premium and led to a temporary appreciation of the peso in these market-determined channels. More broadly, these three market-determined series display more continuous, high-frequency volatility that reacts intensely to both the initial devaluation and the subsequent market liberalization in April 2025.

Table 3 reports the descriptive statistics for the daily return series of all four markets. All series exhibit positive mean returns, confirming the persistent depreciation of the Argentine peso over the sample period. The official exchange rate records the highest mean return (0.2798) and the largest standard deviation (3.2236), primarily driven by the government's abrupt devaluation of the official rate by over 50% in December 2023. In contrast, the three market-determined rates display comparable levels of volatility, with standard deviations ranging from 1.95 to 2.10 percentage points, suggesting that the informal and stablecoin markets share similar risk profiles. Notably, the official rate exhibits extraordinarily high positive skewness (21.4018) and kurtosis (510.3473), reflecting the extreme one-sided tail risk associated with discrete policy-driven devaluations. The blue dollar also displays positive skewness (1.2835), though at a considerably more moderate level, while the two stablecoin series exhibit slight negative skewness, implying a marginally higher propensity for sharp peso appreciations in these markets. The Jarque-Bera test decisively rejects the null hypothesis of normality for all series at the 1% significance level, confirming the presence of sharp peaks, fat tails, and non-Gaussian behavior. This evidence of pronounced non-normality underscores the importance of examining tail dynamics and extreme quantiles, which motivates our adoption of a quantile-based spillover framework. Finally, both the ADF and PP unit root tests reject the null hypothesis of a unit root for all return series at the 1% level, confirming that all series are stationary and suitable for subsequent econometric analysis.

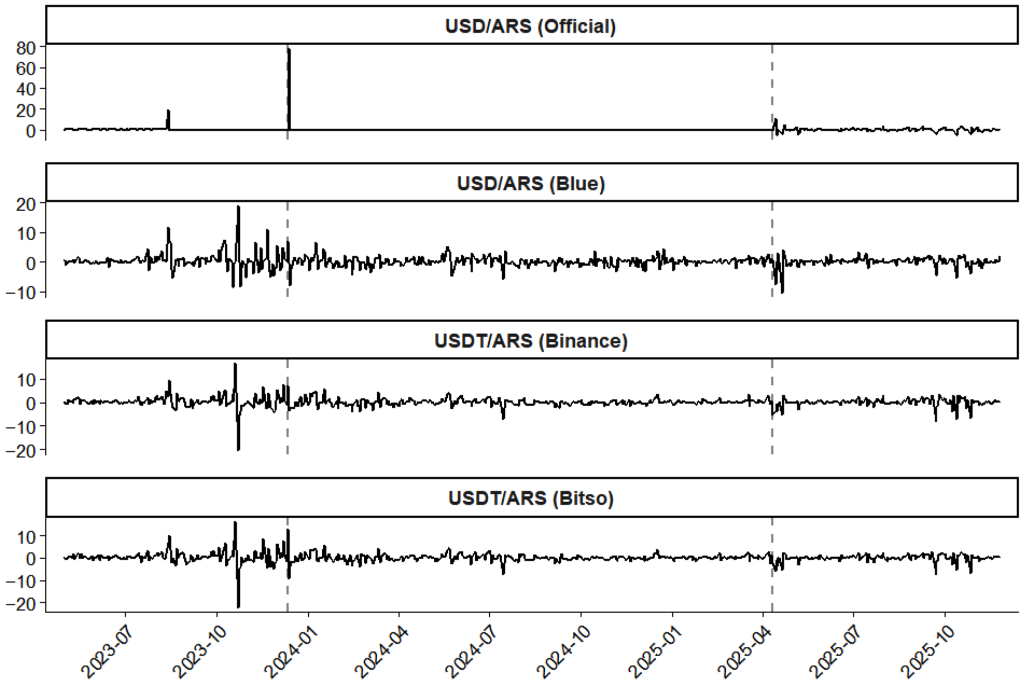

Figure 2. Time series plots of returns. *Notes:* The figure displays the daily return series for each of the four USD/ARS markets over the sample period. The two vertical dashed lines demarcate key structural events. The first dashed line (13 December 2023) marks the Argentine government's sharp devaluation of the official exchange rate by over 50%. The second dashed line (14 April 2025) marks the dismantlement of Argentina's longstanding currency controls (cepo cambiario).

Table 3. Descriptive statistics.

	USD/ARS (Official)	USD/ARS (Blue)	USDT/ARS (Binance)	USDT/ARS (Bitso)
Mean	0.2798	0.1695	0.1831	0.1822
Median	0.0616	0	0.1245	0.0881
Std. Dev	3.2236	2.0238	1.9538	2.0962
Skewness	21.4018	1.2835	−0.7766	−0.7535
Kurtosis	510.3473	19.3655	30.872	32.3353
Jarque-Bera	7,226,130.9988 ***	7649.4377 ***	21,721.9134 ***	24,051.4367 ***
ADF	−25.7249 ***	−22.7246 ***	−23.6316 ***	−24.705 ***
PP	−25.681 ***	−22.4762 ***	−23.5228 ***	−24.6056 ***

Notes: Returns are computed as $100 \times \Delta \ln(P_t)$ and are therefore measured in percentage points. Std. Dev. represents the standard deviation; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Figure 3 presents the Pearson correlation coefficient matrix for the four return series. The most striking result is the exceptionally strong positive correlation between USDT/ARS (Binance) and USDT/ARS (Bitso) (0.943, $p < 0.01$), indicating that the two stablecoin markets move almost in lockstep. This is intuitive, as both pairs reflect the price of the same stablecoin (USDT) denominated in Argentine pesos, and arbitrage activity across centralized exchanges naturally enforces price convergence. The blue dollar market exhibits moderate and statistically significant positive correlations with both stablecoin markets (0.314 and 0.316, respectively, $p < 0.01$), suggesting meaningful return co-movement between the informal foreign exchange market and the cryptocurrency-based parallel market. This linkage likely arises because both channels serve as alternative vehicles for Argentine residents seeking to circumvent capital controls and hedge against peso depreciation. In contrast, the official exchange rate shows negligible correlations with the other three markets: its correlation with USD/ARS (Blue) is only 0.077 ($p < 0.10$), that with USDT/ARS (Binance) is a statistically insignificant 0.006, and that with USDT/ARS (Bitso) is -0.082 ($p < 0.10$).

This near-zero correlation reflects the administered and tightly managed nature of the official rate, which is largely insulated from the market forces that drive the informal and stablecoin segments, thus highlighting a clear segmentation between the official market and the remaining three market-driven rates, while simultaneously underscoring the close integration among the latter.

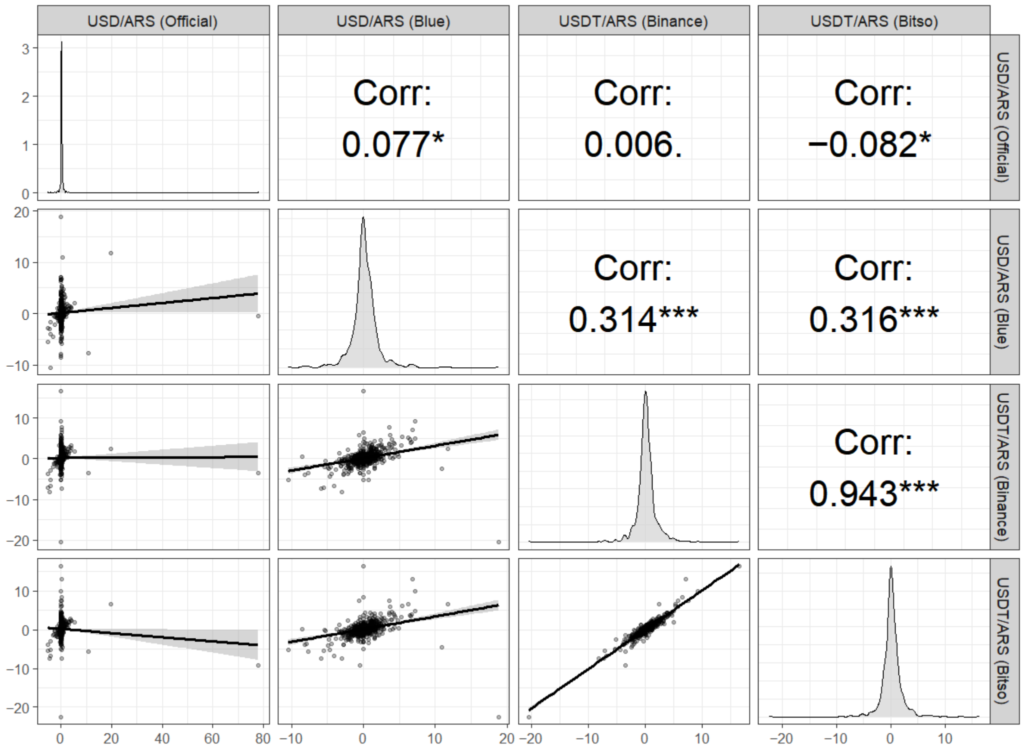

Figure 3. Correlation coefficient matrix. *Notes:* The lower part of the figure is the scatter plot of each pair of variables. The upper part is the correlation coefficient. The coefficients vary from -1 to $+1$. Values near $+1$ or -1 indicate a significant link, while values near 0 indicate a weak or non-existent correlation. A positive correlation suggests that when one currency's value increases, so does the value of the other. Distributions are presented on the diagonal using gray plots. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

5. Methodology

In the present study, each exchange-rate channel is treated as a subsystem within a broader and interconnected USD access system. Directional spillovers capture directed interdependencies among subsystems, net connectedness identifies whether a subsystem predominantly transmits or absorbs shocks, and the total connectedness index summarizes the degree of system-wide coupling. The quantile dimension represents different system states ranging from normal conditions to tail-risk episodes, whereas frequency decomposition distinguishes short-term adjustment from long-term structural transmission. Rolling estimation then allows us to examine how policy shocks alter the architecture of contagion and the resilience of the overall system over time. This mapping enables the econometric framework to speak directly to systems questions concerning structural vulnerability, adaptive reconfiguration, and the monitoring of systemic instability.

This study employs the quantile frequency connectedness framework developed by Chatziantoniou et al. [15], which combines the frequency-domain connectedness methodology of Baruník and Křehlík [14] with the quantile-based connectedness approach of Chatziantoniou et al. [40]. By conditioning on both quantiles and frequencies, this framework enables us to examine spillover dynamics among Argentina's official exchange rate, the parallel (blue-dollar) market, and the stablecoin market under different market conditions and across different time horizons.

5.1. Quantile Vector Autoregressive Model

The starting point of our analysis is a quantile vector autoregressive (QVAR) model of order p. Let $\boldsymbol{y}_t$ denote an $N \times 1$ vector of endogenous variables, which in our case consists of the returns of the official exchange rate, the blue-dollar rate, and the stablecoin rate. The QVAR (p) model is specified as

$$\boldsymbol{y}_t = \boldsymbol{\mu}(\tau) + \boldsymbol{\Phi}_1(\tau)\boldsymbol{y}_{t-1} + \boldsymbol{\Phi}_2(\tau)\boldsymbol{y}_{t-2} + \cdots + \boldsymbol{\Phi}_p(\tau)\boldsymbol{y}_{t-p} + \boldsymbol{\varepsilon}_t(\tau), \quad (1)$$

where $\tau \in (0,1)$ indexes the quantile of the conditional distribution under consideration, $\boldsymbol{\mu}(\tau)$ is an $N \times 1$ vector of quantile-dependent intercepts, $\boldsymbol{\Phi}_k(\tau)$ ($k = 1, \ldots, p$) are $N \times N$ coefficient matrices that vary with the quantile level, and $\boldsymbol{\varepsilon}_t(\tau)$ is an $N \times 1$ error vector with a variance–covariance matrix $\boldsymbol{\Sigma}(\tau)$. The quantile-dependent parameterization is crucial in our context, as it permits the spillover structure among Argentina's exchange rate segments to differ between normal market states around the median quantile and extreme market states in the lower and upper tails of the conditional distribution.

5.2. Frequency Response and Spectral Representation

To transition from the time domain to the frequency domain, we express the QVAR model in its quantile vector moving-average, QVMA (∞), representation and define the associated frequency response function:

$$\boldsymbol{B}(e^{-i\omega}) = \sum_{h=0}^{\infty} \boldsymbol{B}_h\, e^{-i\omega h}, \quad i = \sqrt{-1}, \quad (2)$$

where $\omega \in (-\pi, \pi)$ denotes the frequency and $\boldsymbol{B}_h$ are the moving-average coefficient matrices obtained through recursive substitution of the QVAR lag polynomials. The spectral density matrix of $\boldsymbol{y}_t$ at frequency ω is then

$$\boldsymbol{S}_y(\omega) = \sum_{h=-\infty}^{\infty} E(\boldsymbol{y}_t\boldsymbol{y}'_{t-h})e^{-i\omega h} = \boldsymbol{B}(e^{-i\omega})\,\boldsymbol{\Sigma}(\tau)\,\boldsymbol{B}'(e^{+i\omega}), \quad (3)$$

where $\boldsymbol{S}_y(\omega)$ captures the distribution of variance across frequencies, $\boldsymbol{\Sigma}(\tau)$ denotes the quantile-specific variance–covariance matrix of the QVAR innovations, and the autocovariance sequence admits the inverse Fourier representation $E(\boldsymbol{y}_t\boldsymbol{y}'_{t-h}) = \int_{-\pi}^{\pi} \boldsymbol{S}_y(\omega)\, e^{i\omega h}\, d\omega$. Thus, $\boldsymbol{\Sigma}(\tau)$ is a covariance matrix rather than a summation operator; summation is denoted by $\sum$ throughout.

5.3. Quantile Frequency Generalized FEVD

We next construct a quantile- and frequency-specific generalized forecast error variance decomposition (GFEVD). The unnormalized contribution of a shock originating from variable j to the forecast error variance of variable i at frequency ω and quantile τ is defined as

$$\theta_{ij,\tau}(\omega) = \frac{(\boldsymbol{\Sigma}(\tau))_{jj}^{-1} \left| \sum_{h=0}^{\infty} \Big(\boldsymbol{B}(\tau)(e^{-i\omega h})\, \boldsymbol{\Sigma}(\tau) \Big)_{ij} \right|^2}{\sum_{h=0}^{\infty} \big(\boldsymbol{B}(e^{-i\omega h})\, \boldsymbol{\Sigma}(\tau)\, \boldsymbol{B}(\tau)(e^{-i\omega h}) \big)_{ii}}. \tag{4}$$

Because the rows of the generalized variance decomposition need not sum to unity, we normalize each entry to obtain

$$\widetilde{\theta}_{ij,\tau}(\omega) = \frac{\theta_{ij,\tau}(\omega)}{\sum_{j=1}^{N} \theta_{ij,\tau}(\omega)}. \tag{5}$$

The quantity $\widetilde{\theta}_{ij,\tau}(\omega)$ can be interpreted as the proportion of the spectrum of variable i, at frequency ω and quantile τ, that is attributable to innovations in variable j.

5.4. Frequency Band Aggregation

A key advantage of operating in the frequency domain is the ability to isolate connectedness over distinct investment horizons. We partition the frequency axis into bands $d = (s, l)$, where $s, l \in (-\pi, \pi)$ and $s < l$, and aggregate the normalized GFEVD over each band:

$$\widetilde{\theta}_{ij,\tau}(d) = \int_{s}^{l} \widetilde{\theta}_{ij,\tau}(\omega)\, d\omega. \tag{6}$$

In our empirical application, we consider two frequency bands corresponding to short-term (high-frequency) and long-term (low-frequency) horizons, enabling us to separately examine transitory and persistent spillover channels among Argentina's segmented foreign exchange markets.

5.5. Connectedness Measures

Building on the frequency-band-specific GFEVD, we define a comprehensive suite of quantile frequency connectedness indicators.

5.5.1. Directional Spillovers Transmitted (TO)

The aggregate spillover that market i transmits to all remaining markets at quantile τ and frequency band d is

$$TO_{i,\tau}(d) = \sum_{j=1, j\neq i}^{N} \widetilde{\theta}_{ji,\tau}(d). \tag{7}$$

5.5.2. Directional Spillovers Received (FROM)

Symmetrically, the total spillover absorbed by market i from all other markets is

$$FROM_{i,\tau}(d) = \sum_{j=1, j\neq i}^{N} \widetilde{\theta}_{ij,\tau}(d). \tag{8}$$

5.5.3. Net Directional Connectedness (NET)

The difference between outgoing and incoming spillovers yields the net directional connectedness of market i:

$$NET_{i,\tau}(d) = TO_{i,\tau}(d) - FROM_{i,\tau}(d). \tag{9}$$

A positive (negative) value of $NET_{i,\tau}(d)$ identifies market i as a net transmitter (receiver) of shocks within the system at the given quantile and frequency band.

5.5.4. Total Connectedness Index (TCI)

The system-wide intensity of interconnectedness is summarized by

$$TCI_{\tau}(d) = N^{-1}\sum_{i=1}^{N} FROM_{i,\tau}(d) = N^{-1}\sum_{i=1}^{N} TO_{i,\tau}(d). \tag{10}$$

5.5.5. Net Pairwise Directional Connectedness (NPDC)

Finally, the bilateral net spillover running from market i to market j is captured by

$$NPDC_{ij,\tau}(d) = \widetilde{\theta}_{ij,\tau}(d) - \widetilde{\theta}_{ji,\tau}(d). \tag{11}$$

Taken together, this set of indicators enables a granular characterization of how innovations are dynamically associated across Argentina's official, parallel, and stablecoin exchange rate markets. By conditioning on τ, we can assess whether the spillover architecture is regime-dependent. For example, this approach allows us to determine whether extreme market states in the blue-dollar market are associated with disproportionately large connectedness to the stablecoin market. Simultaneously, the frequency decomposition reveals whether such transmissions are predominantly short-term or long-term, offering differentiated insights for policymakers and market participants.

5.6. Interpretation and Identification Limits

The QVAR–GFEVD framework is a reduced-form connectedness approach. Directional connectedness indicates that innovations in one series account for a larger share of another series' forecast error variance within the estimated system; it does not, by itself, identify structural causality. Common macroeconomic news, policy announcements, arbitrage activity, liquidity differences, trading-hour mismatches, and transaction costs may all contribute to the observed dependence structure. Accordingly, when we describe a market as a "net transmitter" or an "early-moving" node, the statement should be read as evidence of relative timing and variance-share importance within the connectedness system, not as proof that the market exogenously causes movements in other channels. This distinction is particularly important in our setting because stablecoin platforms trade continuously, while the official and blue-dollar series are observed at daily frequency and operate under different institutional frictions.

6. Empirical Results

6.1. Time-Frequency Connectedness Under Normal Market Conditions

Table 4 presents the averaged time-frequency connectedness for the Argentine USD/ARS and stablecoin markets at the median quantile ($\tau = 0.5$). We begin by examining the pairwise directional spillovers and own-variance shares on the main diagonal. The most striking observation is the high degree of isolation of the official exchange rate market: its own forecast error variance share reaches 91.82%, implying that only 8.18% of its variation is attributable to shocks from other markets. This pattern is consistent with Argentina's stringent capital controls (cepo cambiario), which restrict market-driven price adjustment and limit shock transmission between the official and parallel markets.

In contrast, the two stablecoin markets (Binance and Bitso) exhibit strong bilateral spillovers: USDT/ARS (Bitso) accounts for 40.78% of USDT/ARS (Binance)'s forecast error variance, while USDT/ARS (Binance) accounts for 40.37% of USDT/ARS (Bitso)'s. Furthermore, stablecoin markets contribute materially to the informal market, with Binance and Bitso explaining 15.89% and 17.41% of the USD/ARS (Blue) forecast error variance, respectively. The frequency decomposition reveals that these spillovers are primarily driven by the short-term component, suggesting that cross-market shock transmission occurs predominantly at higher frequencies.

Turning to net directional spillovers and the total connectedness index (TCI), both USDT/ARS (Binance) and USDT/ARS (Bitso) emerge as net transmitters, with net values of 5.31% and 6.55%, respectively, while USD/ARS (Blue) is the largest net receiver (−10.56%). This pattern is consistent with the notion that continuously traded stablecoins appear as more active net transmitters within the connectedness system, whereas the traditional informal "blue dollar" market functions primarily as a net absorber of these spillovers, a finding that aligns with the broader literature on "cryptoization" in EMEs [11,17,19,22]. Finally, the TCI of 38.40% indicates moderate overall connectedness, with the short-term component (27.31%) substantially exceeding the long-term component (11.09%), suggesting that systemic connectedness in this market is predominantly shaped by rapid, high-frequency market responses.

Table 4. Averaged time-frequency connectedness.

	USD/ARS (Official)	USD/ARS (Blue)	USDT/ARS (Binance)	USDT/ARS (Bitso)	FROM
USD/ARS (Official)	91.82 (76.61; 15.21)	0.91 (0.75; 0.16)	3.68 (3.00; 0.69)	3.59 (2.95; 0.64)	8.18 (6.70; 1.48)
USD/ARS (Blue)	2.26 (1.66; 0.60)	64.44 (50.55; 13.89)	15.89 (11.06; 4.83)	17.41 (12.13; 5.28)	35.56 (24.85; 10.71)
USDT/ARS (Binance)	2.12 (1.53; 0.59)	11.73 (8.17; 3.56)	45.36 (32.10; 13.27)	40.78 (28.50; 12.28)	54.64 (38.20; 16.44)
USDT/ARS (Bitso)	2.50 (1.90; 0.60)	12.37 (8.89; 3.48)	40.37 (28.72; 11.64)	44.77 (32.53; 12.24)	55.23 (39.51; 15.72)
TO	6.88 (5.08; 1.80)	25.00 (17.81; 7.19)	59.94 (42.78; 17.16)	61.78 (43.58; 18.20)	TCI
Net	−1.30 (−1.62; 0.32)	−10.56 (−7.04; −3.52)	5.31 (4.58; 0.72)	6.55 (4.07; 2.48)	38.40 (27.31; 11.09)

Notes: The table displays the averaged time-frequency connectedness at the 0.5 quantile. The 1st and 2nd values in brackets stand for short-term and long-term connectedness, respectively. See Section 4 for the definitions of 'FROM', 'TO', 'NET', and 'TCI'.

Table 5 summarizes additional node-level network diagnostics derived from the same median-quantile connectedness matrix. The total strength measure, computed as the sum of outgoing and incoming spillovers, confirms the centrality of the two stablecoin venues in the connectedness network. USDT/ARS (Bitso) and USDT/ARS (Binance) have the largest total strengths and positive net strengths, while USD/ARS (Blue) has the largest negative net strength. The official rate is the weakest node by total strength, consistent with its partial administrative insulation during much of the sample.

Figure 4 illustrates the dynamic total connectedness under normal market conditions. The total connectedness is markedly time-varying and exhibits three distinct structural phases closely tied to Argentina's policy transitions.

The first structural shift occurs in July 2024, when total connectedness rises sharply from approximately 28% to a new plateau of 38–42%. This jump reflects the market-wide repercussions of the peso devaluation implemented on 13 December 2023; as the extreme post-devaluation volatility progressively dominates the estimation window, cross-market spillovers escalate substantially and stabilize at a higher equilibrium. Subsequently, connectedness remained broadly elevated but stable through early 2025, suggesting that markets had temporarily absorbed the devaluation shock and settled into a new connectedness regime. The second and more dramatic shift is triggered by the dismantling of the stringent foreign exchange controls (cepo cambiario) and the transition to a managed float on 14 April 2025. The spillover had a sharp, transitory spike exactly around this date, followed by a continuous and steep upward climb through the second half of 2025, with total connectedness reaching its highest historical level and exceeding 50%. The removal of capital barriers eliminated the artificial segmentation between the official USD/ARS, the informal "blue" market, and stablecoin markets, fundamentally restructuring the information transmission structure of the system.

Table 5. Node-level network diagnostics at the median quantile.

Market	Out	In	Net	Total Strength	Role
USD/ARS (Official)	6.88	8.18	−1.30	15.06	Weak receiver
USD/ARS (Blue)	25.00	35.56	−10.56	60.56	Receiver
USDT/ARS (Binance)	59.94	54.64	5.31	114.58	Transmitter
USDT/ARS (Bitso)	61.78	55.23	6.55	117.01	Transmitter

Notes: Out-strength corresponds to TO spillovers, in-strength corresponds to FROM spillovers, net strength is Out minus In, and total strength is Out plus In. Values are expressed in percentage points of forecast error variance shares and are calculated from Table 4.

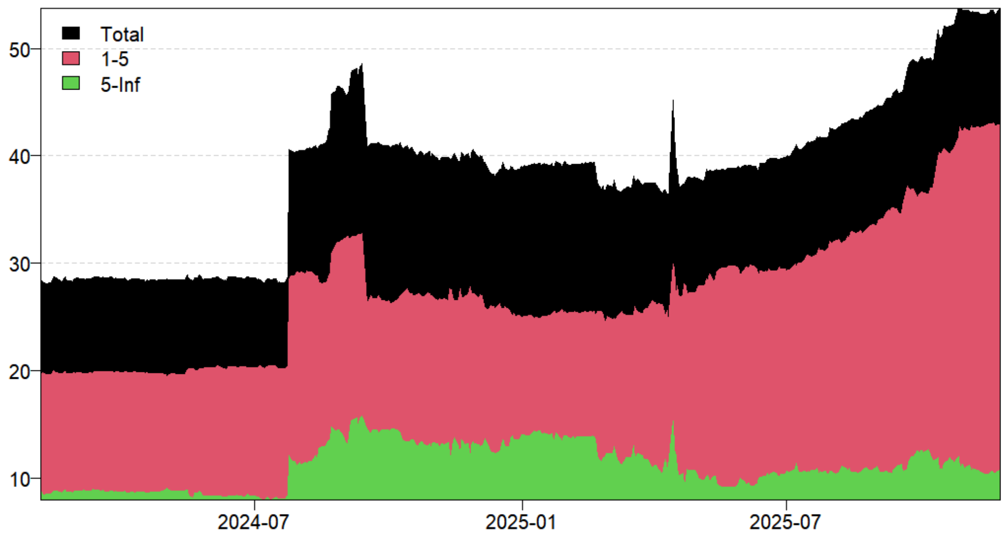

Figure 4. Dynamic total connectedness ($\tau = 0.5$). *Notes:* The results are estimated using a QVAR(1) model, with the lag order selected by the BIC. The estimation is based on a 200-day rolling window and a 100-step-ahead generalized forecast error variance decomposition (GFEVD). The black area represents the total dynamic connectedness, while the red and green areas depict the short-term and long-term results, respectively.

In the frequency domain, the short-term connectedness fluctuates between approximately 19% and 42%, closely tracking and predominantly driving the total index across all sample periods. By contrast, long-term connectedness remains considerably more stable, generally constrained between 8% and 12%, with only a modest upward tendency in the post-liberalization period. These results suggest that cross-market connectedness in the Argentine parallel and stablecoin markets is primarily associated with short-term interactions. The continuously traded stablecoin markets appear to be associated with faster short-term adjustment within the connectedness network. By contrast, the relatively subdued long-term connectedness suggests that these shocks are largely transitory in nature: once the immediate market reaction runs its course, cross-market pressures gradually dissipate over longer horizons, consistent with the gradual stabilization of exchange rate expectations under the managed float framework.

Figure 5 depicts the net total directional connectedness, enabling us to identify whether a particular market serves as a net spillover receiver (values below zero) or transmitter (values above zero) within the Argentine exchange rate system. In general, the net spillovers exhibit significant time-varying characteristics and are predominantly driven by short-term interactions.

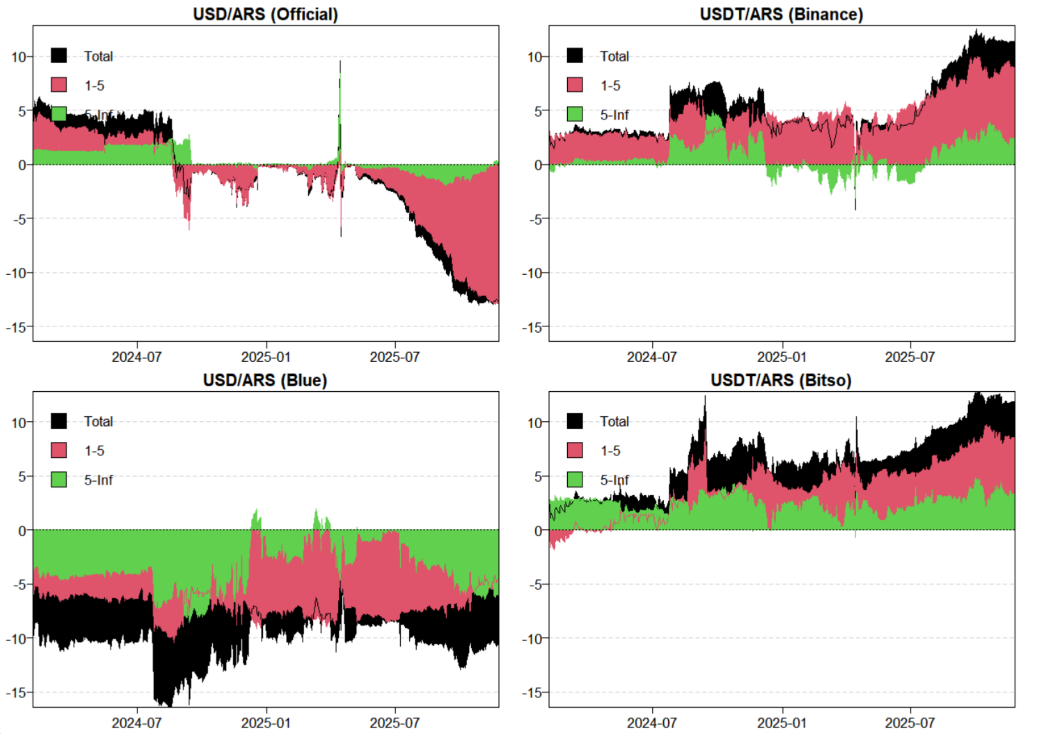

Figure 5. Dynamic net total directional connectedness ($\tau = 0.5$). *Notes:* The results are estimated using a QVAR(1) model, with the lag order selected by the BIC. The estimation is based on a 200-day rolling window and a 100-step-ahead generalized forecast error variance decomposition (GFEVD). The black area represents the total dynamic connectedness, while the red and green areas depict the short-term and long-term results, respectively.

When observing the stablecoin markets, both USDT/ARS (Binance) and USDT/ARS (Bitso) exhibit a consistent pattern as net spillover transmitters throughout the observation period, corroborating their dominant role identified in the static analysis. Following the official peso devaluation and the subsequent April 2025 liberalization (dismantling of the "cepo cambiario"), both markets experienced a dramatic upward surge in net transmitted spillovers. With capital controls lifted, the highly liquid, continuously traded stablecoin markets appear as the largest net transmitters in the connectedness network, with intensified short-term dependence relative to other markets. It is noteworthy that between the two stablecoin venues, USDT/ARS (Bitso) exhibits a comparatively larger long-term transmission component.

Conversely, the informal USD/ARS (Blue) market consistently acts as a net spillover receiver. Notably, it experienced pronounced downward spikes around July 2024, as well as in late 2025. The mid-2024 movement closely corresponds to the delayed manifestation of the official peso devaluation. This pattern is consistent with the traditional parallel market acting as a receiver of volatility and information spillovers associated with the digital stablecoin markets during major monetary policy adjustments.

Striking shifts are observed in the official market (USD/ARS Official), whose trend closely tracks the evolution of Argentina's exchange rate regimes. Initially, the official market exhibited a positive net connectedness. However, capturing the lagged effect of the severe December 2023 devaluation and the subsequent implementation of a strict "crawling peg" regime, its net spillover sharply dropped and hovered near zero from mid-2024 to mid-2025. This near-zero plateau indicates a state of extreme isolation, reflecting the period when the official rate was artificially anchored by the predetermined crawling path and temporarily detached from market-driven realities. Subsequently, tracing the lagged impact of the April 2025 policy shift, the official market moves into deep negative territory, appearing as a substantial net spillover receiver. This vividly illustrates the transition to the managed float regime: once the strict peg was abandoned, the official exchange rate became more closely connected with the broader financial system, absorbing market pressures from the parallel and crypto-dollar markets. This increase in connectedness and shock absorption is consistent with the re-establishment of financial integration and the enforcement of no-arbitrage conditions across previously segmented FX segments.

6.2. Dynamic Net Pairwise Directional Connectedness

Finally, Figures 6–8 present the dynamic net pairwise directional connectedness across all six market pairs, where a positive value indicates that the first market is a net transmitter to the second, and a negative value implies the reverse. Consistent with preceding findings, the short-term component (red area) accounts for much of the dynamic linkages across most pairs. We organize our discussion around three sets of relationships: (i) stablecoin versus conventional markets, (ii) between the two conventional markets, and (iii) between the two stablecoin markets.

The first set examines the relationships between stablecoin markets and the two conventional markets. The USD/ARS (Blue)–USDT/ARS (Binance) and USD/ARS (Blue)–USDT/ARS (Bitso) pairs are persistently negative throughout the sample period, indicating the informal market's structural role as a continuous receiver of crypto-market shocks within the reduced-form system. Both pairs register intensified negative spillovers around mid-2024 and again throughout the second half of 2025, corresponding to the peso devaluation shock and the aftermath of the liberalization, respectively. Notably, the two pairs exhibit near-identical dynamics in both magnitude and frequency composition, with short-term and long-term components contributing comparably across both relationships. This similarity suggests that the two stablecoin markets have functionally similar connectedness with the informal Blue market, with shocks appearing at similar horizons.

The relationships between the official market and the two stablecoin markets reveal a particularly striking regime shift. During the crawling peg and cepo period, both pairwise indices hovered near zero, consistent with the near-complete administrative isolation of the official exchange rate documented above. Following the April 2025 liberalization, however, both indices plunged abruptly into deep negative territory. This transition captures the consequence of reconnecting the official rate to market forces: once the *cepo* was dismantled, the official series became much more exposed to pricing information already reflected in the parallel and stablecoin channels.

The second set focuses on the interaction between the two conventional markets (USD/ARS (Official)–USD/ARS (Blue)). Following the mid-2024 structural break, the index declined sharply toward zero, reflecting the progressive decoupling of the two markets as the post-devaluation equilibrium stabilized. After the April 2025 transition to a managed float, the index turned negative, indicating that the official rate absorbed depreciation pressures long reflected in the parallel Blue market.

The third set examines the net pairwise connectedness between the two stablecoin platforms (USDT/ARS Binance–USDT/ARS Bitso). In stark contrast to all other pairs, this index remains relatively contained, generally fluctuating within a narrow band around zero. This weak net spillover can be associated with the homogeneity and high arbitrage efficiency within the stablecoin ecosystem. Because both platforms process macroeconomic news almost simultaneously and share highly overlapping investor bases, their mutual transmission of volatility largely cancels out, resulting in negligible net directional flows.

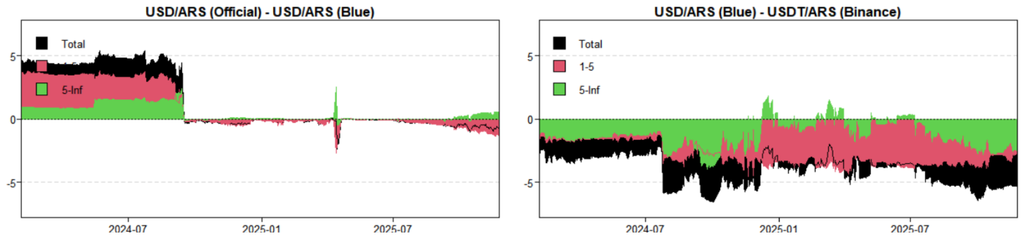

Figure 6. Dynamic net pairwise directional connectedness between the official, blue-dollar, and Binance USDT channels ($\tau = 0.5$). *Notes:* The results are estimated using a QVAR(1) model, with the lag order selected by the BIC. The estimation is based on a 200-day rolling window and a 100-step-ahead generalized forecast error variance decomposition (GFEVD). The black area represents the total dynamic connectedness, while the red and green areas depict the short-term and long-term results, respectively.

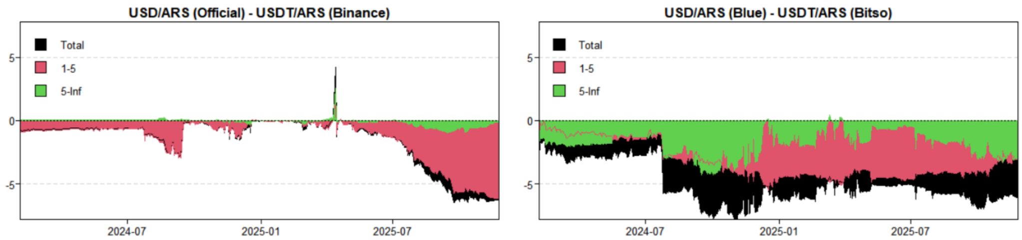

Figure 7. Dynamic net pairwise directional connectedness for official–Binance and blue-dollar–Bitso pairs ($\tau = 0.5$). *Notes:* The results are estimated using a QVAR(1) model, with the lag order selected by the BIC. The estimation is based on a 200-day rolling window and a 100-step-ahead GFEVD. The split format enlarges the original six-panel figure to improve readability.

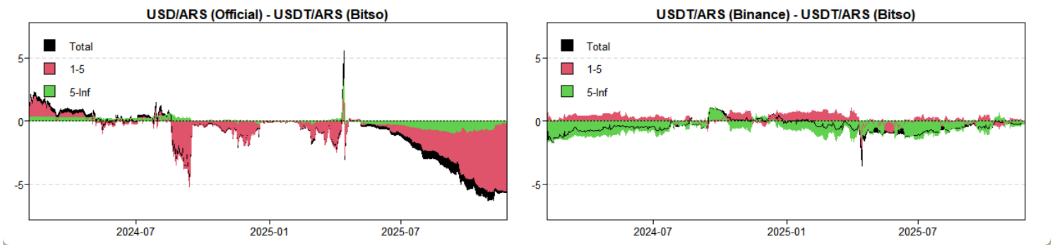

Figure 8. Dynamic net pairwise directional connectedness for official–Bitso and Binance–Bitso pairs ($\tau = 0.5$). *Notes:* The results are estimated using a QVAR(1) model, with the lag order selected by the BIC. The estimation is based on a 200-day rolling window and a 100-step-ahead GFEVD. Black, red, and green areas denote total, short-term, and long-term components, respectively.

6.3. Time-Frequency Connectedness Under Extreme Market Conditions

In this subsection, we delve deeper into the system's dynamics under extreme market conditions by examining the quantile-varying heatmaps. Figure 9 plots the total, short-term, and long-term dynamic total connectedness across various quantiles. In the heatmaps, warmer (darker) shades indicate stronger connectedness, while cooler (lighter) shades indicate weaker connectedness. It is important to recall that since our underlying series are expressed as USD/ARS exchange rates, positive returns correspond to peso depreciation.

Accordingly, the upper and lower tails of the conditional distribution capture different extreme market states.

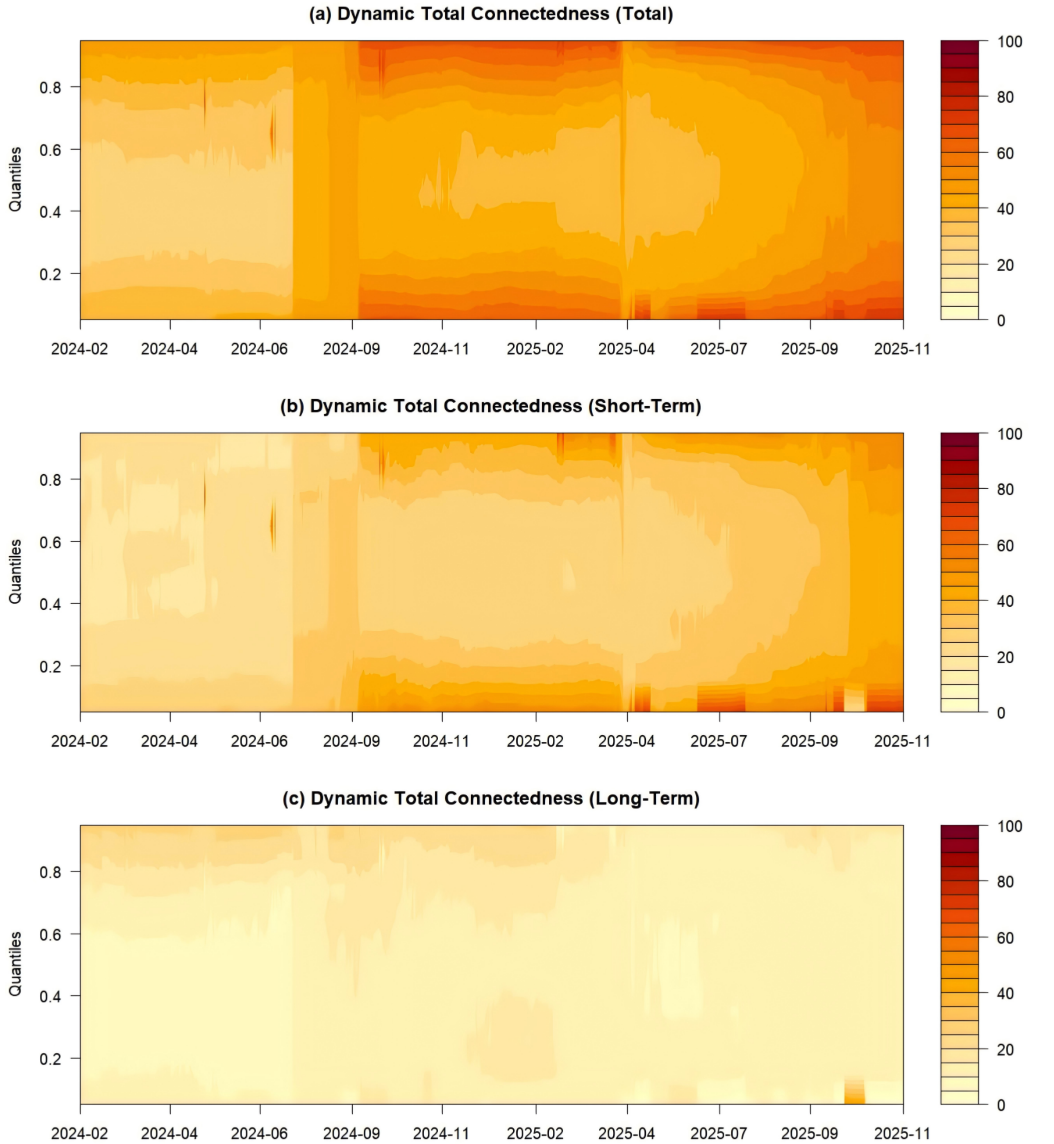

Figure 9. Dynamic total connectedness across various quantiles. *Notes:* The results are estimated using a QVAR(1) model, with the lag order selected by the BIC. The estimation is based on a 200-day rolling window and a 100-step-ahead generalized forecast error variance decomposition (GFEVD), where darker red areas indicate stronger connectedness and lighter yellow areas indicate weaker connectedness.

Figure 9a,b reveal that both the total and short-term dynamic total connectedness exhibit a pronounced symmetric, U-shaped pattern around the median quantile ($\tau = 0.5$). The shades become progressively warmer as we move toward both the extreme upper (>0.8) and extreme lower (<0.2) tails of the distribution. Interestingly, this symmetrical pattern suggests that information spillovers behave similarly across lower-tail and upper-tail extreme market states. Regardless of the shock's direction, extreme market conditions accelerate the transmission of pricing information across the official, parallel, and stablecoin markets. In contrast, the connectedness displays the coldest shades at the middle quantiles, indicating significantly weaker information spillovers under normal market conditions. This finding, that connectedness intensifies during extreme conditions and weakens under normal market states, is in accordance with the results of [40–42]. From a practical perspective, this low connectedness at the median provides valuable implications for local residents and investors: during periods of market tranquility, the relative decoupling of these platforms offers potential opportunities for effective portfolio diversification and risk management.

Furthermore, these connectedness dynamics are markedly time-varying: the colors deepen substantially across all quantiles around mid-2024 and become particularly intense throughout the second half of 2025. This temporal evolution aligns closely with Argentina's policy trajectory, demonstrating that the dismantling of the cepo capital controls was associated with stronger short-term information transmission across the entire spectrum of market conditions.

Turning to Figure 9c, the long-term dynamic connectedness presents a stark contrast. The overall magnitude remains notably subdued (generally below 20%) across almost the entire time-quantile spectrum. This weak long-term profile firmly reinforces our preceding conclusion that information transmission within the Argentine exchange rate system is overwhelmingly dominated by short-term market interactions. Interestingly, unlike the symmetric short-term dynamics, the long-term connectedness exhibits a distinct asymmetry during the initial phase of our sample (prior to February 2025). Specifically, the upper quantiles display visibly warmer shades than the corresponding lower quantiles. This structural asymmetry suggests that during the strict capital control period, extreme upper-tail shocks became embedded into investors' long-term expectations, generating more persistent cross-market information linkages. Conversely, lower-tail episodes were likely viewed as transient anomalies with little enduring impact. As time progresses, however, and particularly as the macroeconomic regime transitions toward the managed float, this long-term asymmetry gradually dissipates, reflecting a normalization of information transmission mechanisms across the traditional and crypto-dollar markets.

Next, we present network visualizations of the net pairwise directional connectedness across various frequency domains and quantile conditions. In Figures 10–12, blue nodes denote net spillover transmitters and yellow nodes represent net spillover receivers. The size of each node reflects the absolute magnitude of its net total directional connectedness, the thickness of connecting arrows indicates the strength of net pairwise spillovers, and the arrowheads indicate the direction of transmission. We use normal market conditions ($\tau = 0.50$) as a benchmark and examine how the net spillovers change under two extreme conditions ($\tau = 0.05$, $\tau = 0.95$). For each quantile-specific network figure, the three panels are arranged from left to right as total connectedness, short-term connectedness, and long-term connectedness. This left-to-right convention is used because the enlarged high-resolution figures omit the panel headings that appeared in the original compact version.

Under normal market conditions ($\tau = 0.50$), the network topology is fully consistent with the results presented in previous sections. The two stablecoin markets (Binance and Bitso) emerge as net transmitters (blue nodes), while the official exchange rate and the Blue Dollar both appear as net receivers (yellow nodes). The short-term network closely resembles the total network in both structure and arrow thickness, reaffirming the dominance of short-term transmission channels. The long-term network exhibits noticeably thinner arrows, confirming the subdued role of long-term spillovers under normal market conditions.

The network changes partially under the upper-tail extreme market state ($\tau = 0.95$). In the total and short-term panels, the structure remains qualitatively similar to the benchmark: stablecoin markets continue to serve as net transmitters, while the official rate and the Blue Dollar remain net receivers. However, a notable role reversal occurs in the long-term panel, where the official exchange rate switches from a yellow node to a blue node. This finding suggests that upper-tail extreme market states are associated with persistent long-horizon connectedness generated by official devaluations. Importantly, this role reversal is confined to the long-term frequency; in terms of total connectedness, the official rate's position as a net receiver remains unchanged.

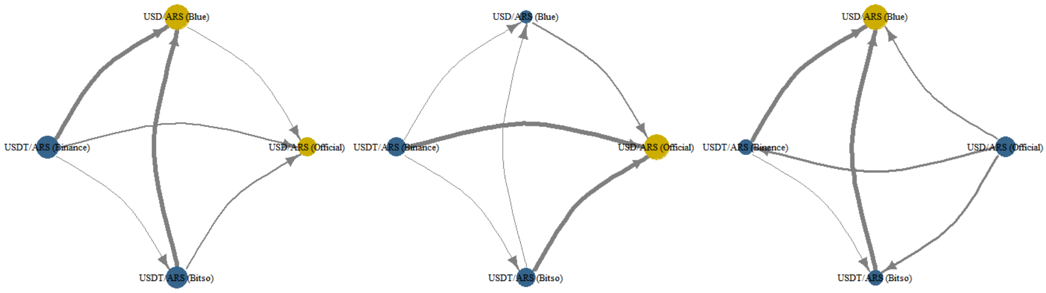

Figure 10. Network plot of the net pairwise directional connectedness under upper-tail extreme market conditions ($\tau = 0.95$; left to right: total, short-term, and long-term connectedness). *Notes:* The left, middle, and right panels correspond to total, short-term, and long-term connectedness, respectively. Blue (yellow) nodes denote net transmitters (receivers) of return spillovers. The size of each node represents the absolute magnitude of its net directional connectedness. The thickness of the arrows reflects the strength of the pairwise spillovers, while the arrowheads indicate the direction of transmission.

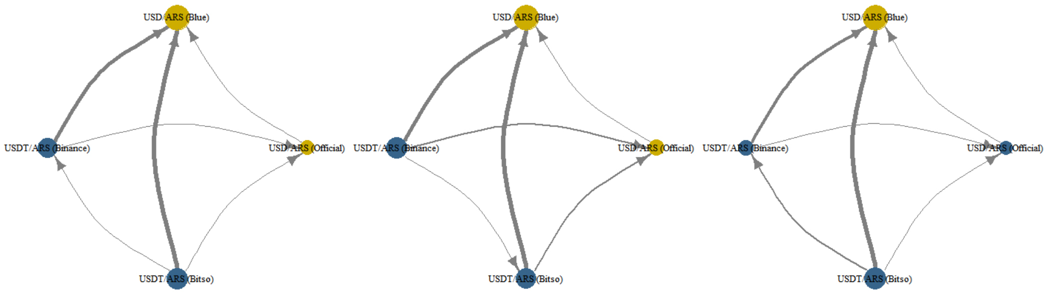

Figure 11. Network plot of the net pairwise directional connectedness under normal conditions ($\tau = 0.50$; left to right: total, short-term, and long-term connectedness). *Notes:* The left, middle, and right panels correspond to total, short-term, and long-term connectedness, respectively. Blue (yellow) nodes denote net transmitters (receivers). The figure is split from the original nine-panel layout to improve label readability.

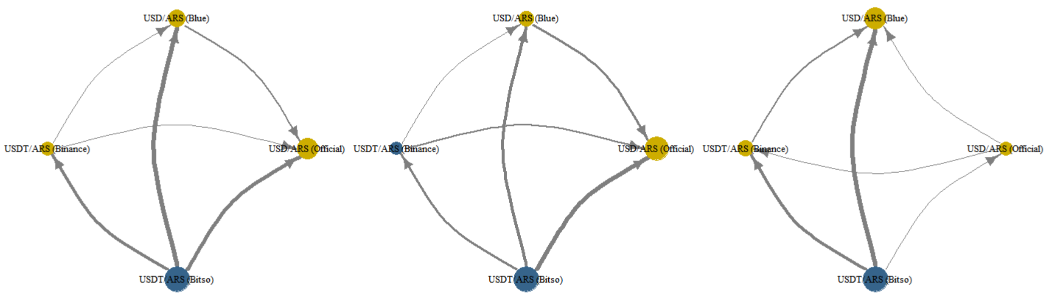

Figure 12. Network plot of the net pairwise directional connectedness under lower-tail extreme market conditions ($\tau = 0.05$; left to right: total, short-term, and long-term connectedness). *Notes:* The left, middle, and right panels correspond to total, short-term, and long-term connectedness, respectively. Blue (yellow) nodes denote net transmitters (receivers). Node size and arrow thickness encode net directional and pairwise spillover magnitudes, respectively.

Under the lower-tail extreme market state ($\tau = 0.05$), the overall network direction remains broadly consistent with the benchmark. The most notable change is that Binance switches from a transmitter to a receiver, indicating that its early-moving connectedness weakens under this condition. By contrast, Bitso retains its transmitter role across all three quantile conditions, establishing itself as the most stable net transmitter in the connectedness network. Unlike the upper-tail extreme market state, the official rate does not undergo a role reversal in the long-term panel at $\tau = 0.05$, remaining a net receiver. This asymmetry confirms that the structural reconfiguration of the official rate is triggered only under upper-tail extreme market states.

Taken together, three findings stand out. First, the early-moving role of stablecoin markets, particularly Bitso, is robust across all market conditions, consistent with cryptoization being an important feature of Argentina's USD markets. Second, upper-tail extreme market states uniquely transform the official exchange rate into a long-term net transmitter, indicating that official devaluation events generate persistent spillovers that reshape the long-term pricing dynamics of the entire dollar market. Third, despite this long-term role reversal, the official rate's overall position as a net receiver is stable across all quantiles, suggesting that the relative connectedness hierarchy, with stablecoin markets playing a more active transmitting role and the official rate generally absorbing shocks, is resilient to changes in market conditions.

Finally, Figure 13 presents the averaged total connectedness across quantiles for the total, short-term, and long-term frequency bands. The total TCI (black line) displays a pronounced U-shaped pattern, confirming that spillovers across the Argentina's USD markets are substantially stronger under extreme market conditions than under normal conditions. This corroborates the heatmap evidence presented in Figure 9 and reinforces the necessity of adopting a quantile-based framework. Similarly, the short-term TCI (red line) closely mirrors the U-shaped trajectory of the total TCI and consistently accounts for the vast majority of the total connectedness across all quantiles. This observation is consistent with the results from Table 4, reaffirming that information transmission within the system is mainly associated with short-term dynamics. In contrast, the long-term TCI (green line) remains relatively flat and subdued across most of the distribution, though it exhibits a slight elevation at the upper-tail extreme quantiles compared to the lower-tail quantiles. These findings carry important practical implications for the Argentine foreign exchange ecosystem. For local residents and corporate treasurers, awareness of these quantile-dependent spillover dynamics can inform strategies for currency hedging and wealth preservation under extreme exchange rate volatility episodes. For policymakers and central bank authorities, the frequency-dependent results highlight the value of monitoring parallel and stablecoin markets as early warning indicators of systemic exchange rate pressures under tail-risk conditions.

6.4. Systemic Vulnerabilities, Resilience, and Monitoring Implications

From a systems perspective, the evidence suggests that the resilience of Argentina's USD access system is state-dependent rather than fixed. We use the terms systemic vulnerability and resilience in a connectedness-based sense. The indices estimated here do not measure balance-sheet losses, leverage, liquidity shortfalls, default probabilities, or welfare costs. Instead, they measure how tightly the official, informal, and digital-dollar channels are dynamically coupled and, therefore, how quickly exchange-rate pressure can be redistributed across subsystems.

Under normal conditions, the system remains only loosely coupled: stablecoin platforms are early-moving nodes in the connectedness network, while the official rate is comparatively insulated by administrative controls. Under stressed conditions, however, the degree of segmentation declines sharply and boundary permeability increases. Pricing information and exchange-rate pressure then propagate more rapidly across official, informal, and digital channels, making connectedness-based vulnerability higher even if the framework does not directly quantify systemic loss.

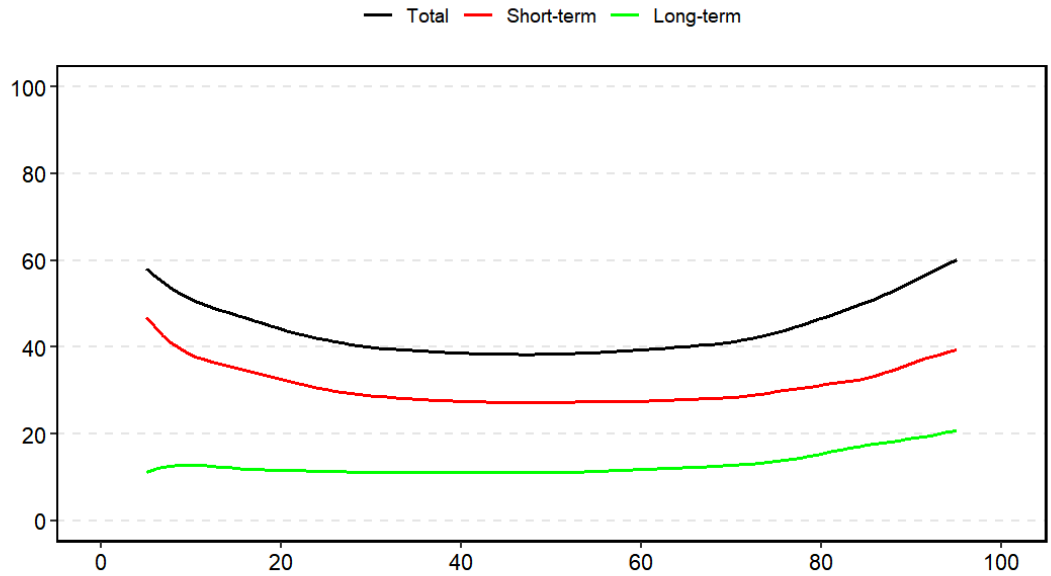

Figure 13. Averaged total connectedness over quantiles. *Notes:* The results are estimated using a QVAR(1) model, with the lag order selected by the BIC. The estimation is based on a 200-day rolling window and a 100-step-ahead generalized forecast error variance decomposition (GFEVD).

These findings also have implications for monitoring. Platform-based digital-dollar channels may provide useful leading indicators of mounting exchange-rate pressure because they react continuously and are less directly constrained by the administrative rules governing the official rate. More broadly, the paper demonstrates how quantile time-frequency connectedness measures can serve as monitoring tools for identifying not only the intensity of spillovers but also the conditions under which dynamic dependence becomes more persistent, asymmetric, and relevant for policy surveillance.

6.5. Robustness Checks

We conduct four model- and parameter-sensitivity checks and two regime-sensitivity validations. The baseline lag order is selected by the BIC, which selects QVAR(1) for the aligned daily return system. Because the baseline QVAR is estimated as a frequentist quantile model rather than a Bayesian TVP-VAR, there are no prior hyperparameters to vary in the main specification. We therefore assess specification sensitivity through benchmark-model comparison, rolling-window variation, forecast-horizon variation, and alternative lag structures, while using formal breakpoint evidence and pre/post-liberalization network comparisons to validate the regime-transition interpretation.

First, we compare our baseline QVAR results (estimated at the median) with those obtained from a standard VAR model. As illustrated in Figure 14, the dynamic connectedness indices derived from both methods exhibit highly consistent overall trends. Specifically, the long-term connectedness generated by the two models is highly consistent. However, the standard VAR model yields higher values for both the short-term and total connectedness. This discrepancy is consistent with the conventional VAR model being more sensitive to extreme observations, which can overstate spillover magnitudes in fat-tailed return data [41]. Despite differences in index levels, the common dynamic pattern supports the robustness of the main time-varying connectedness result.

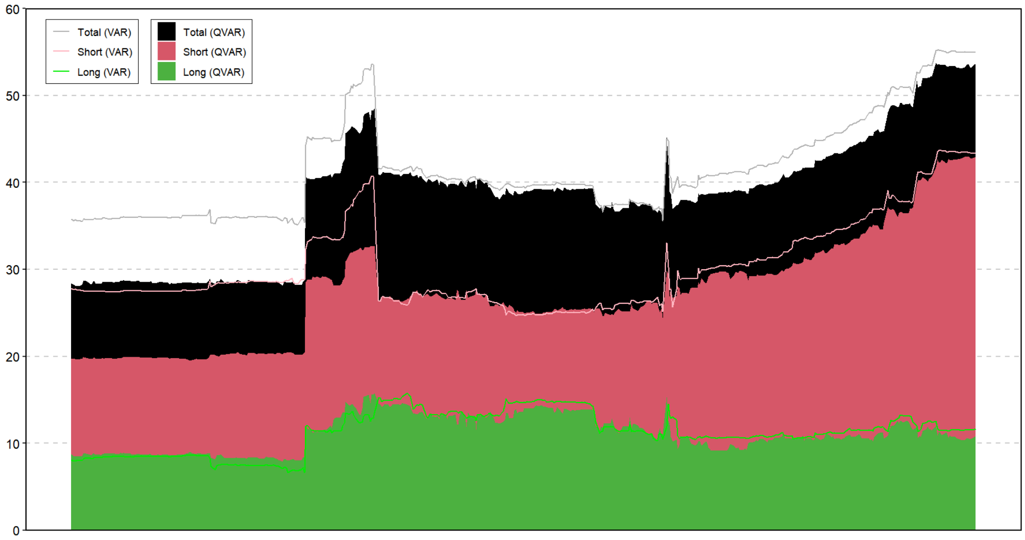

Figure 14. Dynamic total connectedness based on VAR and QVAR models. *Notes:* Dynamic total, short-term, and long-term connectedness based on VAR(1) and QVAR(1) models. The lag order is selected by the BIC. The estimation is based on a 200-day rolling window and a generalized forecast error variance decomposition (GFEVD) with a 100-step forecast horizon.

Second, we assess the sensitivity of our results by setting the length of the rolling window to 150, 200 (baseline), and 250 days. As shown in Figure 15, consistent with the findings of [41,43], a shorter rolling window corresponds to a higher level of dynamic connectedness. Importantly, despite the gaps in magnitude caused by the window variations, the overall trends depicted by the curves remain consistent, suggesting no material changes in the interpretation of regime-related connectedness shifts.

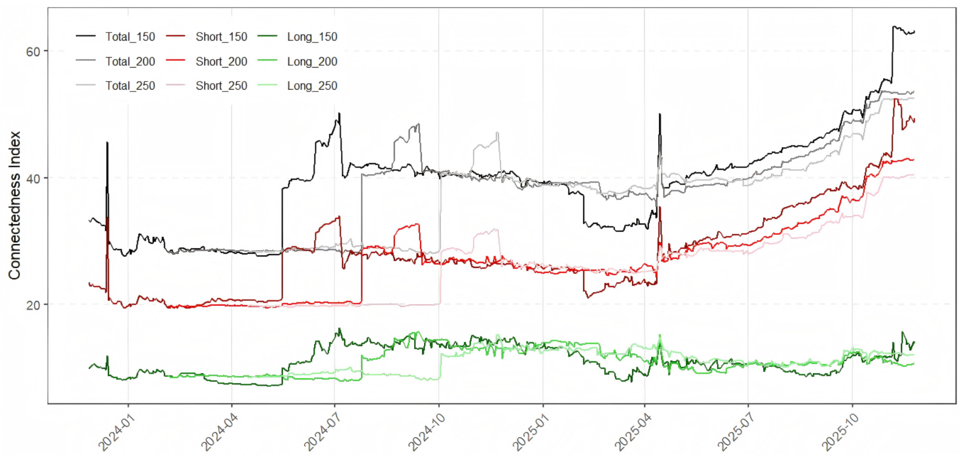

Figure 15. Dynamic total connectedness based on different window lengths.

Third, we conduct sensitivity analyses covering various forecast horizons (50, 100 (baseline), and 150). As shown in Figure 16, the resulting curves are highly similar over the sample period. This consistency indicates that the estimated spillover network is not sensitive to the particular 100-step-ahead horizon used in the baseline specification.

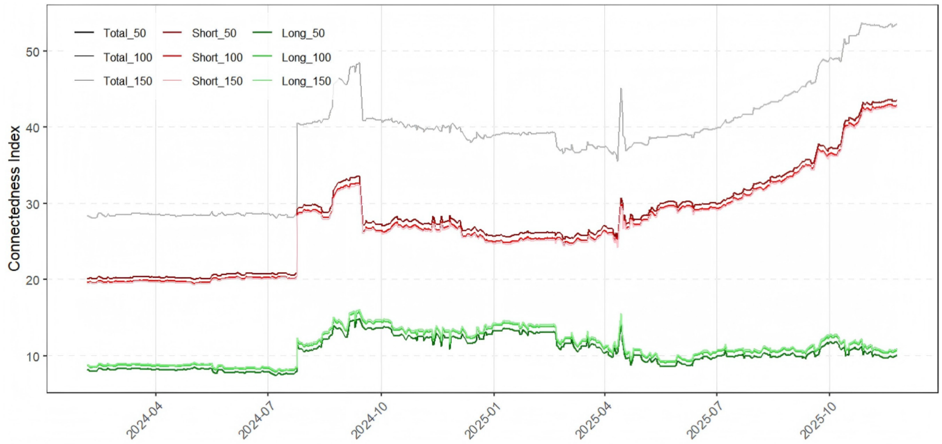

Figure 16. Dynamic total connectedness based on different forecast horizons.

Fourth, we examine alternative lag structures by re-estimating the median-quantile connectedness system using QVAR(1), QVAR(2), and QVAR(3), while keeping the rolling window length at 200 days and the forecast horizon at 100 steps. Figure 17 shows that the connectedness levels are not identical across lag specifications, but the main dynamic patterns remain qualitatively stable. In particular, the regime-related increases in connectedness, the dominance of the short-term component, and the relatively subdued long-term component are preserved. This suggests that the baseline findings are not driven by the specific lag order selected by the BIC.

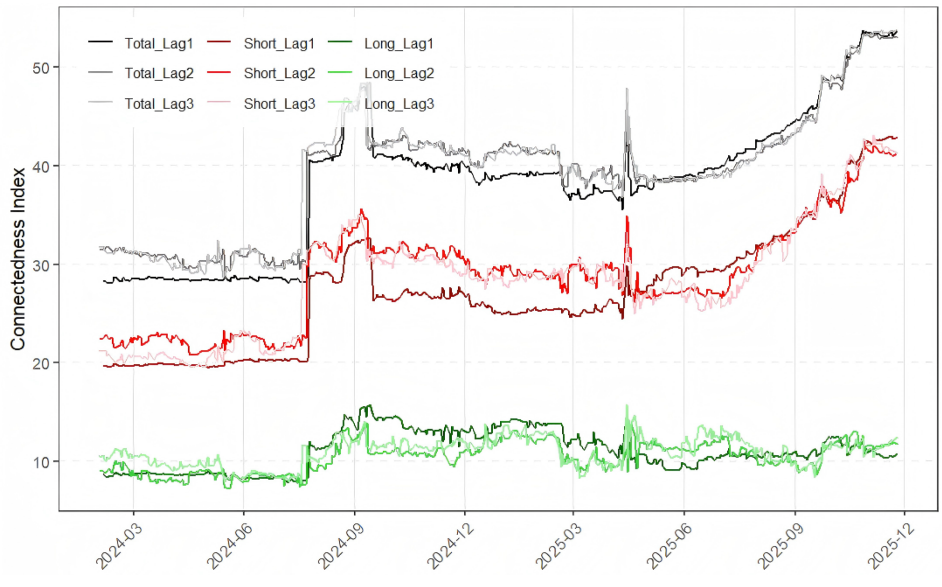

Figure 17. Dynamic total connectedness based on alternative lag structures. *Notes:* The figure compares total, short-term, and long-term dynamic connectedness estimated using QVAR(1), QVAR(2), and QVAR(3). The rolling window is fixed at 200 days, the forecast horizon is fixed at 100 steps, and the quantile is fixed at $\tau = 0.5$.

Beyond these robustness checks, we formally test for structural change in the official USD/ARS price series. We estimate breakpoints in the mean of the official exchange-rate level using a minimum segment length h and complement this with a supF test of parameter constancy. The supF statistic equals 2388.87, far above the bootstrap 99% critical value of 12.16, and the bootstrap p-value is below 0.001. As reported in Table 6, the one-break specification identifies a break between 12 December and 13 December 2023, while the two-break specification with $h = 0.15$ selects breaks between 12 December and 13 December 2023 and between 11 April and 14 April 2025. These dates coincide with the two institutional events emphasized in the paper: the large official devaluation and the subsequent exchange-rate liberalization. The formal breakpoint evidence therefore supports the economic interpretation that the observed connectedness changes are aligned with structural shifts in the official exchange-rate regime.

Table 6. Structural-break validation for the official USD/ARS price series.

Specification	Minimum Segment	Estimated Break Dates	Interpretation
1 break	$h = 0.15$	12/13 December 2023	Main devaluation break; supF rejects no structural break
2 breaks	$h = 0.15$	12/13 December 2023; 11/14 Aprrl 2025	Main policy-regime shifts

Notes: Break dates are reported as the last observation before the break and the first observation after the break because the sample uses daily market observations with weekends and holidays excluded. The one-break supF statistic is 2388.87 with a bootstrap p-value below 0.001 based on 4999 replications; bootstrap 90%, 95%, and 99% critical values are 7.18, 8.62, and 12.16, respectively.

Finally, we conduct a subsample network validation around the April 2025 exchange-rate liberalization. Specifically, we compare quantile-specific network topologies before and after the liberalization event. Figures 18 and 19 show that the connectedness structure is not fixed across policy regimes. After liberalization, cross-channel linkages become more pronounced, especially under upper-tail extreme market states, and node roles become more sensitive to market conditions. This evidence supports the interpretation that policy liberalization reconfigured the transmission architecture of the fragmented USD access system rather than affecting a single market in isolation. We interpret this exercise as subsample validation of regime-dependent network reconfiguration, not as evidence of structural causality.

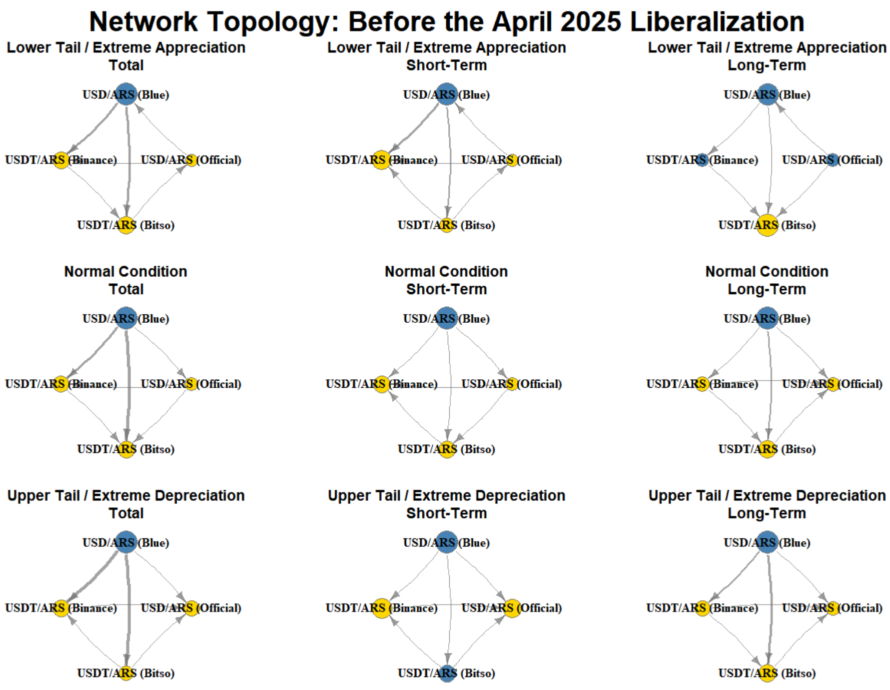

Figure 18. Network topology before the April 2025 liberalization. *Notes:* The three rows report lower-tail extreme, normal, and upper-tail extreme market states, corresponding to $\tau = 0.05$, $\tau = 0.50$, and $\tau = 0.95$, respectively. The three columns report total, short-term, and long-term connectedness. Blue nodes denote net transmitters and yellow nodes denote net receivers. Arrow thickness is proportional to the magnitude of net pairwise directional connectedness, while node size reflects the absolute magnitude of net total directional connectedness.

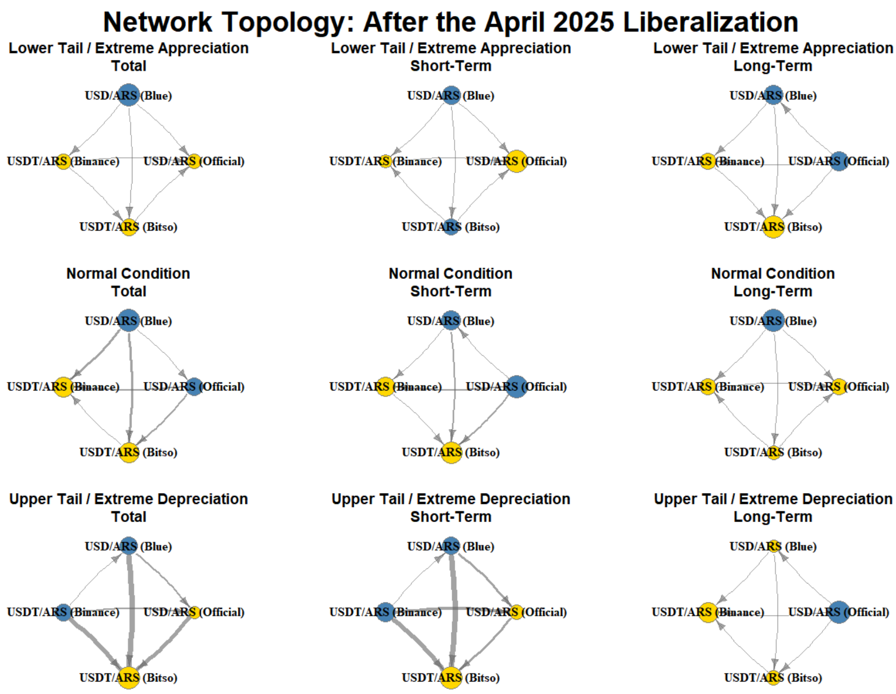

Figure 19. Network topology after the April 2025 liberalization. *Notes:* The three rows report lower-tail extreme, normal, and upper-tail extreme market states, corresponding to $\tau = 0.05$, $\tau = 0.50$, and $\tau = 0.95$, respectively. The three columns report total, short-term, and long-term connectedness. Blue nodes denote net transmitters and yellow nodes denote net receivers. Arrow thickness is proportional to the magnitude of net pairwise directional connectedness, while node size reflects the absolute magnitude of net total directional connectedness.

7. Conclusions

Rather than treating Argentina's official rate, Blue Dollar, and stablecoin prices as separate markets, this paper analyzed them as interdependent components of a fragmented and interconnected USD access system shaped by inflation, capital controls, policy transitions, and digital trading infrastructure. Using a quantile time-frequency connectedness framework, we show that the behavior of this system is state-dependent, horizon-dependent, and highly responsive to institutional change.

The empirical evidence reveals four central features of the system. First, system-wide connectedness is dominated by short-term transmission, indicating that exchange-rate pressure and pricing information propagate primarily through rapid adjustment mechanisms rather than slow-moving long-term channels. Second, stablecoin markets consistently appear as early-moving net transmitters under normal conditions, while the Blue Dollar and official rate primarily absorb shocks. Third, tail events intensify cross-channel connectedness in a symmetric U-shaped pattern, showing that both lower-tail and upper-tail extreme market states increase the coupling of the system. Fourth, under upper-tail extreme market states, the official rate becomes a long-term net transmitter, implying that major devaluation episodes can temporarily reconfigure the system's long-horizon transmission structure.

The broader implication is that stablecoins should be understood not merely as additional crypto assets or alternative trading venues but as infrastructural elements of a complex financial system. Their platform-based, continuously traded architecture increases the permeability of boundaries between formal and informal channels and accelerates short-term information adjustment. As a result, digital dollarization changes not only who accesses dollar-linked value but also how exchange-rate pressure is transmitted, redistributed, and monitored across the broader financial system.

For policymakers, the results suggest that surveillance in high-inflation economies should move beyond isolated market indicators and adopt a system-level monitoring framework that jointly tracks official, informal, and digital-dollar segments. For researchers, the Argentine case illustrates how quantile time-frequency connectedness can be used as a data-driven tool for identifying connectedness-based vulnerabilities, tracking dynamic dependence under stress and evaluating the resilience of fragmented financial systems under policy transition.

Several limitations should guide interpretation. The QVAR–GFEVD framework does not identify structural causality, and some of the estimated directional connectedness may reflect common macroeconomic news, policy signals, liquidity differences, transaction costs, or continuous trading in stablecoin venues. In addition, the empirical stablecoin channel is dominated by USDT/ARS because USDC and other stablecoin pairs are much thinner in the Argentine data. Future research could combine high-frequency order-book data, transaction-cost measures, formal regime-switching models, or external instruments to distinguish causal transmission more sharply from reduced-form dependence and test whether the patterns documented here generalize to other EMEs and other forms of digital money.

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Data Availability Statement: The data used in this study are compiled from publicly accessible market sources and third-party databases, but licensing restrictions apply to parts of the exchange-level trading data. The processed dataset required to reproduce the main results is available from the corresponding author upon reasonable request.

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Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

ARS	Argentine peso
BCRA	The Central Bank of Argentina
CEX	centralized exchanges
EMEs	emerging market economies
GFEVD	generalized forecast error variance decomposition
QVAR	quantile vector autoregressive
TCI	Total connectedness index
USD	United States Dollar
USDC	USD Coin
USDT	Tether USD

Notes

[1] See https://www.prnewswire.com/news-releases/latin-america-s-crypto-conquest-is-driven-by-consumers-needs-819718066.html (accessed on 1 May 2026).
[2] See https://www.ey.com/en_gl/technical/tax-alerts/argentine-central-bank-issues-new-regulations-on-foreign-exchang (accessed on 1 May 2026).
[3] See https://www.bcra.gob.ar/archivos/Pdfs/comytexord/A6770.pdf (accessed on 1 May 2026).
[4] See https://www.reuters.com/graphics/ARGENTINA-CURRENCY/dwvkdlkmwpm/ (accessed on 1 May 2026).
[5] See https://www.bcra.gob.ar/politica-monetaria/nuevo-marco-de-politica-monetaria-y-cambiaria/ (accessed on 1 May 2026).
[6] See https://www.bloomberg.com/news/articles/2023-12-13/argentina-to-target-2-monthly-devaluation-of-peso?embedded-checkout=true (accessed on 1 May 2026) and https://www.reuters.com/world/americas/argentina-inflation-ticks-up-27-december-ends-2024-1178-2025-01-14/ (accessed on 1 May 2026).
[7] See https://www.trade.gov/market-intelligence/argentina-eliminates-capital-controls-and-payment-timelines (accessed on 1 May 2026).
[8] See https://www.bcra.gob.ar/noticias/inicio-de-la-fase-3-del-programa-economico/ (accessed on 1 May 2026).
[9] See https://bluedollar.net/ (accessed on 1 May 2026).
[10] See https://www.investing.com/currencies/usd-ars (accessed on 1 May 2026) and https://www.investing.com/currencies/usd-arsb (accessed on 1 May 2026).
[11] See https://www.binance.com/en/support/announcement/detail/23630cd14227410fae3543c6effad115 (accessed on 1 May 2026).

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