

Leveraging Large Language Models to Bridge On-chain and Off-chain Transparency in Stablecoins

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Abstract—Stablecoins such as USDT and USDC aspire to peg stability by coupling issuance controls with reserve attestations. In practice, however, the transparency is split across two worlds: verifiable on-chain traces and off-chain disclosures locked in unstructured text that are unconnected. We introduce a large language model (LLM)-based automated framework that bridges these two dimensions by aligning on-chain issuance data with off-chain disclosure statements. First, we propose an integrative framework using LLMs to capture and analyze on- and off-chain data through document parsing and semantic alignment, extracting key financial indicators from issuer attestations and mapping them to corresponding on-chain metrics. Second, we integrate multi-chain issuance records and disclosure documents within a model context protocol (MCP) framework that standardizes LLMs access to both quantitative market data and qualitative disclosure narratives. This framework enables unified retrieval and contextual alignment across heterogeneous stablecoin information sources and facilitates consistent analysis. Third, we demonstrate the capability of LLMs to operate across heterogeneous data modalities in blockchain analytics, quantifying discrepancies between reported and observed circulation and examining their implications for cross-chain transparency and price dynamics. Our findings reveal systematic gaps between disclosed and verifiable data, showing that LLM-assisted analysis enhances cross-modal transparency and supports automated, data-driven auditing in decentralized finance (DeFi).

Index Terms—stablecoins, on/off-chain transparency, LLMs, semantic alignment, DeFi

I. INTRODUCTION

Stablecoins play a pivotal role in the digital asset ecosystem by bridging the volatility of cryptocurrencies and the stability of fiat-denominated currencies [1]. They facilitate trading, remittances, and collateralization in decentralized finance (DeFi), and are increasingly regarded as foundational components of the emerging Web3 financial infrastructure [2]. Despite their intended stability, recent crises such as the 2022 collapse of TerraUSD (UST) and LUNA [3], as well as the 2025 depegging of Ethena USD (USDe) that occurred during a broader market downturn, which erased nearly 20 billion USD in value, have revealed persistent fragilities in stablecoin mechanisms and limitations in their transparency. These episodes indicate that the resilience of stablecoins depends

not only on their structural design but also on the degree of operational transparency maintained by their issuers [4], [5].

Transparency in this context spans two dimensions: on-chain data that record verifiable issuance and redemption, and off-chain disclosures such as attestations and reserve reports published by issuers. As highlighted in recent studies [6], inconsistencies between these two layers can undermine trust and pose systemic risks. Understanding and reconciling these transparency dimensions is therefore essential for assessing the credibility of stablecoins and ensuring market integrity.

However, aligning on-chain and off-chain transparency remains challenging. While aggregate on-chain indicators (e.g., total circulating supply) are accessible through data providers, the underlying transactions are distributed across heterogeneous blockchains, which complicates direct verification. Meanwhile, off-chain disclosures remain largely opaque: reserve attestations and financial statements are typically published in unstructured formats such as PDF filings or narrative regulatory reports [1], [6], which resist automated parsing and often exhibit timing mismatches with on-chain activity.

Existing research on stablecoin transparency predominantly focuses on on-chain behavior [7]–[12], while off-chain disclosures are treated as supplementary references rather than analyzable evidence. Despite increasing recognition of transparency as a core determinant of stablecoin credibility [13], [14], no existing framework systematically integrates textual issuer disclosures with quantitative issuance data. This gap underscores the need for a unified analytical approach that semantically bridges off-chain attestations and on-chain indicators.

This separation across modalities highlights a central research gap: the absence of an automated, scalable approach that reconciles on-chain records with issuer disclosures. To address this gap, this paper first introduces an LLM-based automated framework that bridges the two transparency dimensions by jointly analyzing on-chain and off-chain data. The main contributions are as follows:

- We propose a novel integrative framework using LLMs to capture, parse, and semantically align data from both domains, extracting key financial indicators from issuer at-

testations and mapping them to corresponding blockchain metrics.

- We introduce a model context protocol (MCP) architecture that bridges multi-chain issuance data and issuer disclosures, enabling standardized LLM access, contextual retrieval, and cross-domain reasoning across quantitative and qualitative stablecoin information sources.
- We demonstrate the ability of LLMs to operate across heterogeneous data types in blockchain analytics, quantifying discrepancies between reported and observed circulation and examining their implications for transparency and price dynamics.

In the following section, we review the relevant literature.

II. RELATED WORK

A. Transparency and Disclosure in Stablecoins

Transparency is central to the credibility of stablecoins, as it determines how users and regulators assess the integrity of reserve management and issuance practices. Prior studies have examined transparency from regulatory, financial, and operational perspectives. Fernández et al. [6] identify major risks arising from inconsistent attestations and non-standard auditing methods, while Catalini et al. [1] stress that credible reserve disclosures and third-party audits are key to sustaining investor confidence. Ito et al. [15] and Moin et al. [16] provide taxonomies of stablecoin mechanisms, emphasizing the role of disclosure and intervention layers in maintaining trust. Collectively, these works highlight that transparency must be measurable, standardized, and independently verifiable to ensure systemic credibility.

Despite these insights, transparency practices across stablecoin issuers remain fragmented and inconsistent. Attestations are released in heterogeneous formats and at irregular intervals, limiting comparability and independent verification [13], [14]. Baughman et al. [17] and Gadzinski et al. [18] further argue that transparency interacts closely with stabilization mechanisms, influencing each stablecoin's resilience. However, most transparency studies rely solely on off-chain documents and overlook blockchain-based issuance data that could provide verifiable evidence. A more complete assessment therefore requires integrating on-chain and off-chain information within a unified analytical framework that captures both operational and disclosure-based dimensions of transparency.

B. Mechanisms and Stability Dynamics in Stablecoins

Stablecoin stability has been widely analyzed through economic, structural, and game-theoretical models. Potter et al. [19] demonstrate that equilibrium stability depends on collateral design and redemption mechanisms, while Klages-Mundt et al. [20] distinguish custodial from decentralized models to explain differences in risk exposure. Li et al. [21] and Moin et al. [16] provide systematic taxonomies of design architectures and stabilization mechanisms, showing that collateral composition is a key determinant of performance. Lyons and Viswanath-Natraj [22] emphasize that efficient arbitrage

access improves peg stability, and Pernice [23] models corrective forces triggered by deviations. These studies collectively suggest that stability arises from design structures and market access rather than short-term shocks.

Empirical and network-based studies complement these theoretical findings by examining real-world dynamics. Duan and Urquhart [5] and Hoang and Baur [24] show that major stablecoins frequently deviate from the one-dollar peg, exhibiting heterogeneous reversion speeds. Ba et al. [3] and Briola et al. [4] apply graph-based methods to analyze the UST-LUNA collapse, revealing contagion pathways and systemic fragility across chains. Thanh et al. [25] find that instability in USDT and USDC spills over to other coins, while Ante et al. [26] identify issuance events as drivers of short-term market efficiency. Fernández-Mejia [27] further demonstrates that tail-risk behavior in stablecoins is driven by liquidity and design heterogeneity. Although these studies deepen understanding of stability dynamics, they often treat transparency as an external condition rather than an analyzable component of stability itself.

C. Analytical Approaches to On-chain and Off-chain Data

On-chain analysis provides verifiable and data-rich insights into blockchain ecosystems. Advances in graph analytics and behavioral modeling have enabled fine-grained tracking of transaction activity and systemic dependencies. Xiang et al. [7] present a large-scale behavioral dataset for Bitcoin addresses, while Tovanich et al. [8] and Chaudhari et al. [9] apply network and anomaly detection methods to identify mining and malicious behaviors. Other works improve transaction classification and community detection through graph-based and subgraph-structural approaches [10], [11]. Yu et al. [12] extend this paradigm using graph neural networks for Web3 asset prediction, demonstrating the scalability of learning-driven blockchain analytics.

Off-chain analysis, by contrast, focuses on textual and document-based data such as financial disclosures, audit reports, and regulatory filings. Fernández et al. [6] and Catalini et al. [1] highlight that these sources are often unstructured, non-standardized, and difficult to compare across issuers. Consequently, most regulatory assessments rely on manual interpretation, introducing ambiguity and time lags. Existing blockchain research primarily targets quantitative on-chain metrics, while the integration of qualitative disclosures remains underexplored. Combining natural language processing with blockchain analytics could therefore enable cross-modal methodologies that link textual and transactional evidence, offering a holistic foundation for automated transparency auditing in digital finance.

III. PROPOSED SCHEME

We design an integrated framework that enables time-aligned, multimodal analysis of stablecoins by combining dated market data with issuer disclosures. As shown in Fig. 1, the framework is organized into three coordinated modules, each responsible for a distinct stage of the analytical process:

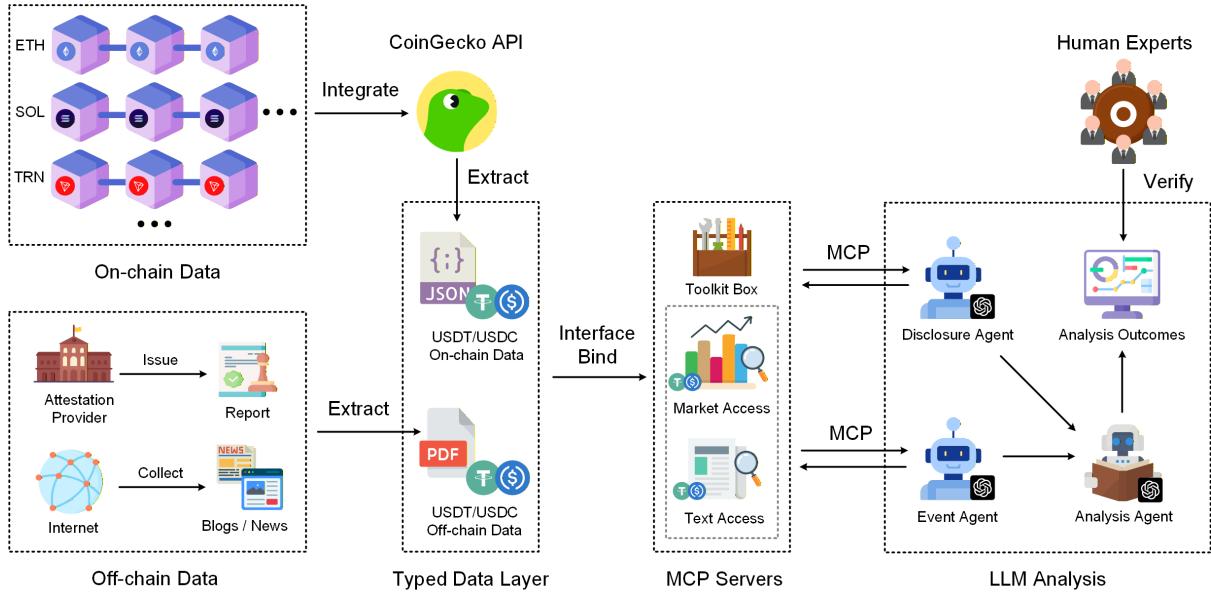


Fig. 1: Framework of the proposed scheme.

- **Module I – Data Collection.** Aggregates on-chain and off-chain information, including market metrics from *CoinGecko* and issuer disclosures from *Tether* and *Circle*.
- **Module II – MCP Unification.** Standardizes access to heterogeneous data sources via the MCP, aligning all data along a common temporal axis for consistent comparison.
- **Module III – LLM Analytical Synthesis.** Employs GPT-5 as the analytical core to retrieve, interpret, and reconcile market and issuer data, producing structured cross-modal analyses.

This modular design enables systematic and interpretable analyses that connect issuer transparency statements with independent market observations, providing a unified and verifiable view of stablecoin integrity. To ensure analytical reliability, all model-generated assessments are subsequently reviewed and validated by human domain experts, guaranteeing the accuracy and interpretability of the outcomes.

A. Module I: Data Collection

This module focuses on integrating quantitative and qualitative dimensions of stablecoin activity through a unified analytical framework. It encompasses data from January 2022 to January 2024, a period sufficient to capture significant market trends and major events influencing the stability and transparency of leading USD-backed stablecoins.

On-chain Data. We collect quantitative on-chain indicators such as market capitalization and token price for both USDT and USDC from *CoinGecko* [28]. These data provide daily aggregated snapshots across all supported blockchains, allowing us to track overall supply fluctuations and price stability over time.

Off-chain Data. Complementary qualitative information is drawn from the official transparency portals of the two largest

stablecoin issuers: *Tether* [29] and *Circle* [30]. We further compile textual disclosures, reserve attestations, and other public statements from these issuers, complemented by publicly available reports and media. These unstructured documents form the basis for semantic extraction and cross-modal alignment with on-chain quantitative metrics.

B. Module II: MCP Module

Architecture. The MCP provides a unified and auditable interface for accessing heterogeneous stablecoin data, connecting market indicators, issuer disclosures, and textual archives through standardized, typed endpoints. All outputs are timestamped and normalized under a common temporal schema, enabling reproducible cross-modal analysis and eliminating inconsistencies arising from asynchronous reporting.

The MCP defines two functional classes encompassing five tools that jointly constitute the data-access layer. The *market class* supplies quantitative inputs via daily price snapshots for USDT and USDC, each returning a structured *PriceSnapshot* object containing price, volume, and capitalization fields. The *textual class* provides qualitative context through three endpoints: two range-query tools that summarize media coverage within date windows, and one direct-access tool retrieving full articles by canonical uniform resource locator (URL).

All endpoints are schema-defined and stateless, producing deterministic outputs keyed by date or URL so that identical queries always yield identical records. Together, these components ensure consistent alignment between numerical and narrative data streams and support verifiable, reproducible analyses across experiments.

Design Properties. The MCP ensures reliable and reproducible access to heterogeneous stablecoin data through three

interrelated properties that jointly guarantee deterministic behavior and modular extensibility. Each market or disclosure endpoint is stateless and keyed by immutable identifiers such as attestation date and blockchain snapshot, ensuring that identical queries always reproduce the same circulation, reserve, or price data. Range queries return compact summaries of daily market activity, supporting efficient and low-latency cross-period analysis.

Furthermore, market, issuer, and textual channels are modularly separated from the analytical reasoning layer. The LLM accesses stablecoin metrics exclusively through typed MCP calls, removing uncontrolled network dependencies and preserving a verifiable trace of every reserve-to-market comparison. This modularity also allows new issuers or data modalities, such as regulatory attestations, to be integrated declaratively without altering the analytical core. Through these mechanisms, the MCP functions as a transparent and auditable bridge that links market indicators, reserve attestations, and textual disclosures within a consistent temporal and structural framework.

C. Module III: LLM Analytical Synthesis

Model Selection. The final module employs GPT-5, a state-of-the-art LLM, as the analytical reasoning engine. GPT-5 is selected for its extensive context capacity, reasoning coherence, and robust integration with external computational tools. Its 400,000-token context window allows entire attestation reports, transaction logs, and historical reserve disclosures to be processed jointly, preserving temporal and semantic continuity that earlier models could not maintain. Through lightweight Python interactions with the MCP server, GPT-5 retrieves and integrates on-chain issuance records, off-chain attestations, and market indicators within a unified analytical environment.

These capabilities enable the model to synthesize heterogeneous information into internally consistent assessments. It evaluates the correspondence between issuer-reported reserves and blockchain-observed circulation, interprets timing differences between disclosure and minting activity, and contextualizes methodological variations across issuers. The resulting analyses provide coherent and interpretable summaries, demonstrating the feasibility of applying a high-capacity reasoning model to transparent and automated evaluation of stablecoin data.

Operational Framework. The analytical reasoning layer implements a *prompt-conditioned code execution framework* in which the LLM functions as a structured decision engine. It orchestrates deterministic data retrieval and synthesis across heterogeneous modalities such as market price feeds and attestation texts through a controlled four-stage reasoning cycle: Thought → Code → Observation → Finalize.

Guided by a fixed system prompt, the model formulates procedural plans, executes corresponding analytical code, and integrates intermediate observations into successive reasoning steps. The cycle concludes with a finalizing stage that yields structured outputs such as reserve discrepancies, correlation

metrics, or alignment summaries between blockchain and disclosure data. Within this operational logic, the model repeatedly applies canonical analytical patterns that formalize how heterogeneous information is interpreted and reconciled.

Agent Design. This multi-agent structure operationalizes the LLM reasoning process, transforming abstract analytical logic into executable and auditable procedures. The architecture consists of three cooperative agents that interact through the MCP interface (as shown in Fig. 1), each fulfilling a distinct role within the reasoning cycle:

- *Disclosure Agent* (agent_disclosure): Parses issuer reports and attestations to extract structured reserve and liability indicators. It interfaces directly with the MCP text and document modules, filters non-extractable or image-only files, and normalizes all valid numerical fields.
- *Event Agent* (agent_event): Retrieves contemporaneous market and chain-level data from MCP market endpoints, constructing a seven-day observation window that spans three days before and after the disclosure date. It establishes a consistent temporal and quantitative context for subsequent evaluation.
- *Analysis Agent* (agent_analysis): Integrates the structured outputs from the disclosure and event agents to produce the final analytical synthesis. Guided by the system prompt, it ranks indicators by importance, evaluates anomaly persistence, magnitude, and scope, and issues a justified classification within normal, suspicious, and abnormal categories.

All agents operate under a shared prompt-conditioned control schema that enforces deterministic data flow and standardized output formatting. The reasoning process follows a reproducible pathway consisting of disclosure and event retrieval, cross-agent binding through MCP, and integrated analysis and classification. This modular design ensures transparency, interpretability, and auditability of analytical outcomes while allowing the LLM to act as a supervisory controller coordinating specialized data agents via the MCP service interface.

Variable Definitions. Table I summarizes the key variables that jointly constitute the data foundation for consistency assessment. Our analysis integrates market data, issuer disclosures, and derived alignment metrics to evaluate the coherence between observed circulation and reported reserves. This unified framework enables systematic comparison between on-chain activity and off-chain attestations, forming the basis for quantitative transparency analysis.

In addition to the variables summarized in Table I, the analysis produces an aggregate result referred to as analysis_outcome. This variable categorizes each observation into three levels: normal, suspicious, and abnormal, based on rule-based thresholds for reserve coverage, attestation quality, and market consistency indicators. Observations with reserve deficits, stale or proxy attestations, or large market discrepancies are labeled as *abnormal*. Cases showing moderate deviations or elevated trading volatility are marked as

suspicious, while all others are considered *normal*, indicating alignment between reported reserves and observed market activity.

TABLE I: Key variables for stablecoin data analysis

Variable	Description
report_date	Reference date of the attestation report.
price_usd	Market price in US dollars.
mcap_usd	Market capitalization derived from supply and price.
volume_daily	Trading volume over the day.
turnover_ratio	Liquidity ratio of volume to market capitalization.
peg_deviation	Deviation of the market price from the one-dollar peg.
volatility_daily	Short-term price volatility over a daily window.
circulation_rep	Reported circulation held by external holders.
asset_value	Total fair value of reserve assets.
liability_value	Total liabilities reported to token holders.
coverage_ratio	Ratio of total assets to total liabilities.
implied_mcap	Market capitalization implied by attested supply and price.
supply_gap	Gap between reported and observed circulation.

In the next section, we demonstrate the practical performance of this approach by applying it to USDT and USDC analysis, quantifying reserve discrepancies, assessing their correlation with market prices, and comparing cross-asset transparency patterns.

IV. EMPIRICAL RESULTS

A. Disclosure Analysis

Overview. This subsection investigates how the attestation layer and on-chain circulation data jointly reveal the reserve adequacy, transparency, and operational behavior of the two dominant fiat-backed stablecoins, i.e., USDT and USDC. Each observation aligns a formal attestation snapshot with contemporaneous blockchain and market indicators drawn from a seven-day window centered on the report date, enabling a cross-view of what issuers disclose versus what the market and on-chain supply actually exhibit.

The analysis emphasizes how attestation quality, reporting cadence, and reserve composition interact with measurable on-chain indicators such as the coverage ratio, turnover ratio, and peg deviation, tracing how reserve information is transmitted into observable price and liquidity dynamics. The empirical outcomes summarized in Tables II and III provide the quantitative basis for this examination.

USDT. As shown in Table II, USDT maintains a consistently narrow price band around its one dollar target throughout all eight observations, with deviations rarely exceeding around 0.2%. Market capitalization remains large and relatively stable, hovering between USD 66 billion (abbreviated as \$66B) and \$92B while daily trading volumes reach tens of billions. This implies high liquidity and continuous market participation. The turnover ratio oscillates between 0.1 and 0.8, peaking during mid-2022, which reflects intense trading activity rather than structural reserve stress. Reported reserves exhibit strong nominal coverage where coverage ratios range from 1.00 to

1.06, and reported liabilities closely match on-chain circulation with supply gaps generally below 0.3%.

Despite this overall adequacy, early observations reveal moments of tension between disclosure timing and market conditions. The May 2022 attestation is classified as abnormal, and August 2022 as suspicious, both coinciding with high turnover above 0.55 and elevated market volatility. These classifications indicate that attestation data lagged real-time adjustments in circulation during a period of broader crypto-market stress. Afterward, turnover normalizes below 0.25, peg deviations tighten toward zero, and classifications return to normal. Nonetheless, Tether's irregular attestation schedule (typically quarterly) and limited auditor transparency constrain the precision of its informational signal.

Overall, USDT displays strong peg stability and liquidity resilience but weaker disclosure reliability. Its coverage remains ample, yet the irregular frequency and limited assurance level of attestations suggest that market confidence is sustained more by liquidity depth and convertibility than by the clarity or rigor of its reserve reporting.

USDC. Table III illustrates that USDC likewise sustains a tight peg, with prices consistently within around 0.15% of \$1.00 across 2022–2024. Market capitalization declines from about \$50B in early 2022 to roughly \$25B by late 2023, but this contraction is accompanied by steady coverage ratios near 1.00–1.01 and small supply gaps, indicating accurate synchronization between reported reserves and circulating supply. Trading volumes fluctuate in the low single-digit billions per day, and turnover remains moderate that is mostly between 0.05 and 0.3, suggesting more stable transactional use rather than speculative churn.

Most USDC disclosures are labeled normal, with a few suspicious designations in November 2022 and again during mid-late 2023. These correspond to short-lived increases in turnover (up to 0.29) and small shifts in reported circulation, not to peg divergence or reserve shortfall. Crucially, each attestation is issued on a fixed monthly basis by Grant Thornton using standardized accounting procedures, which reduces temporal lag and enhances methodological transparency. This consistent cadence ensures that reserve data remain timely and comparable across periods, facilitating market verification and minimizing informational asymmetry.

In sum, USDC's disclosure framework combines high transparency with operational regularity. Even amid supply contraction, the alignment between attested and on-chain values and the predictability of reporting cadence indicate strong disclosure governance and a higher level of informational assurance than its peers.

Comparative Insights. Both USDT and USDC maintain effective reserve coverage and close peg adherence, yet their disclosure dynamics diverge systematically along three dimensions: operational scale, attestation structure, and transparency consistency.

First, in terms of *scale* and *liquidity*, USDT dominates: its capitalization and daily trading activity are several times larger,

TABLE II: USDT data overview and analysis outcomes

report_date	price_usd	mcap_usd	volume_daily	turnover_ratio	peg_deviation (%)	volatility_daily	circulation_rep	asset_value	liability_value	coverage_ratio	implied_mcap	supply_gap (%)	analysis_outcome
18/05/2022	9.996E-01	8.227E+10	6.479E+10	7.875E-01	-3.550E-02	6.349E-02	8.219E+10	8.242E+10	8.226E+10	1.002E+00	8.216E+10	1.384E-01	abnormal
10/08/2022	1.001E+00	6.630E+10	3.764E+10	5.676E-01	1.486E-01	3.043E-01	6.627E+10	6.641E+10	6.620E+10	1.003E+00	6.637E+10	-1.000E-01	suspicious
10/11/2022	1.002E+00	6.785E+10	2.380E+10	3.508E-01	1.976E-01	1.074E-01	6.781E+10	6.806E+10	6.781E+10	1.004E+00	6.794E+10	-1.270E-01	normal
08/02/2023	1.000E+00	6.622E+10	1.727E+10	2.607E-01	1.789E-02	3.847E-02	6.606E+10	6.704E+10	6.608E+10	1.015E+00	6.607E+10	2.334E-01	normal
09/05/2023	1.002E+00	7.979E+10	1.894E+10	2.373E-01	2.022E-01	8.336E-02	7.945E+10	8.183E+10	7.939E+10	1.031E+00	7.961E+10	2.263E-01	normal
31/07/2023	9.990E-01	8.328E+10	9.642E+09	1.158E-01	-9.810E-02	8.073E-02	8.326E+10	8.650E+10	8.320E+10	1.040E+00	8.318E+10	1.152E-01	normal
31/10/2023	9.999E-01	8.327E+10	1.842E+10	2.213E-01	-1.380E-02	0.000E+00	8.324E+10	8.638E+10	8.318E+10	1.039E+00	8.323E+10	5.153E-02	normal
31/01/2024	1.002E+00	9.172E+10	5.521E+10	6.020E-01	2.024E-01	1.114E-01	9.166E+10	9.702E+10	9.160E+10	1.059E+00	9.185E+10	-1.440E-01	normal

TABLE III: USDC data overview and analysis outcomes

report_date	price_usd	mcap_usd	volume_daily	turnover_ratio	peg_deviation (%)	volatility_daily	circulation_rep	asset_value	liability_value	coverage_ratio	implied_mcap	supply_gap (%)	analysis_outcome
25/02/2022	1.001E+00	4.979E+10	1.917E+09	3.850E-02	7.130E-02	0.000E+00	5.003E+10	5.003E+10	5.003E+10	1.000E+00	5.007E+10	-5.450E-01	normal
31/03/2022	1.002E+00	5.357E+10	3.635E+09	6.786E-02	2.436E-01	1.438E-02	5.350E+10	5.350E+10	5.350E+10	1.000E+00	5.363E+10	-1.070E-01	normal
29/04/2022	1.003E+00	5.185E+10	3.853E+09	7.430E-02	3.268E-01	2.310E-01	5.139E+10	5.139E+10	5.139E+10	1.000E+00	5.156E+10	5.750E-01	normal
23/05/2022	9.984E-01	4.914E+10	4.521E+09	9.200E-02	-1.640E-01	6.748E-02	4.926E+10	4.926E+10	4.926E+10	1.000E+00	4.918E+10	-7.750E-02	normal
28/07/2022	1.001E+00	5.581E+10	4.017E+09	7.198E-02	1.360E-01	4.323E-02	5.557E+10	5.557E+10	5.557E+10	1.000E+00	5.565E+10	3.006E-01	normal
24/08/2022	9.988E-01	5.440E+10	8.372E+09	1.539E-01	-1.200E-01	1.845E-01	5.449E+10	5.462E+10	5.449E+10	1.002E+00	5.442E+10	-4.180E-02	normal
23/09/2022	1.000E+00	5.184E+10	4.652E+09	8.973E-02	1.376E-01	1.655E-01	5.226E+10	5.243E+10	5.226E+10	1.003E+00	5.227E+10	-8.140E-01	normal
25/10/2022	1.000E+00	4.743E+10	2.504E+09	5.280E-02	3.755E-02	2.172E-01	4.726E+10	4.748E+10	4.726E+10	1.005E+00	4.728E+10	3.165E-01	normal
22/11/2022	1.000E+00	4.258E+10	6.534E+09	1.534E-01	-3.630E-03	7.794E-02	4.351E+10	4.375E+10	4.351E+10	1.006E+00	4.351E+10	-2.120E+00	suspicious
22/12/2022	1.001E+00	4.323E+10	2.212E+09	5.118E-02	1.218E-01	7.651E-02	4.324E+10	4.340E+10	4.324E+10	1.004E+00	4.329E+10	-1.510E-01	normal
25/01/2023	1.000E+00	4.469E+10	1.550E+09	3.469E-02	2.837E-02	2.471E-02	4.455E+10	4.469E+10	4.455E+10	1.003E+00	4.457E+10	2.868E-01	normal
02/03/2023	1.002E+00	4.254E+10	4.071E+09	9.571E-02	2.254E-01	1.240E-01	4.229E+10	4.234E+10	4.229E+10	1.001E+00	4.238E+10	3.701E-01	normal
30/03/2023	1.001E+00	4.256E+10	3.004E+09	7.059E-02	7.531E-02	5.923E-02	4.240E+10	4.246E+10	4.240E+10	1.001E+00	4.244E+10	2.789E-01	normal
28/04/2023	1.001E+00	3.256E+10	2.906E+09	8.925E-02	1.369E-01	8.751E-02	3.252E+10	3.257E+10	3.252E+10	1.002E+00	3.256E+10	4.528E-03	normal
30/05/2023	1.000E+00	3.051E+10	4.963E+09	1.627E-01	4.030E-02	5.279E-03	3.049E+10	3.055E+10	3.049E+10	1.002E+00	3.051E+10	2.788E-03	normal
30/06/2023	9.997E-01	2.890E+10	2.594E+09	8.974E-02	-3.220E-02	1.171E-01	2.887E+10	2.893E+10	2.887E+10	1.002E+00	2.886E+10	1.413E-01	normal
28/07/2023	9.998E-01	2.795E+10	3.538E+09	1.266E-01	-2.480E-02	1.184E-02	2.738E+10	2.744E+10	2.738E+10	1.002E+00	2.738E+10	2.104E+00	suspicious
30/08/2023	9.997E-01	2.619E+10	4.492E+09	1.715E-01	-2.620E-02	1.721E-01	2.641E+10	2.646E+10	2.641E+10	1.002E+00	2.640E+10	-7.830E-01	normal
29/09/2023	9.998E-01	2.614E+10	4.230E+09	1.618E-01	-2.360E-02	3.723E-04	2.615E+10	2.621E+10	2.615E+10	1.002E+00	2.615E+10	-8.150E-03	normal
30/10/2023	9.996E-01	2.558E+10	6.656E+09	2.602E-01	-4.140E-02	6.145E-04	2.497E+10	2.503E+10	2.497E+10	1.002E+00	2.496E+10	2.469E+00	suspicious
30/11/2023	1.000E+00	2.493E+10	7.160E+09	2.872E-01	8.055E-03	2.304E-01	2.467E+10	2.472E+10	2.467E+10	1.002E+00	2.467E+10	1.065E+00	suspicious
22/12/2023	1.000E+00	2.455E+10	6.943E+09	2.827E-01	2.507E-02	4.532E-02	2.448E+10	2.453E+10	2.448E+10	1.002E+00	2.448E+10	2.911E-01	normal
30/01/2024	9.985E-01	2.484E+10	1.298E+10	5.223E-01	-1.480E-01	1.288E-01	2.464E+10	2.469E+10	2.464E+10	1.002E+00	2.460E+10	9.665E-01	normal

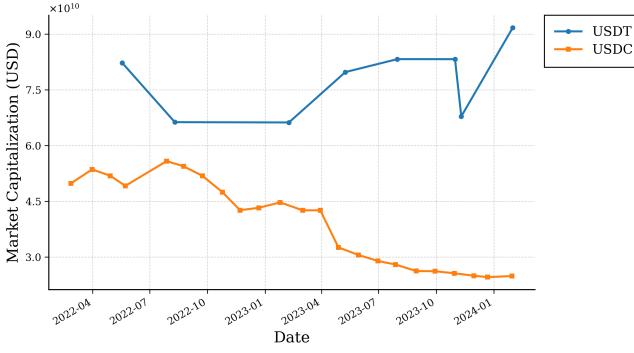
Note: The disclosure file on 22/06/2022 is image-based and therefore excluded from the analysis.

supporting its role as the primary settlement medium in crypto markets. As shown in Fig. 2, USDT's market capitalization remains above \$60B while USDC steadily declines below \$30B, and its trading volume consistently exceeds that of USDC by a wide margin. These patterns confirm USDT's dominant market presence and substantiate the interpretation that its scale advantage underpins higher transactional velocity. However, this same liquidity intensity contributes to greater short-term variability in turnover and occasional classification anomalies, particularly during stress periods.

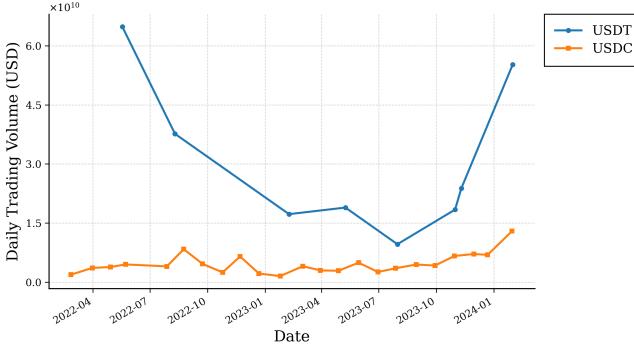
Second, regarding *disclosure cadence* and *assurance*, USDC's standardized monthly attestations contrast with USDT's irregular and less formal reporting cycle. As illustrated in Fig. 3, both stablecoins maintain coverage ratios at or above one, but USDT's ratio rises sharply after mid-2022, exceeding 1.05 by early 2024, while USDC stays close to parity throughout. This divergence highlights how USDC's stable and well-verified disclosures support steady confidence,

whereas USDT's more variable reserve margin reflects less frequent updates and greater sensitivity to market conditions. While both maintain coverage above unity, USDC's higher attestation frequency and consistent auditor engagement strengthen the reliability of its reserve representation, whereas USDT's episodic reports leave temporary informational gaps that coincide with market stress episodes.

Third, in terms of *behavioral patterns* and *classification outcomes*, USDT's few abnormal and suspicious observations align with periods of heightened trading and redemption pressure, implying sensitivity to liquidity shocks and reporting lag. As shown in Fig. 4, USDT exhibits sharper swings in peg deviation and a wider range of turnover ratios, often above 0.5 during stress intervals, whereas USDC remains comparatively stable with smaller fluctuations around zero deviation and lower turnover. These patterns reinforce that USDT's market behavior is more reactive to shocks, while USDC's steadier profile reflects slower but more controlled

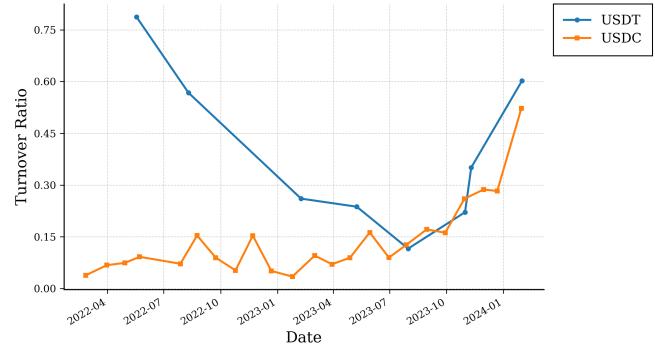


(a) Market capitalization

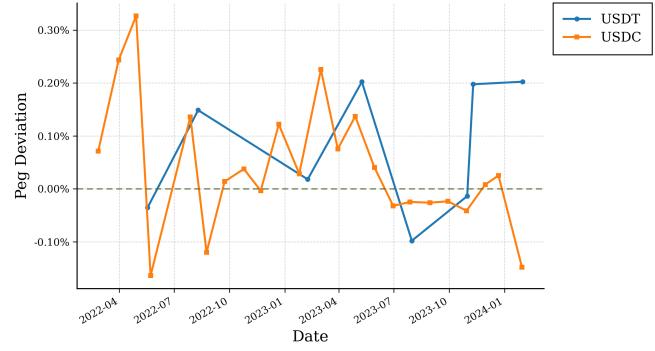


(b) Daily trading volume

Fig. 2: Comparative scale and liquidity indicators of major stablecoins.



(a) Turnover ratio



(b) Peg deviation

Fig. 4: Comparative liquidity dynamics and peg stability indicators of major stablecoins.

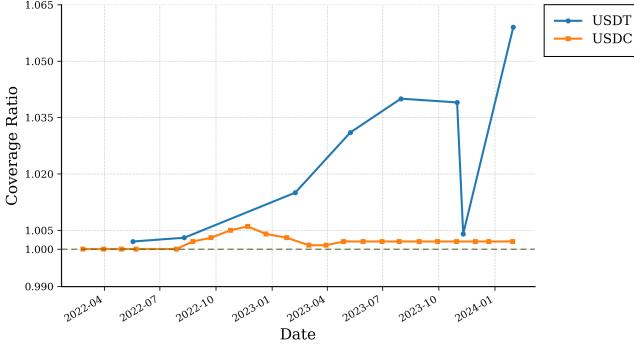


Fig. 3: Comparative reserve coverage and disclosure indicators of major stablecoins.

adjustment dynamics. By contrast, USDC’s limited suspicious flags are isolated and transitory, reflecting minor operational frictions rather than structural misalignment.

Taken together, these findings highlight a trade-off between scale-driven liquidity assurance and disclosure-driven transparency assurance. USDT exemplifies a market-dominant but disclosure-light model, where stability depends on liquidity depth and redemption capacity. USDC, although smaller in scale, demonstrates a disclosure-centric equilibrium in which predictable attestation practices and transparent reserve reconciliation underpin market trust. This contrast underscores

how stability in fiat-backed stablecoins can emerge from either market liquidity depth or institutionalized transparency, which are two distinct but complementary mechanisms of credibility.

B. Even Analysis

May 2022: Terra Collapse and USDT Deppeg. The first stress episode occurred on May 12, 2022, amid the collapse of the algorithmic stablecoin UST between May 7–13, 2022 [31], [32]. During this period, USDT briefly lost its peg, averaging about \$0.996 with daily trading volume near \$150B. In contrast, USDC remained slightly above parity at around \$1.001 with increased activity. Between May 11 and May 13, USDT’s market capitalization fell by roughly \$3.8B, while USDC’s rose by about \$1.4B, indicating a short-term flight to quality. On May 13, Tether issued an assurance update reaffirming full reserve backing and highlighting a shift toward U.S. Treasury bill holdings to reinforce confidence.

The LLM analysis captured rapid circulation changes and attestation responses during the episode. On-chain data showed accelerated USDT redemptions and simultaneous USDC inflows into exchanges, consistent with the observed market-cap shifts. Off-chain disclosures verified that Tether adjusted its reserve mix within weeks, and the LLM identified the temporal alignment between attestation language emphasizing liquidity quality and observed recovery of peg stability. The model correctly inferred that the disclosure cadence lagged real-time

market stress, explaining why the classification model briefly marked May 2022 as an abnormal disclosure phase.

March 2023: U.S. Banking Turmoil and USDC Depeg.

The second major shock occurred from March 10–13, 2023, when Silicon Valley Bank (SVB) collapsed amid broader U.S. banking turmoil [33], [34]. *Circle* subsequently disclosed about \$3.3B of USDC reserves held at SVB, triggering a temporary depeg: USDC fell to roughly \$0.88–0.90 on March 11 before rebounding to \$1 by March 13 after regulators guaranteed deposits. During this period, USDT traded at a small premium of about \$1.01 as investors rotated liquidity. Both stablecoins experienced sharp volume increases, but net flows favored USDT, expanding its market share while USDC contracted.

The LLM detected a pronounced divergence between off-chain reserve exposure and on-chain circulation behavior. It linked the timing of SVB-related disclosures with observed contraction in USDC mint/burn activity and rising USDT transaction velocity. By combining attestation metadata, reserve composition, and transaction-level flows, the LLM identified that the root cause of the instability lay in off-chain counterparty concentration rather than on-chain redemption mechanics. This reasoning was validated by post-event data, as market equilibrium returned once regulatory assurances restored confidence.

V. DISCUSSION

A. Strengths

The proposed framework demonstrates significant advantages in bridging the gap between on-chain verifiable data and off-chain textual disclosures. By integrating these heterogeneous sources under a unified MCP, the system enables structured, reproducible, and interpretable analyses that were previously infeasible using traditional financial auditing methods. This unified architecture allows analysts and regulators to cross-validate issuer claims with blockchain evidence in near real time, improving both accountability and data transparency. The use of an LLM such as GPT-5 further enhances interpretability by extracting and normalizing complex attestation narratives to create a semantic bridge between human-readable documents and quantitative blockchain data.

Another key advantage lies in automation and scalability. Manual reviews of reserve attestations are costly, error-prone, and infrequent. The LLM-driven approach automates this process with high precision and adaptability across issuers and time periods. Its multi-agent structure ensures modularity where each agent handles disclosure parsing, event detection, or cross-validation independently, allowing new issuers or asset classes to be integrated with minimal overhead. The combination of rule-based classification and expert validation provides a transparent decision pipeline, reducing subjective bias while maintaining analytical rigor. Given the agent-based coordination and embedded validation mechanisms, the extracted data demonstrate internal accuracy, although future extensions could incorporate formal benchmarking for

completeness. In practice, this framework can serve as an independent auditing layer for decentralized finance (DeFi), supporting data-driven oversight and early detection of reserve inconsistencies or systemic risks.

B. Limitations

Despite its strengths, several limitations remain. First, the reliability of the framework ultimately depends on data quality and availability. Many issuer disclosures are provided in unstructured or image-based formats, limiting extraction accuracy even with advanced language models. Inconsistent attestation schedules or incomplete reserve details may also hinder perfect temporal alignment between disclosure and market observations. While the LLM's contextual understanding mitigates some of these challenges, residual uncertainty remains in cases where off-chain data lack verifiable granularity. Additionally, the reliance on publicly available sources implies that any omission or delay in publication directly constrains the analytical scope.

Second, the framework's current evaluation logic is partly rule-based, which is interpretable but may not fully capture nonlinear dependencies between market indicators, such as multi-day liquidity feedback or contagion dynamics. The use of threshold-driven classification provides transparency but may oversimplify complex causal relationships during extreme market conditions. Moreover, the model does not yet incorporate real-time streaming data or adaptive calibration based on evolving issuer behavior. Future work should integrate dynamic statistical learning methods, multimodal embeddings, and regulator-verified data pipelines to enhance robustness, precision, and temporal responsiveness.

VI. CONCLUSION

This study presents an automated and interpretable framework that employs LLMs to connect on-chain and off-chain transparency in stablecoins. By integrating blockchain data, issuer attestations, and market indicators within a unified analytical protocol, the framework quantifies reserve discrepancies, disclosure timeliness, and stability behavior for leading fiat-backed stablecoins. The empirical analysis of USDT and USDC shows that the approach effectively identifies transparency gaps, aligns issuer statements with observable data, and reveals that market liquidity and disclosure quality represent two distinct sources of stability.

Future work will focus on extending the framework toward real-time and multimodal auditing. Incorporating image-based attestations, regulatory data feeds, and causal reasoning modules can further enhance analytical reliability and interpretability. By operationalizing cross-modal consistency, the approach converts fragmented on-chain and off-chain information into coherent transparency indicators that support automated, data-driven auditing and strengthen accountability, oversight, and public trust in the stablecoin ecosystem.

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REFERENCES

- [1] C. Catalini, A. de Gortari, and N. Shah, "Some simple economics of stablecoins," *Annual Review of Financial Economics*, vol. 14, no. 1, pp. 117–135, 2022.
- [2] H. Mai and D. B. AG, "Stablecoins: Defi, libra and beyond," *Deutsche Bank Research*, 2022.
- [3] C. T. Ba, B. Steer, M. Zignani, and R. Clegg, "Investigating the luna-terra collapse through the temporal multilayer graph structure of the ethereum stablecoin ecosystem," *ACM Transactions on the Web*, 2025.
- [4] A. Briola, D. Vidal-Tomás, Y. Wang, and T. Aste, "Anatomy of a stablecoin's failure: The terra-luna case," *Finance Research Letters*, vol. 51, p. 103358, 2023.
- [5] K. Duan and A. Urquhart, "The instability of stablecoins," *Finance Research Letters*, vol. 52, p. 103573, 2023.
- [6] F. J. J. Fernández, M. Á. E. Fernández, and S. L. N. Alonso, "The asset-backing risk of stablecoin trading: The case of tether," *Economics and Business Review*, vol. 10, no. 1, pp. 57–80, 2024.
- [7] Y. Xiang, Y. Lei, D. Bao, T. Li, Q. Yang, W. Liu, W. Ren, and K.-K. R. Choo, "Babd: A bitcoin address behavior dataset for pattern analysis," *IEEE Transactions on Information Forensics and Security*, vol. 19, pp. 2171–2185, 2024.
- [8] N. Tovanich, N. Soulié, N. Heulot, and P. Isenberg, "An empirical analysis of pool hopping behavior in the bitcoin blockchain," in *2021 IEEE International Conference on Blockchain and Cryptocurrency (ICBC)*. IEEE, 2021, pp. 1–9.
- [9] D. Chaudhari, R. Agarwal, and S. K. Shukla, "Towards malicious address identification in bitcoin," in *2021 IEEE international conference on blockchain (Blockchain)*. IEEE, 2021, pp. 425–432.
- [10] A. Wahrstätter, J. Gomes, S. Khan, and D. Svetinovic, "Improving cryptocurrency crime detection: Coinjoin community detection approach," *IEEE Transactions on Dependable and Secure Computing*, vol. 20, no. 6, pp. 4946–4956, 2023.
- [11] Y. Xiang, T. Li, and Y. Li, "Leveraging subgraph structure for exploration and analysis of bitcoin address," in *2022 IEEE International Conference on Big Data (Big Data)*. IEEE, 2022, pp. 1957–1962.
- [12] G. Yu, Q. Wang, T. Altaf, X. Wang, X. Xu, and S. Chen, "Predicting nft classification with gnn: A recommender system for web3 assets," in *2023 IEEE International Conference on Blockchain and Cryptocurrency (ICBC)*. IEEE, 2023, pp. 1–5.
- [13] A. Mahrouse, M. Caprolu, and R. Di Pietro, "Sok: A structured analysis of economic and technical stablecoin-related research," in *2025 IEEE International Conference on Blockchain and Cryptocurrency (ICBC)*. IEEE, 2025, pp. 1–21.
- [14] L. Ante, I. Fiedler, J. M. Willruth, and F. Steinmetz, "A systematic literature review of empirical research on stablecoins," *FinTech*, vol. 2, no. 1, pp. 34–47, 2023.
- [15] K. Ito, M. Mita, S. Ohsawa, and H. Tanaka, "What is stablecoin?: A survey on its mechanism and potential as decentralized payment systems," *International Journal of Service and Knowledge Management*, vol. 4, no. 2, pp. 71–86, 2020.
- [16] A. Moin, K. Sekniqi, and E. G. Sirer, "Sok: A classification framework for stablecoin designs," in *International conference on financial cryptography and data security*. Springer, 2020, pp. 174–197.
- [17] G. Baughman, F. Carapella, J. Gerszten, and D. C. Mills, "The stable in stablecoins," *FEDS Notes*, no. 2022-12, p. 17, 2022.
- [18] G. Gadzinski, A. Castello, and F. Mazzorana, "Stablecoins: Does design affect stability?" *Finance Research Letters*, vol. 53, p. 103611, 2023.
- [19] Y. Potter, K. Pongmala, K. Qin, A. Klages-Mundt, P. Jovanovic, C. Parfoulour, A. Gervais, and D. Song, "What drives the (in) stability of a stablecoin?" in *2024 IEEE International Conference on Blockchain and Cryptocurrency (ICBC)*. IEEE, 2024, pp. 316–324.
- [20] A. Klages-Mundt, D. Harz, L. Gudgeon, J.-Y. Liu, and A. Minca, "Stablecoins 2.0: Economic foundations and risk-based models," in *Proceedings of the 2nd ACM Conference on Advances in Financial Technologies*, 2020, pp. 59–79.
- [21] D. Li, D. Han, T.-H. Weng, Z. Zheng, H. Li, and K.-C. Li, "On stablecoin: Ecosystem, architecture, mechanism and applicability as payment method," *Computer Standards & Interfaces*, vol. 87, p. 103747, 2024.
- [22] R. K. Lyons and G. Viswanath-Natraj, "What keeps stablecoins stable?" *Journal of International Money and Finance*, vol. 131, p. 102777, 2023.
- [23] I. G. A. Pernice, "On stablecoin price processes and arbitrage," in *International Conference on Financial Cryptography and Data Security*. Springer, 2021, pp. 124–135.
- [24] L. T. Hoang and D. G. Baur, "How stable are stablecoins?" *The European Journal of Finance*, vol. 30, no. 16, pp. 1984–2000, 2024.
- [25] B. N. Thanh, T. N. V. Hong, H. Pham, T. N. Cong, and T. P. T. Anh, "Are the stabilities of stablecoins connected?" *Journal of Industrial and Business Economics*, vol. 50, no. 3, pp. 515–525, 2023.
- [26] L. Ante, I. Fiedler, and E. Strehle, "The influence of stablecoin issuances on cryptocurrency markets," *Finance Research Letters*, vol. 41, p. 101867, 2021.
- [27] J. Fernandez-Mejia, "Extremely stablecoins," *Finance Research Letters*, vol. 63, p. 105268, 2024.
- [28] CoinGecko. (2025) Coingecko. Accessed: Oct. 10, 2025. [Online]. Available: <https://www.coingecko.com>
- [29] Tether Holdings Limited. (2025) Tether transparency. Accessed: Oct. 10, 2025. [Online]. Available: <https://tether.to/en/transparency>
- [30] Circle Internet Financial, LLC. (2025) Circle transparency and reserve disclosures. Accessed: Oct. 10, 2025. [Online]. Available: <https://www.circle.com/transparency>
- [31] R. De Blasis, L. Galati, A. Webb, and R. I. Webb, "Intelligent design: stablecoins (in) stability and collateral during market turbulence," *Financial Innovation*, vol. 9, no. 1, p. 85, 2023.
- [32] B. Eichengreen, M. T. Nguyen, and G. Viswanath-Natraj, "Stablecoin devaluation risk," *The European Journal of Finance*, pp. 1–28, 2025.
- [33] A. E. Wilmarth Jr, "We must protect investors and our banking system from the crypto industry," *Wash. UL Rev.*, vol. 101, p. 235, 2023.
- [34] P. O. Diop, J. Chevallier, and B. Sanhaji, "Collapse of silicon valley bank and usdc depegging: A machine learning experiment," *FinTech*, vol. 3, no. 4, pp. 569–590, 2024.