Stablecoin Devaluation Risk

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Abstract

Stablecoins' reliance on centralized custodians introduces devaluation risk similar to that of traditional currencies under fixed exchange rate regimes. We construct market-based measures of stablecoin devaluation risk using spot and futures prices for Tether, estimating an average devaluation probability of 60 basis points annually and peaking at over 200 basis points during the 2022 Terra-Luna crash. Key risk factors include market volatility and transaction velocity, with elevated interest rates indicating devaluation risk. Deviations from covered interest rate parity point to segmentation between traditional and stablecoin markets, driven by leverage trading and arbitrage costs. Our findings suggest the need for increased transparency and regulatory oversight to mitigate stablecoin risk.

Keywords: Cryptocurrency, stablecoins, futures, bank runs, Tether, Bitcoin

JEL Classifications: E5, F3, F4, G15, G18

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1 Introduction and Motivation

Stablecoins are popular onramps and offramps for purchases and sales of units in the digital universe. They are widely utilized as vehicles for transactions in popular cryptocurrencies such as Bitcoin (BTC), for example. They find some use for remittances and other cross-border transactions (von Luckner et al., 2021; Adams et al., 2023). Their advocates suggest that they will gain broader acceptance in financial and commercial transactions.

The dominant stablecoins rely on a centralized custodian of assets held as collateral or reserves, where these assets are held off-chain. Sometimes such assets, or a portion thereof, are less liquid than the custodian's liabilities – that is, than the stablecoin itself. This resembles the liquidity mismatch that characterizes the balance sheet of a bank whose business is maturity transformation. It thus gives rise to a problem of run risk analogous to that to which banks are subject. Relatedly, there is an analogy between a run on a central bank seeking to maintain a set value for a national currency (seeking to defend a currency peg), something that if sufficiently intense can result in the currency's devaluation, and a run on a centralized custodian seeking to maintain a set value for a stablecoin against a national currency, something that if sufficiently intense can force that set value to be abandoned.

It follows that stablecoin devaluation risk can be priced using futures contracts in much the manner that the risk that a national currency will be devalued can be priced using forward foreign exchange contracts. Our analysis of this relationship focuses on Tether, the most actively traded stablecoin and the only one with traded futures. We use these futures to construct a measure of devaluation risk, which we define as the probability of a speculative attack on the stablecoin peg.

We show that Tether futures regularly trade at a discount to spot prices. On average, Tether devaluation risk implicit in this discount is priced at approximately 60 points in annualized terms. There is also significant time variation: the peak annualized devaluation probability through mid-2022 was 200 basis points.

This devaluation risk is increasing in Bitcoin volatility. Higher volatility may induce more transactions by investors who have taken BTC positions on margin, transactions that may cause them to close out their positions in the stablecoin. In turn this will require the centralized custodian to liquidate collateral. Since liquidating collateral can be easier said than done, this need, and the associated uncertainty, show up as an increase in the perceived probability of devaluation.

Network characteristics such as stablecoin velocity (rate of turnover) and redemptions are also associated with an increase in devaluation risk. Increased velocity may indicate that investors are paying more attention to the custodian's balance sheet and trading in response. Increased redemption behavior may intensify contagion effects and the risk that individual investors, in touch with one another or observing one another's transactions, will launch an attack on the stablecoin.[1]

Two case studies illustrate these connections. Our first case study is the TerraUSD crash of May 9th, 2022, when Tether's price fell to 95 cents in intra-day trading. We document an estimated 200 basis point probability of Tether devaluation. We observe an increase in velocity and redemption behavior as some investors exited the cryptocurrency market and others re-balanced their portfolios toward other cryptocurrencies.

The second case study is USDC stablecoin de-pegging when Silicon Valley Bank went bust in March 2023. This event raised concerns about whether USDC was still fully backed, given that USDC held reserves at SVB. At one point, USDC fell to 87 cents. This rise in perceived devaluation risk was accompanied by a rise in monetary velocity, just as in the TerraUSD crash (our second case study). USDC stabilized when it successfully transferred cash reserves at SVB to other banking partners. Redemptions following the event then helped stabilize the coin's secondary market value.

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[1] For example, large deposit outflows are alleged to have facilitated the run on Silicon Valley Bank (Vo and Le, 2023).

Investors can be compensated for devaluation risk through stablecoin lending, earning interest that reflects this risk (Gorton et al., 2022b). We examine the behavior of Tether's borrowing and lending interest rates, analyzing how they are influenced by devaluation risk, by the Crypto Fear and Greed Index, and by USD money market rates. Our analysis reveals that a one percentage point increase in devaluation risk corresponds to a similar rise in Tether interest rates on platforms like Compound and Aave, indicating that these rates compensate for risk. We also find a strong positive correlation between the Crypto Fear and Greed Index and stablecoin interest rates, suggesting that market optimism raises interest rates as traders take leveraged positions through stablecoin borrowing.

Stablecoin rates are negatively correlated with USD money market rates in our sample, in contrast to the positive pass-through expected from monetary policy to traditional money-market rates. Further evidence of this disconnect between money market and stablecoin rates is the lack of response to Federal Reserve announcements. While conventional money market instruments typically react to changes in the Fed funds rate on announcement days, stablecoin interest rates are unaffected. An analysis of variance (ANOVA) shows that market sentiment is the primary driver of stablecoin interest rate variation, explaining 22%, while devaluation risk and money market rates contribute just 3.5% and 1%, respectively. Our findings highlight a disconnect between traditional financial and stablecoin markets.

We conduct a formal test of market integration by constructing a measure of covered interest rate parity. This parity condition compares rates after hedging exchange rate risk using futures contracts. Stablecoin interest rates are systematically higher than money market rates during our sample after hedging exchange rate risk. There are systematic deviations from covered interest parity, in other words. As explanations, we point to market segmentation due to the presence of leveraged trading and limits to arbitrage between the two markets. The latter include the lack of term structure in DeFi interest rates, lack of arbitrage capital in cryptocurrency markets, and costs of arbitrage such as gas fees charged to validate transactions on the blockchain.

Over time, stablecoins could potentially come to be used more widely for remittances and other payments, leading to closer connections between stablecoin markets and traditional financial markets. If these connections strengthen, concerns may arise about volatility in stablecoin markets spilling over into conventional financial systems. The question is what to do about this. One approach might involve limiting stablecoin volatility through real-time audits using proof-of-reserve systems. These systems, powered by smart contracts, would allow new tokens to be minted only when verified reserve balances increase, providing real-time detection of custodial issues.

Another approach could be for regulatory authorities to license stablecoin platforms, impose capital and liquidity requirements, and conduct regular audits of their balance sheets, similar to how banks are regulated. Alternative private money arrangements, such as tokenized deposits and reserve-backed tokens, could preserve monetary stability by ensuring that issuers operate as narrow banks with fully backed assets (Garratt and Shin, 2023; Goel, 2024). These options, which we discuss further in an online appendix, offer different strategies for managing the risks associated with stablecoins.

Related Literature. Our work contributes to a growing literature on stablecoin markets. Empirical studies have examined stablecoin properties and compared them with traditional financial assets (Eichengreen, 2019; Berentsen and Schär, 2019; Bullmann et al., 2019; Dell'Erba, 2019; Arner et al., 2020; Frost et al., 2020; Force et al., 2020; Barthelemy et al., 2021; Oefele et al., 2023), explored arbitrage opportunities in cryptocurrency markets (Lyons and Viswanath-Natraj, 2023; Makarov and Schoar, 2019, 2020; Borri and Shakhnov, 2018; Pernice, 2021; Kozhan and Viswanath-Natraj, 2021; Ma et al., 2023; Hautsch et al., 2018), and analyzed stablecoin price dynamics (Baur and Hoang, 2020; Hoang and Baur, 2021, 2020; Baumöhl and Vyrost, 2020; Wang et al., 2020; Bianchi et al., 2020; Gloede and Moser, 2021; Nguyen et al., 2022; Duan and Urquhart, 2023). Additionally, studies have discussed the macroeconomic and financial stability implications of stablecoins (Cong and Mayer, 2021; Catalini and de Gortari, 2021; Catalini and Shah, 2021; Allen et al., 2022; Gorton and Zhang, 2021; Gorton et al., 2022a; Murakami and Viswanath-Natraj, 2021; Barthelemy et al., 2021; Kim, 2022; Liu et al., 2023; Martin, 2022; Charoenwong et al., 2022; Dionysopoulos et al., 2024). Our work is perhaps most closely related to the concept of stablecoin inconvenience yields, as discussed by Gorton and Zhang (2021); Gorton et al. (2022a), which suggests that stablecoins require higher interest rates due to their imperfect substitution for conventional money.

In terms of the literature on interest rates in lending protocols (Gorton et al., 2022b; Chaudhary et al., 2023; Barbon et al., 2023; Heimbach and Huang, 2023; Park and Stinner, 2023; Cornelli et al., 2024), we complement Gorton et al. (2022b) by demonstrating that stablecoin devaluation risk is priced and that leveraged trading driven by market sentiment significantly influences interest rate variation on these platforms.

Theoretically, our study aligns with research on stablecoin price dynamics, reserve buffers, and over-collateralization aimed at preventing speculative attacks and peg discounts (Routledge and Zetlin-Jones, 2018; Li and Mayer, 2021; Cong et al., 2021; Kwon et al., 2021; d'Avernas et al., 2022; Bertsch, 2022; Uhlig, 2022; Aldasoro et al., 2023). We link our empirical measure of stablecoin devaluation risk to speculative demand, network characteristics, and market volatility, supporting the theoretical framework of stablecoin runs in Bertsch (2022).

Finally, our paper relates to the literature on speculative attacks on pegged exchange rates and models of devaluation risk in currency boards (Obstfeld, 1996; Asici and Wyplosz, 2003; Krugman, 1979; Eichengreen et al., 1995; Morris and Shin, 1998; Chamley, 2003; Cukierman et al., 2004; Blagov and Funke, 2016; Zhang and Drapeau, 2022; Drapeau et al., 2021; Schmukler and Servén, 2002). Like these studies, we use forward prices to estimate devaluation risk, applying this approach to stablecoins.

The remainder of this paper is structure as follows. In section 2 we introduce a taxonomy of stablecoin risks, outline our data sources, and construct a market-based measure of run-risk from spot and futures data. In section 3 we analyze the determinants of run-risk, marshaling both econometric and case-study evidence, and present evidence on the behavior of stablecoin interest rates at DeFi lending protocols. Section 4 concludes.

2 Definitions and Data

2.1 Stablecoin taxonomy

Stablecoins operate on the blockchain and are typically pegged at parity to the US dollar. US dollar based stablecoins reached a peak of nearly 160 USD Billion of market capitalization in late 2021, and are dominated by stablecoins Tether, USDC, Binance USD, and DAI, as shown in Panel A of Figure 1. They serve as vehicles for trading crypto assets generally, owing to the fact that they, like other crypto assets, operate on the blockchain, thereby reducing intermediation and transactions costs.[2] Specific use cases include providing a vehicle currency on Uniswap (an open source protocol through which tokens can be traded without trusted intermediaries) and on DeFI lending protocols for leveraged trading. In addition, there is limited use of stablecoins for remittances and cross-border payments, and residents of developing countries may use stablecoins to evade capital controls and avoid high domestic-currency inflation.

Stablecoins typically follow three designs, as outlined in Panel B of Figure 1. A first type, as in the case of Tether, is backed by collateral held off chain by a custodian. In Tether's case, the custodian is centralized. It is responsible for managing Tether's fixed peg to the dollar, and can be thought of analogously to a currency board that manages a fixed currency peg to the dollar. The second-largest stablecoin, USDC, has decentralized governance, with multiple custodians providing and redeeming tokens. Not all dollar reserves are held in the form of cash or cash-equivalents. Historically, Tether and USDC's

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[2] Stablecoins are widely used in the cryptocurrency market due to the added intermediation costs when trading cryptocurrencies against dollars and their usability across a greater cross-section of crypto exchanges. For example, total trading volume between Bitcoin and Tether surpassed the trading volume of Bitcoin/USD in 2019.

balance sheets have included commercial paper and other assets that may become illiquid during risk-off events.

A second design is decentralized, cryptocurrency (over) collateralized, and custodian free, as in the case of MakerDAO's DAI. Investors deposit Ethereum into a collateralized position that allows them to borrow DAI. The number of DAI they can borrow is limited by a smart (auto-executing) contract.[3] This approach is capital inefficient since positions are over-collateralized.

A third design is algorithmic. In this case there may be zero collateral. The algorithm managing the system is programmed to increase and reduce the supply of the stablecoin as its value rises and falls relative to parity. A leading algorithmic stablecoin is TerraUSD, which reached a peak market capitalization of 40 USD billion in April 2022. TerraUSD is entirely backed by Luna, the native token of the Terra blockchain. Users can create 1 USD worth of TerraUSD by burning 1 USD of Luna. The Luna token is used to pay fees for validating transactions on the blockchain, staking tokens in governance votes, and earning yields on DeFi lending protocols.

This third approach economizes on capital costs (since there is no capital) but is prone to instability, as evident in the substantial discounts at which algorithmically collateralized stablecoins sometimes trade. An example is when the TerraUSD peg was broken on May 12, 2022, triggering loss of confidence in the Terra blockchain and governance token. This triggered a spiral of falling Luna and TerraUSD prices; on May 12, 2022 the ratio of the value of Luna to the circulating supply of TerraUSD declined to approximately 0.1.

Compared to dollar-backed stablecoins like Tether and over-collateralized crypto-backed coins like as DAI, algorithmically-backed stablecoins such as TerraUSD suffer from absence of an effective arbitrage mechanism between primary and secondary markets. The governance token Luna is unsuitable as collateral backing since it is systemically

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[3] The contract liquidates underlying Ethereum collateral if the value of that collateral is less than 150% of the corresponding DAI-borrowing value. Agents therefore have an incentive to scale back borrowing by redeeming DAI when Ethereum prices fall in order to prevent their collateral from breaching the 150% level.

dependent on the value of the TerraUSD token and hence on the growth of the Terra blockchain.

2.2 Stablecoin risks

It is useful to distinguish four risks associated with stablecoins: custodial risk, devaluation risk, systemic risk, and payments risk.

- **Custodial Risk**: This can arise when a centralized issuer responsible for reserve management absconds with funds.
- **Devaluation risk**: This can arise when reserves or backing are less than 100 percent of the value of issuance or less than perfectly liquid.
- **Systemic risk**: Stablecoins used in cryptocurrency markets can increase risk exposures of financial intermediaries. Because stablecoin issuers hold traditional assets, a run on stablecoins can lead to systemic risks to the financial sector and financial intermediation, for example when they are forced to engage in fire sales of commercial paper and other assets held by stablecoin issuers as collateral.
- **Payment risk**: If a firm or other entity has receivables denominated in stablecoins, its flows are subject to devaluation risk.[4] This is similar to the exchange rate risk that occurs when firms denominate liabilities in foreign currency and are subject to a revaluation of foreign debt when the local currency depreciates (Eichengreen et al., 2007).

We can illustrate these risks in the context of Tether, the stablecoin that is the focus of our empirics. Since May 13th 2021 Tether has provided a breakdown of its reserves, which are subject to quarterly attestation reports by accounting firm BDO. Tether's first statement of May 2021 revealed that it was only 75.6 per cent backed by cash or cash equivalents (less

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[4] Other use cases for stablecoin payments are in cross-border flows or as a hedge against macroeconomic risk

liquid asset categories such as commercial paper, fiduciary deposits and treasury bills).[5] In the latest quarterly attestation at the time of writing (Q1 2023), Tether had liquidated its commercial paper holdings. However, it still had just 84.65 per cent of its assets in the form of cash or cash-equivalents. The remaining 15.35 per cent were in less liquid assets such as corporate bonds, precious metals, and cryptocurrencies, including Bitcoin (Table 1).

In the absence of 100 percent liquid reserves, Tether can be susceptible to bank-run-like problems. If demands to redeem Tether exceed liquid reserves, Tether must suspend redemptions or sell less liquid assets at a loss. This is analogous to how, at the height of the Global Financial Crisis in 2008, money market funds were forced to "break the buck" when the value and liquidity of their commercial paper holdings fell.

An issue here is Tether's holdings of Bitcoin, whose price is volatile. While these holdings constituted just a small fraction (1.8 per cent) of Tether's balance sheet on March 31st, 2023, they made the value of Tether's backing subject to fluctuations. A crash in the value of cryptocurrencies, such as Bitcoin, can reduce the value of Tether's assets. This decline in asset value can trigger redemptions, as demonstrated by the link between the profitability of Tether's balance sheet and stablecoin growth in Dionysopoulos et al. (2024). We study the role of this market risk in Section 3.2. While our study focuses on Tether, we show that concerns about the valuation of assets and extent of collateralization are relevant to other stablecoins. In Section 3.2.2, we highlight the role of Silicon Valley Bank's collapse in triggering a USDC de-pegging event that occurred in March 2023, when the bank, which held cash reserves for USDC, went bankrupt. The reaction of USDC in this episode was much like the reaction of Tether in other instances.

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[5] Quarterly statement released by Tether Ltd on breakdown of reserves. Statement issued on May 13th,2021 on Tether's twitter account. Available at `https://twitter.com/Tether_to/status/1392811872810934276`

2.3 Stablecoin risk management

Opacity and lack of auditing requirements can heighten the risks enumerated above. For example, because Tether's assets are kept off-chain, investors are unable to confirm that its balance sheet is fully collateralized in real time. Attestations are done only once a quarter. Doubts about the value of collateral can then give rise to mass redemptions as holders seek to avoid being last in the queue, a la Diamond and Dybvig (1983).

Real-time audits using third-party proof-of-reserve systems such as Chainlink are one possible solution to this problem. These audits provide transparency on collateral values and alert stakeholders to anomalies. Auditing is at high frequency, in contrast to units like Tether and USDC, which provide audit reports monthly or quarterly. By more tightly tying the minting of new tokens to reserves, such systems enforce full collateralization, thereby reducing the risk of a stablecoin run. However, concerns about oracle risk remain. A possible solution here is to require decentralized consensus among oracles.

Regulatory frameworks have also been proposed to address stablecoin devaluation risk. These frameworks potentially entail capital requirements, access to central bank liquidity facilities, and potential insurance for stablecoin users. Stablecoin issuers might be required to align with Basel regulations on capital requirements for banks.

Finally, alternative stablecoin designs are proposed by policymakers to mitigate devaluation risks. These include tokenized deposits and reserve-backed tokens (RBTs). Tokenized deposits, as outlined by Garratt and Shin (2023), operate on a non-bearer instrument model, ensuring singleness of value within a platform by settling transactions on a central bank's balance sheet, eliminating credit exposures across institutions. Reserve-backed tokens, discussed by Goel (2024), involve issuers holding asset reserves with a central bank, functioning as narrow banks to maintain peg stability. RBTs offer advantages such as financial stability, independence from custodians, and reduced risk through full backing by safe assets. Together, these models provide viable alternatives to current stablecoin designs, addressing key risks associated with their use.

We provide additional detail on these risk management solutions in Appendix A.

2.4 Data

2.4.1 Network measures

Tables 2 and 3 present definitions and summary statistics for variables used in the analysis. Network measures are from Coin Metrics, a blockchain data company providing transfer value and related variables for major cryptocurrencies. We classify transactions that are "sent" as deposits, and transactions when the Treasury receives Tether as redemptions. We only consider Tether circulation net of supply held by the Treasury; this is labeled free float supply in the Coin Metrics database. We construct the measure of Tether in circulation for the three blockchains that account for over 95% of Tether creation: Omni, Ethereum and Tron. For each platform, we utilize data on transactions of the Tether Treasury with secondary market wallets. Panel A of Figure 2 plots Tether supplied on each blockchain. While Tether was initially issued on the Omni blockchain, the two primary blockchains since 2019 have been Ethereum and Tron. Tether's move to the Ethereum and Tron blockchain is driven by several factors, including ability to serve a larger number of cryptocurrency investors, facilitate exchange with Ethereum (ERC20) and Tron (TRX) tokens, enable faster arbitrage opportunities, and reduce transaction costs.[6] For example, cryptocurrency exchanges like Bittrex and Huobi recognize the benefits of the Ethereum blockchain for Tether.[7]

In addition to Tether in circulation, we employ a measure of velocity: the ratio of value transferred in the trailing year divided by the current supply at the end of the period. This can be thought of as turnover – as the number of times that an average native unit has

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[6] ERC20 and TRX are standards which provide features including the transfer of tokens from one account to another, measuring the current token balance of an account, and measuring the total supply of the token available on the network. It deploys smart contracts, auto-executing code on the blockchain, to perform these various functions.

[7] Huobi exchange statement on the migration to the Tether blockchain, https://prn.to/2ZkPzw0

been transferred in the past year. Panel B of Figure 2 plots velocity across all 3 blockchains, together with a value-weighted measure. As value on the Omni network declined, so did the velocity of transactions. In contrast, we see an increasing trend in velocity on the Tron blockchain, followed by an increase in the value-weighted measure.

2.4.2 Spot and futures

For USDT spot and futures prices, we draw data from Coinapi, which gives historical cryptocurrency OHLCV (Open, High, Low, Close and Volume) data through an API.[8] Prices for Tether futures are available from the FTX exchange from February 28, 2020 until June 18, 2022.[9] Closing futures prices are at a daily frequency. To control for the futures prices approaching spot at the expiry of the contract, we create a constant maturity series by linearly interpolating between successive futures contracts. For spot prices the earliest historical series for Tether is obtained from the Kraken exchange, the most liquid exchange for spot USDT/USD trading, which is available from April 2017.

Figure 3 plots spot and the futures prices and the basis, defined as the difference between futures and spot rates. The basis is typically negative, consistent with investors pricing devaluation risk. For a measure of market volatility risk, we use a measure of intra-day volatility of Bitcoin, calculated as the square root of the daily average sum of squared returns over hourly intervals.

2.4.3 Interest rates

For interest rates on Tether we use borrow and supply (lending) rates from both Compound and Aavev2, available from the Kaiko API, which provides data from August 5 2021.[10] These are the two major lending protocols during our sample period, and we use

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[8] Data available at `https://www.coinapi.io/`.

[9] Our sample closes with the June 2022 futures contract, however we note that our sample is not contaminated by the closure of FTX in November 2022, where contracts at the time may reflect increased counterparty and settlement risk.

[10] API available at `https://docs.kaiko.com/v/kaiko-rest-api/defi-and-blockchain/lending-and-borrowing-data/lending-rates`.

them to construct a value-weighted borrow and supply interest rate for our analysis in Section 3. These rates are compounded every block (approximately every 15 seconds on the Ethereum blockchain) and are determined by the utilization percentage in the market, which is the percentage of the asset supplied to the protocol that is borrowed.[11] For money market rates, we use the 3 month USD OIS rate from Bloomberg. The 3 month maturity matches the term structure of 3 month futures USDT/USD contracts.

2.4.4 Market sentiment

To measure market sentiment, we use the Crypto Fear and Greed Index.[12] It is designed to quantify the emotional sentiment in the cryptocurrency market, specifically focusing on Bitcoin. The index is calculated on a scale from 0 to 100, where 0 indicates "Extreme Fear" and 100 indicates "Extreme Greed."

The index combines data from five key sources. Volatility, which makes up 25% of the index, compares Bitcoin's current volatility and maximum drawdowns against the past 30 and 90-day averages to assess market fear. Market Momentum and Volume, also contributing 25%, evaluate daily trading activity relative to historical averages to identify market greed. Social Media accounts for 15% by analyzing Twitter activity and interaction rates to measure public interest and sentiment. Dominance, comprising 10%, looks at Bitcoin's market cap dominance as a sign of market fear or greed, particularly in relation to alt-coins. Finally, Trends, making up the remaining 10%, utilizes Google Trends to track changes in search volumes for Bitcoin-related queries, which can indicate shifts in market sentiment.

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[11] For example, the interest rate model for borrowing rates on the Compound protocol is given by the piecewise equation (1). a_0 is the base rate, and is the rate corresponding to zero utilization. The slope parameter b_0 measures the sensitivity of interest rates to utilization. Typically the threshold is set at 0.8.

$$i_{USDT}^{borrow} = \begin{cases} a_0 + b_0 u, u \leq \bar{u} \\ a_0 + b_0 \bar{u} + b_1(u - \bar{u}), u > \bar{u} \end{cases} \tag{1}$$

[12] Available through an API at `https://alternative.me/crypto/fear-and-greed-index/`.

3 Model and Evidence

3.1 Model of Devaluation Risk

We set out a simple model of devaluation risk, following a literature that estimates currency risk of the Hong Kong Currency Board (Blagov and Funke, 2016; Zhang and Drapeau, 2022; Drapeau et al., 2021; Schmukler and Servén, 2002). Define s_t, f_t as the spot and futures rates, expressed as the dollar price of a unit of Tether. Assume that the spot price follows an AR(1) process with mean-reversion coefficient ρ in equation (2).

$$s_{t+1} = 1 + \rho(s_t - 1) + \epsilon_{t+1}, 0 < \rho < 1 \tag{2}$$

Stability requires $\rho < 1$. The coefficient ρ provides an estimate of the half-life of the system.[13] The reduced form dynamics of the peg captures an arbitrage mechanism through which peg-price deviations are reduced and eliminated. Intuitively, a positive peg premium increases stablecoin supply through arbitrage flows, having a stabilizing effect on the price. Practically, half-life typically is short, 1 to 5 days for major stablecoins (Lyons and Viswanath-Natraj, 2023).

The AR(1) process allows for a tractable mapping between the spot price today and the spot price at expiry. [14] Iterating equation (2) forward, we obtain an expression for the peg-price deviation at expiry $t + h$ of the contract in equation (3). This is equal to the current deviation discounted by the mean-reversion coefficient ρ, in addition to a discounted sum of Tether-specific shocks ϵ_{t+s}.

$$s_{t+h} = 1 + \rho^h(s_t - 1) + \sum_{s=1}^{h} \rho^{h-s}\epsilon_{t+s} \tag{3}$$

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[13] To measure the half-life, we run an auto-regressive process of order 1 on the deviations, $\Delta = \rho\Delta_{t-1} + u_t$. The half-life, or the time it takes for a shock to dissipate by 50%, is $T = \frac{log(0.5)}{log(\rho)}$.

[14] Alternatives such as a VAR model augmented with a Markov regime switching method have been used in (Blagov and Funke, 2016; Zhang and Drapeau, 2022).

The spot rate at expiry follows equation (4). With probability $\mathcal{P}$, the stablecoin regime collapses. In this scenario, the spot rate approaches $\underline{s} < 1$. Full default requires $\underline{s} = 0$. With probability $1 - \mathcal{P}$, the spot rate is equal to an exponential decay of peg-price deviations, reflecting a series of shocks that are discounted by the mean reversion coefficient ρ.

$$s_{t+h} = \begin{cases} 1 + \rho^h(s_t - 1) + \sum_{s=1}^{h} \rho^{h-s} \epsilon_{t+s}, & \text{with probability } 1 - \mathcal{P} \\ \underline{s}, & \text{with probability } \mathcal{P} \end{cases} \tag{4}$$

Under the expectations hypothesis, the futures price for a contract expiring h periods from now is equal to the expectation of the spot rate h periods from now. The futures contract at expiry is given by equation (5).

$$\begin{aligned} f_t &= \mathbb{E}_t[s_{t+h}] && (5) \\ &= (1 - \mathcal{P}) \times (\mathbb{E}_t[s_{t+h}] | \text{No Default}) + \mathcal{P} \times (\mathbb{E}_t[s_{t+h}] | \text{Default}) && (6) \\ &= (1 - \mathcal{P}) \times \Big(1 + \rho^h(s_t - 1)\Big) + \mathcal{P} \times \underline{s} && (7) \end{aligned}$$

Utilizing the probabilities of the 'default' and 'no-default' states, we can show that stablecoin futures equal the expected price.

The probability of a run is captured by equation (8).

$$\mathcal{P}_t = \frac{1 + \rho^h(s_t - 1) - f_t}{1 + \rho^h(s_t - 1) - \underline{s}} \tag{8}$$

This probability can be estimated using observable spot and futures rates. It is decreasing in the futures rate and increasing in the spot rate. It is inversely related to the futures-spot basis $f_t - s_t$. As the horizon of the futures contract $h \to \infty$, when the exchange rate in the devaluation state is $\underline{s} = 0$ the equation simplifies to $\mathcal{P} = 1 - f_t$.

We show our measure of devaluation risk in Panel C of Figure 3.[15] There is significant time variation in the implied probability, with a peak of 2 per cent (annualized). The two local peaks are the 'Black Thursday' March 12th, 2020 Crypto crash, when the prices of major currencies such as Bitcoin fell by 50 per cent; and the TerraUSD crash on May 9th, 2022, when investors priced an increase in the probability of a Tether-de-pegging event. We discuss the TerraUSD crash further in section 3.2.

In Panel D of Figure 3, we measure the average default probability conditional on different degrees of devaluation $\underline{s}$. The default probability has an average of 62 basis points for the baseline specification of $\underline{s} = 0$, suggesting there is an approximate 0.6 per cent probability (annualized) of complete default. In contrast, the probability of partial default of 5% devaluation ($\underline{s} = 0.95$) is 10 percentage points annualized.

3.2 Correlates of run risk

We test for the determinants of the probability of a stablecoin devaluation using equation (9). Explanatory variables include network measures such as the rate of turnover (also referred to as monetary velocity). Proxies for market volatility include measures of intra-day volatility and returns on Tether and Bitcoin. Finally, we consider a variable capturing periods of net redemptions of Tether, that is, periods when the supply of Tether (net of Treasury) falls.

$$\mathcal{P}_t = \beta_0 + \beta_1 Velocity_t + \beta_2 \sigma_{BTC\,t} + \beta_3 D_{redemption_t} + \epsilon_t \tag{9}$$

Table 4 presents the results. Columns (1) to (4) use the baseline measure of devaluation risk based on equation (9). Columns (5) to (8) use the devaluation risk measure based on linear interpolation of futures contracts. Our findings are robust to using both deval-

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[15] To compute the default probability, we first estimate the auto regressive parameter ρ in equation (2). and use an average estimate of $\rho = 0.67$ over the full sample. In calculating the annualized probability, we use the estimate of ρ and assume a horizon $h = 90$ of the futures contract. We assume $\underline{s}$ for the baseline specification.

uation risk measures. Velocity is positively associated with devaluation risk. In our full specifications in columns (4) and (8), a unit increase in velocity increases the devaluation risk measures by 2.4 and 2.8 basis points respectively. The increased rate of turnover may be due to investors re-balancing the coin in their portfolios because there are concerns that the coin is overvalued, or panicking and seeking redeem the coin at par on secondary market exchanges or with the issuer.

In addition, devaluation risk is associated with high Bitcoin volatility. Periods of high Bitcoin volatility can increase devaluation risk due to investor concerns about the role of Tether as a vehicle for transactions in Bitcoin and related cryptocurrencies. In our full specifications in columns (4) and (8), a 1 percentage point increase in Bitcoin volatility increases the devaluation risk measures by 3.3 and 5.8 basis points respectively. Finally, we control for redemption behavior of investors. Periods of redemptions are often associated with run-risk and panic due to contagion effects. We find periods of redemptions are associated with an increase in devaluation risk. Based on our full specifications in columns (4) and (8), periods of redemptions are associated with an 8.4 and 18 basis point increase in our measures of devaluation risk.

These results are broadly consistent with the implications of theoretical models of stablecoin devaluation risk (Bertsch, 2022; Routledge and Zetlin-Jones, 2018; Li and Mayer, 2021; d'Avernas et al., 2022). In these models, cryptocurrency-related fundamentals matter for stablecoin devaluation risk. For example, a decline in the value of stablecoins as a means of payment, owing to an increase in market volatility or transaction rate in the network, can heighten the susceptibility to a run. If investors believe the expected value of Bitcoin and similar cryptocurrencies will fall, this will lead to an increased probability of states where they redeem stablecoins in order to reduce their holdings of cryptocurrencies. For example, Tether has exposure to Bitcoin on its balance sheet, and in 2021 it was reported that 4 per cent of Tether's assets were used to make collateralized Bitcoin loans. A decline in the value of Bitcoin could therefore lead to an under-collateralized peg.[16]

3.2.1 Case study: The May 9th, 2022, TerraUSD crash

TerraUSD is an algorithmic stablecoin backed by Luna, the native token of the Terra blockchain. (In other words, TerraUSD is not collateralized by dollar reserves. The TerraUSD treasury also holds reserves of Bitcoin for use in extremis, but only limited amounts.) TerraUSD is pegged to 1 USD by arbitrage. When the price of TerraUSD is above par, an investor can sell 1 USD worth of Luna and buy TerraUSD for 1 USD, and then sell TerraUSD in the secondary market for an arbitrage profit. Conversely, when the dollar price of TerraUSD is below one, an investor can buy TerraUSD on the exchange and sell TerraUSD for 1 USD worth of Luna tokens.

This arbitrage is not risk-free: investor profits are driven by expectations of the valuation of the governance token. It follows that algorithmic stablecoins such as TerraUSD are prone to instability (Briola et al., 2023; Liu et al., 2023; Ma et al., 2023; Uhlig, 2022). An instance of this problem was in May 2022, when TerraUSD traded at a large discount from the peg. This in turn triggered a loss of confidence in the blockchain and the governance token, resulting in a spiral of falling Luna and TerraUSD prices. The TerraUSD treasury's Bitcoin reserve was fully depleted.

Although design features affecting the TerraUSD peg were not shared by other stablecoins such as Tether, Tether fell to 95 cents USD intra-day on May 12th, 2022, three days after the initial TerraUSD collapse. This may have indicated investor expectations of reduced utility of stablecoins for cryptocurrency transactions. In addition, Liao (2022) document a shift from Tether toward USDC, an alternative stablecoin with more transparent and extensive backing, suggestive of investor search for greater transparency and security.

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[16] Refer to `https://www.ft.com/content/0035016c-29ad-4e6f-9163-2a17df490aa5` In the December 2022 attestation report conducted by accounting firm BDO, Tether reports up to 5.8 USD Billion of its total 67 USD Billion (8.7 per cent) are in the category of "Secured loans" which can include loans collateralized with Bitcoin and other risky cryptocurrencies.

Figure 4 shows the dynamics of Tether spot and futures prices, the implied probability of default, and various network characteristics around the event. While there was a decline in spot prices, futures prices fell by more and did not rebound as quickly. The implied probability of Tether default rose to 200 basis points annualized. The basis (futures less spot) took weeks to recover to levels prevailing prior to the TerraUSD collapse.

In addition there was an increase in Tether velocity and a consequent decline in the measure of free float supply of Tether in circulation. As investors exited, redemptions were required to stabilize the peg. The increase in velocity presumably reflected a tendency for investors to rebalance their portfolios toward other stablecoins such as USDC, consistent with the narrative in Liao (2022).

In the face of this negative shock, supply should be reduced commensurate with demand, and redemption mechanisms should operate so as to return the price to par. Following the de-pegging event, we in fact observe a -10 USD Billion change in the supply of Tether in circulation. This redemption mechanism is analogous to how a central bank defends an exchange rate peg. When the peg trades at a discount to par, arbitrageurs have an incentive to buy Tether in the secondary market and redeem at the Treasury at par. The consequent reduction in stablecoin suppply stablizes the price in the secondary market. Limits to redemptions, such as fees and minimum withdrawals, can lead to inefficiency of this process.

3.2.2 Case study: March 11th, 2023, The USDC De-Pegging Event

Another case is the USDC de-pegging event in March 2023, when Silicon Valley Bank, which held reserves for USDC, went bankrupt. USDC reportedly held some 3.3 USD billion of cash reserves at SVB. The run on SVB caused investor concern about whether these reserves would be lost, since they far exceeded the cap on federal deposit insurance. In turn this spawned questions about whether or not the coin was still fully backed. USDC fell to 87 cents on March 11th. Prices then stabilized on March 13th, when the FDIC had announced that all deposits at SVB would be fully guaranteed and available, and USDC transferred its reserves to other banking partners.[17]

Although we lack futures data for the USDC stablecoin, we can still assess the external validity of our interpretation by examining the behavior of related variables during periods of heightened devaluation risk, as depicted in Figure 5. Using the estimated specification in equation (8), we construct a counterfactual measure of USDC devaluation risk based on observables such as velocity, market volatility, and redemption behavior. We assume that these variables relate to USDC devaluation risk in a manner similar to Tether.

Our devaluation risk measure, in Panel A, shows an increase of up to 50 basis points following the USDC de-pegging event on March 11th, 2023. This rise in the counterfactual devaluation risk coincides with a significant increase in velocity, indicating intensified secondary market trading as investors sought to exchange USDC for USD reserves. In the subsequent weeks, redemptions reduced the free float supply of USDC from 40 billion USD to 32 billion USD, a critical move to maintain the peg, akin to the redemptions during Tether's de-pegging in May 2022. These actions helped to stabilize USDCâs secondary market value at par by exerting upward pressure on prices.

The impact of market volatility was temporary and limited to the USDC peg, without affecting the broader cryptocurrency market. During the de-pegging event, the substitutability between stablecoins played a crucial role, as noted by Oefele et al. (2024). Investors transitioned to Tether, which has less exposure to U.S. banks, thereby mitigating the contagion effect of USDCâs de-pegging on the broader market.

In sum, these patterns suggest a narrative consistent with the Tether de-pegging event discussed earlier. We now turn to the determinants of interest rates and whether devaluation risk is priced.

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[17] For a full account of USDC's reserve composition and the de-pegging event, we refer readers to `https://www.circle.com/blog/an-update-on-usdc-and-silicon-valley-bank`

3.3 Interest rate determinants

If stablecoins face devaluation risk, we expect this risk to translate into higher stablecoin interest rates. We consider formally the determinants of Tether borrowing and lending interest rates in equation (10), where we regress interest rates on DeFi platforms on our measure of devaluation risk, the Crypto Fear and Greed Index, which captures market sentiment on risky cryptocurrencies, and a money market rate, the USD 3 month OIS rate.

$$i_{USDT} = \beta_0 + \beta_1 \mathcal{P}_{baseline} + \beta_2 FG_{index} + \beta_3 i_{USD} + \epsilon_t \tag{10}$$

Table 5 presents the results. Columns (1) to (4) use the USDT borrowing interest rate as the outcome variable. Columns (5) to (8) use the USDT supply rate as the outcome variable. Interest rates are calculated as a value-weighted average of aggregate liquidity supplied in Aavev2 and Compound, the two major lending protocols in our sample. In Appendix B, we present results for interest rates on Compound and Aavev2 separately.

Devaluation risk is priced in both borrow and supply interest rates. In columns (1) and (5), a 1 percentage point increase in our measure of devaluation risk is associated with an increase in USDT borrow and supply rates of 1.25 and 1.11 percentage points respectively. This complements findings in Gorton et al. (2022b) which argue that stablecoin interest rates are compensation for taking leveraged positions.

The second determinant of interest rates in our specification is the Fear and Greed Index, which proxies for market sentiment regarding risky cryptocurrencies. We find a robust positive association between the index and stablecoin rates. This is consistent with a number of studies that shows how users borrow stablecoins in lending protocols to undertake leveraged trading in financial markets (Gorton et al., 2022b; Chaudhary et al., 2023; Barbon et al., 2023; Cornelli et al., 2024). In the cryptocurrency market, a speculator may use lending protocols to borrow stablecoins to buy risky currencies and take long leveraged positions. During periods of optimism, as captured by high levels of market sentiment, traders increase their borrowing of stablecoins to finance these positions, driving stablecoin interest rates up.[18]

The third variable in columns (3) and (6) is a USD money market rate. If money markets and stablecoins are perfectly integrated, we expect these interest rates to move one-for-one; a higher USD risk-free rate would cause portfolio re-balancing by investors and reduce their supply of stablecoins in lending protocols, leading to higher stablecoin rates and a positive pass-through. However, based on the results in our sample, money market rates are negatively correlated.

In our full specifications in columns (4) and (8), market sentiment is the most robust predictor of variation in stablecoin rates. Using an analysis of variance (ANOVA) estimation, reported in Appendix B, we find that market sentiment explains up to 22% of total variation in value-weighted borrowing and supply rates. In contrast, our measure of devaluation risk explains only 3.5%, and money market rates only explains up to 1% of total variation, with the remainder attributed as unexplained variation in stablecoin interest rates. Part of the unexplained variation in our sample can be due to liquidity mining programs that encourage investors to supply and borrow stablecoins through governance token rewards (Park and Stinner, 2023). These liquidity mining incentives can distort stablecoin rates, making them depart from traditional money market rates.

To further explore the disconnect between money market and stablecoin rates, Table 6 investigates the impact of Federal Reserve policy rate announcements on borrowing and supply rates, prices and issuance. The outcome variable y_t are stablecoin interest rates, prices and issuance. We regress changes in the outcome variable on a $FOMC_{dummy}$, which takes a value equal to 1 on FOMC announcement days, and 0 otherwise, Δi_{USD}, which is the change in USD interest rate, and $FOMC_{dummy}*\Delta i_{USD}$, which is the interaction variable

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[18] Stablecoin borrowing rates are algorithmically determined on lending protocols to be a positive function of utilization. Holding the supply of the stablecoin in the lending protocol constant, the increase in borrowing increases utilization, and therefore the borrowing and supply rates.

between $FOMC_{dummy}$ and Δi_{USD}.

$$y_{t+1} - y_t = \beta_0 + \beta_1 FOMC_{dummy} + \beta_2 \Delta i_{USD} + \beta_3 FOMC_{dummy} \times \Delta i_{USD} \tag{11}$$

These results suggest that stablecoin markets do not respond to money market rates on announcement days. In specifications (1) to (2), we find no effect of FOMC announcements on borrowing rates or lending rates, consistent with the hypothesis that stablecoin rates are disconnected from conventional financial markets. We do however find, in specifications (3) and (4), that stablecoin spot prices and subsequent issuance responds to interest rates. An increase in the Federal Funds rate on monetary announcement days is followed by a decline in stablecoin prices and issuance. This is consistent with higher interest rates causing portfolio re-balancing toward high yielding interest-bearing assets. This translates into a decline in stablecoin demand, requiring a fall in issuance to stabilize the peg.

In sum, our results are consistent with a segmented markets. While money market rates reflect the relative supply of savings and demand for investment projects in the real economy, there are different, non-overlapping sets of investors that trade in cryptocurrency and traditional markets.

3.4 Deviations from covered interest rate parity

Our analysis so far finds a disconnect between interest rates and futures prices in the stablecoin market on the one hand, and conditions in conventional financial markets on the other. To test integration between markets more concretely, we can measure deviations from covered interest parity (CIP).

We use borrowing and lending rates for Tether, on decentralized finance lending protocols such as Compound and Aave, together with futures contracts to investigate the existence of such deviations. Equivalently, we can use them to construct the risk premium of holding Tether instead of the USD after hedging the exchange rate risk. The deviation from CIP is computed as in equation (12). It is the difference between a synthetic dollar rate $i_{\$,t}^{synthetic}$ and a direct dollar rate $i_{\$,t}$. The synthetic dollar rate can be constructed by converting dollars to Tether at spot rate s_t, lending Tether at $i_{usdt,t}$, and then re-converting Tether to dollars at maturity at the forward rate f_t.

In a frictionless setting, we would expect interest rates to be equalized after hedging exchange risk using a futures contract. Therefore, the benchmark for efficient interest rate markets suggests that CIP deviations should be zero or within bounds governed by transaction costs such as gas fees (fees users pay to process transactions or use smart contracts) on the Ethereum blockchain.

$$
\begin{aligned}
CIP_t &= i_{\$,t}^{synthetic} - i_{\$,t} && (12)\\
&= \left(\left(\frac{f_t}{s_t}(1 + i_{usdt,t}\frac{h}{360}) - 1\right) \times \frac{360}{h} - i_{\$,t}\right) \times 100 && (13)
\end{aligned}
$$

Figure 6 plots the CIP deviation (along with the synthetic dollar interest rate and direct dollar rates). Deviations are persistently positive. The average CIP deviations based on borrowing and supply rates are 4.43 and 3.14 percentage points respectively. These indicate the existence of a risk premium embedded in stablecoin rates even after controlling for exchange risk using a futures contract. Note that the deviation narrows somewhat in the second half of the sample period, and is negative for CIP deviations based on supply rates towards the end of our sample.

3.4.1 Limits to arbitrage in CIP trade

Our explanation for the weak integration between stablecoin and traditional interest rates has primarily focused on market segmentation and the influence of leveraged trading on lending protocols. We now consider a second source of friction: limits to arbitrage in these markets. In a classic covered interest rate parity (CIP) arbitrage trade, money market rates in two currencies must share the same maturity. However, while money market rates are fixed for specific maturities, interest rates on lending protocols lack a term structure; interest accrues approximately every 15 seconds in block time on the Ethereum blockchain.

Because Tether interest rates are not fixed at a 3-month term like USD money market rates, there is no risk-free arbitrage profit in a standard CIP trade. To construct a synthetic dollar interest rate, an investor would need to lock funds in Tether for 3 months before reconverting to dollars at a forward rate, relying on the expected interest rate over that period. The positive premium on stablecoin rates over money market rates may partly reflect this interest-rate risk.

Arbitrage between stablecoin interest rates and money market rates entails transaction costs, given the need to move capital from financial intermediaries to decentralized finance platforms. These costs include gas fees, as noted above, analogous to commissions paid on exchanges. In this case these costs are paid to miners authenticating transactions on the Ethereum blockchain. Other costs of providing liquidity to stablecoin markets can include costs of liquidating debt. In addition there is the cost of supporting an off-ramp from Tether to USD in order to conduct a round-trip arbitrage trade. Retail investors need to access spot markets in USD/USDT on centralized cryptocurrency exchanges like Bitfinex. Processing lags for withdrawals of dollars on these exchanges are substantial, and fees are imposed when dollar withdrawals are frequent or large.[19] Finally, counterparty risk on a futures exchange, including the risk of liquidations due to not positing sufficient margin, can also be a limit to arbitrage, which is documented for the Bitcoin/USD pair (Schmeling et al., 2023).

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[19] For more information, refer to the following announcements by Bitfinex: `https://bit.ly/2NEzITW` and `https://www.bitfinex.com/posts/311`. Bitfinex states that it takes investors 7 to 15 days to make dollar withdrawals from their platform in order to comply with intermediation procedures. Bitfinex has also introduced a transaction cost of 3% for investors who make more than two dollar withdrawals a month, or for withdrawals of more than $1 million in a given month.

4 Conclusion

Stablecoins are integral to the cryptocurrency ecosystem, facilitating the purchase and sale of cryptoassets at lower costs than national currencies and serving as vehicles for remittances and cross-border transactions. Popular stablecoins depend on centralized custodians holding off-chain assets. When collateralization is partial and less liquid, this practice can prompt mass withdrawals, risking suspension of convertibility and collapse of the peg.

This paper presents a market-based measure of devaluation probabilities using Tether futures, the dominant stablecoin. On average, this devaluation probability is priced at 60 basis points annually, with significant time variation that can spike.

Several factors contribute to this devaluation risk, including market risks like BTC volatility and network characteristics such as transaction velocity and investor redemptions, which can lead to run-like behavior on stablecoins.

We find that stablecoin interest rates incorporate devaluation risk. However, we identify a disconnect between stablecoin and traditional financial markets, as stablecoin rates are more influenced by market sentiment and devaluation risk than by conventional money market rates. Even after hedging exchange rate risk using futures contracts, stablecoin rates remain systematically higher, violating covered interest parity. Contributing factors to the weak integration between stablecoin and traditional markets include market segmentation, lack of term structure in DeFi interest rates, and transaction costs in arbitrage.

While stablecoins primarily function as vehicles for leveraged trading within the cryptocurrency market, their broader adoption for cross-border and financial transactions could significantly impact traditional financial markets, raising important considerations for investors, regulators, and policymakers.

Managing these risks will likely entail both private initiatives and government policies. For instance, in February 2023, the stablecoin TrueUSD implemented real-time audits with

Chainlink, ensuring that new tokens are only issued when reserve balances are verified. Increased government regulation could involve capital requirements, central bank support, or insurance to protect users. Alternative stablecoin designs like tokenized deposits and reserve-backed tokens (RBTs), combining the stability of central bank-backed assets with the features of private digital currencies, are other potential possibilities (Garratt and Shin, 2023; Goel, 2024).

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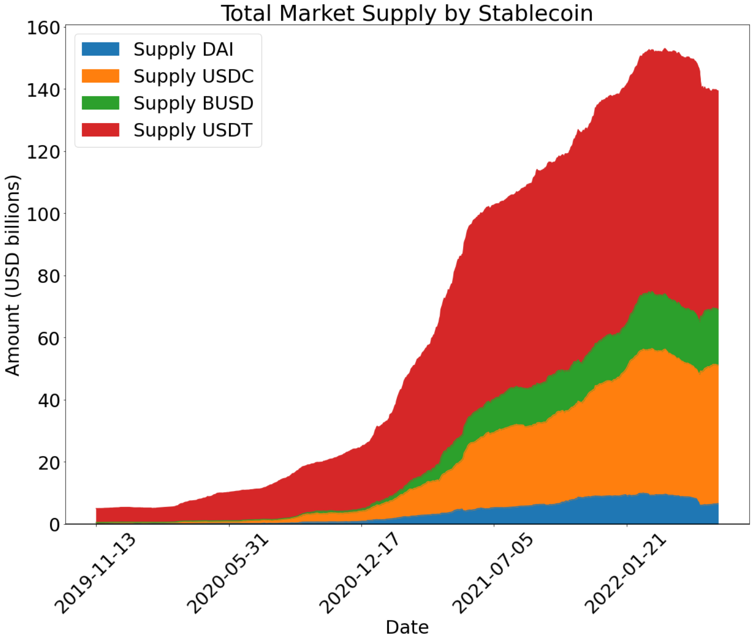
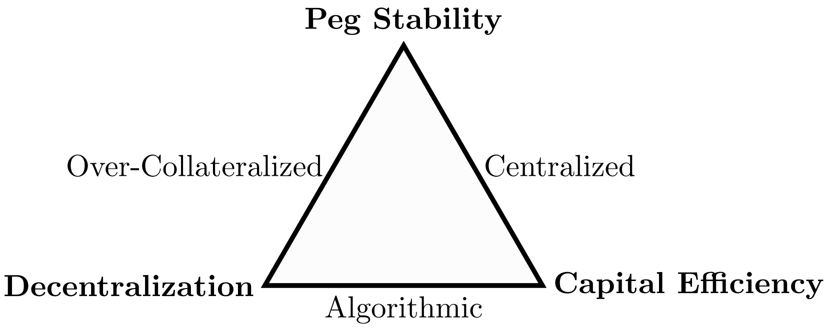
Figures

Figure 1: Stablecoin ecosystem

Panel A: Total supply of DAI, USDC, BUSD, and USDT

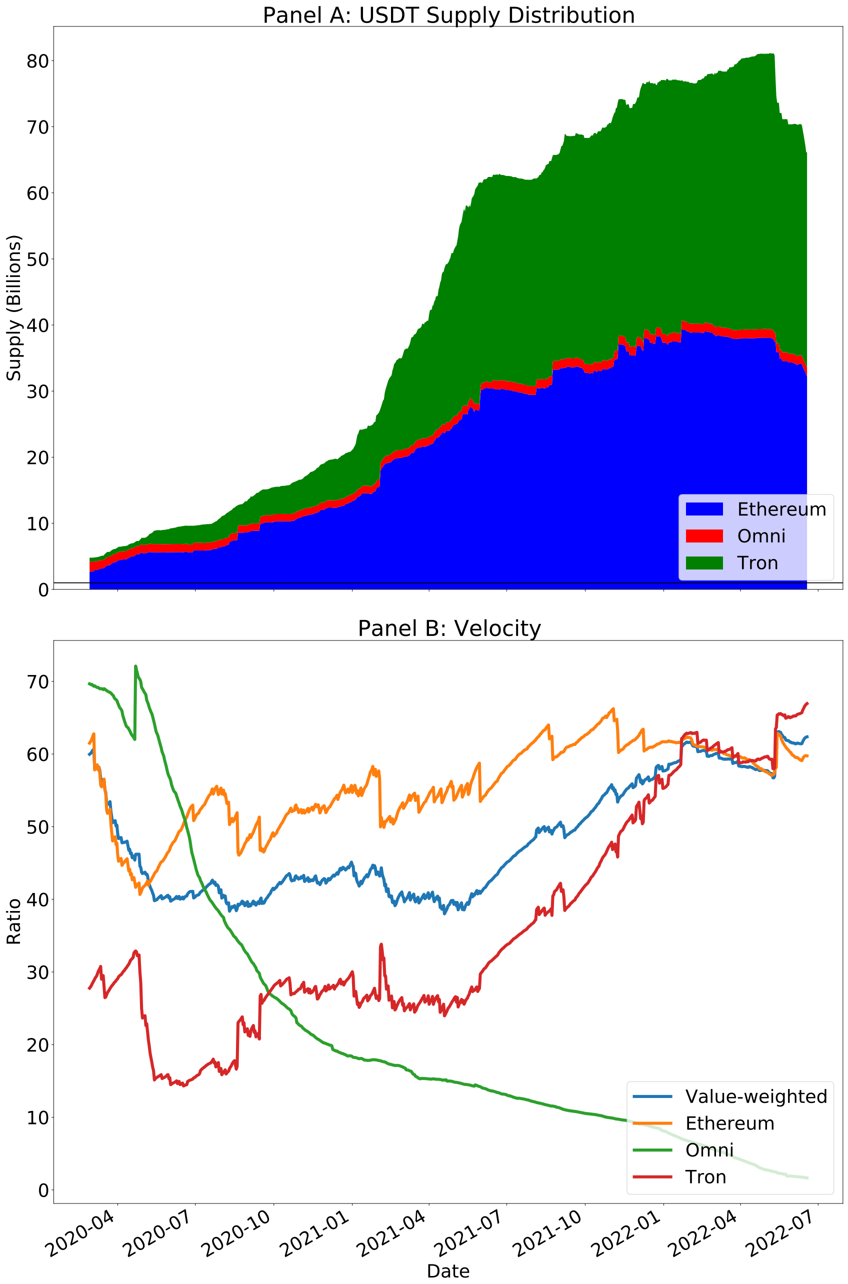


Panel B: Stablecoin Trilemma



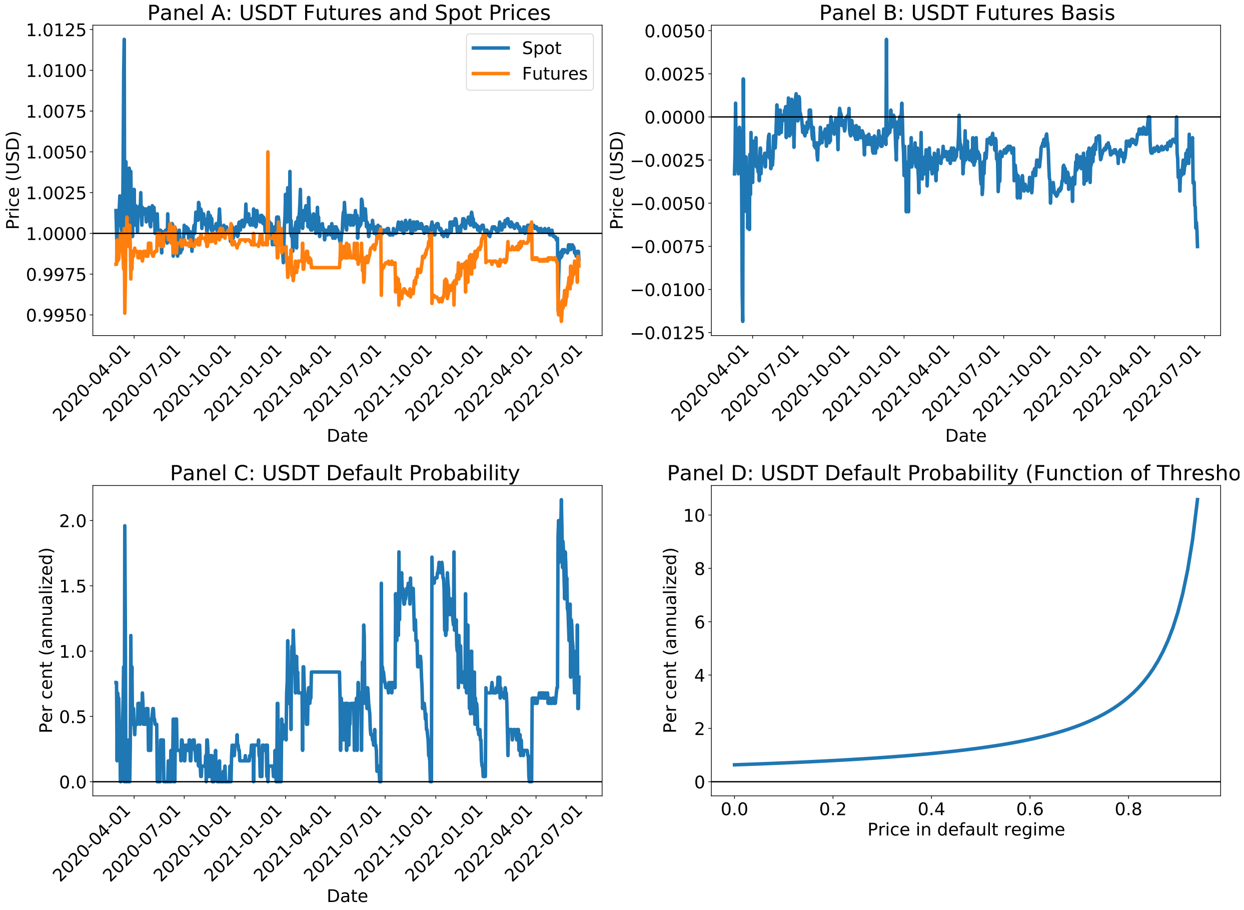
Note: Panel A reports the aggregate free float supply of stablecoins Tether (USDT), USDC, BUSD and DAI, in Billions USD. Panel B reports the trilemma, which states that stablecoins face a trade-off between three objectives: peg stability, decentralization, and capital efficiency. Stablecoin designs can be categorized into centralized, over-collateralized (decentralized), and algorithmic stablecoins based on which objectives they achieve.

Figure 2: Stablecoin network characteristics



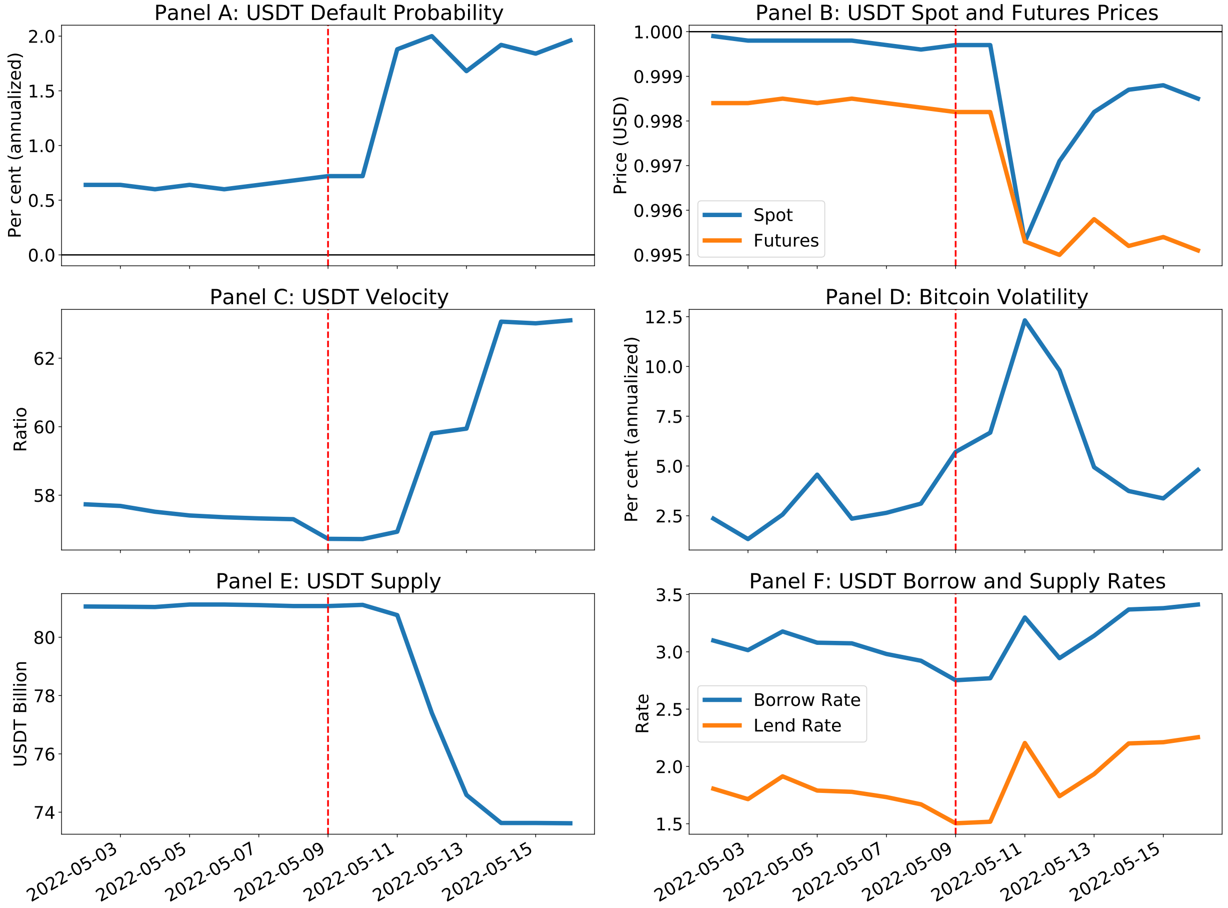
Note: Panel A reports the total free float supply of Tether across blockchains Omni, Tron and Ethereum, in Billions USD. Panel B reports the velocity of Tether transactions on Omni, Tron and Ethereum blockchains. Free float supply is measured as Tether in circulation held by wallets net of Treasury balances. Velocity is defined as the ratio of the value transferred (i.e., the aggregate size of all transfers) divided in the last year to date. It can be interpreted as the number of times that an average native unit has been transferred in the past 1 year.

Figure 3: USDT Futures and Spot Prices on FTX Exchange



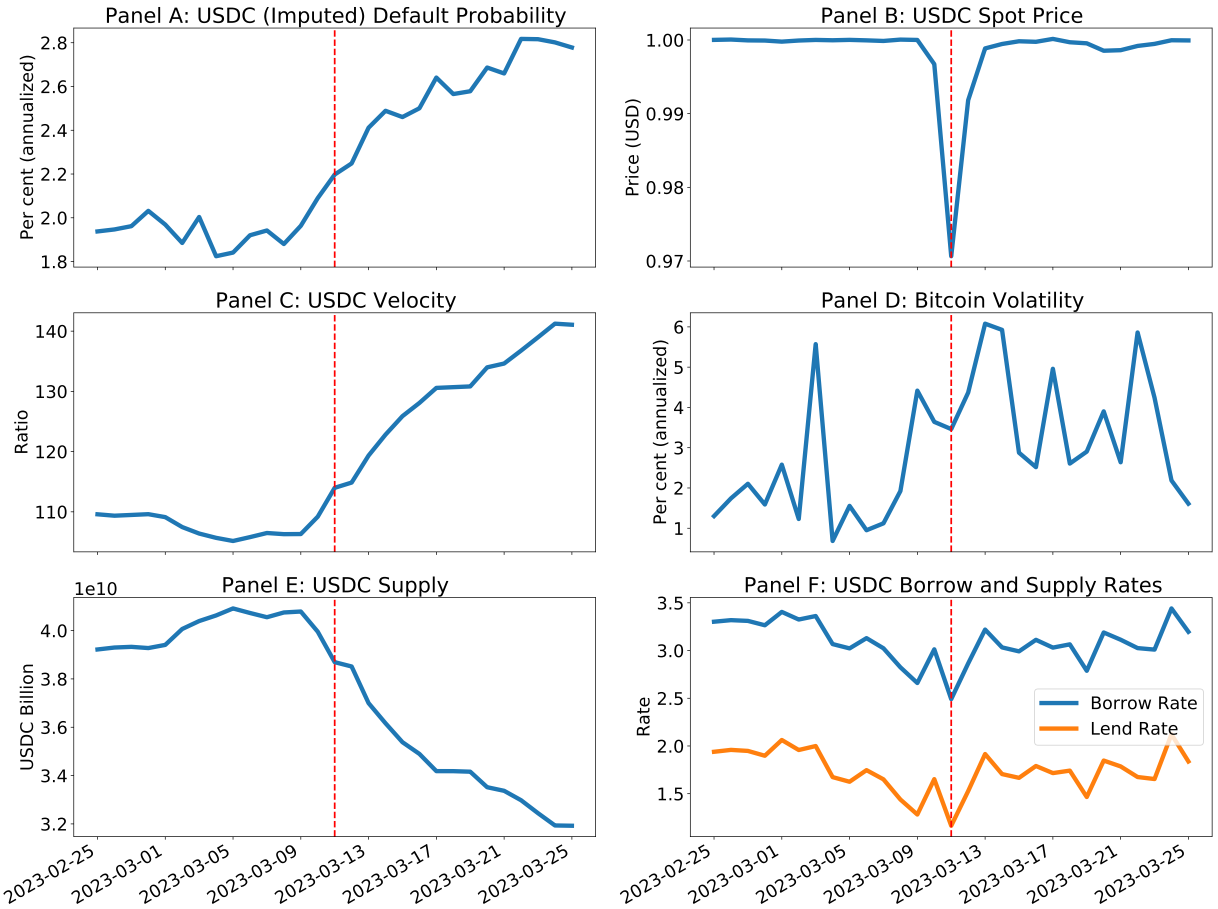
Note: Panel A reports USDT futures and spot prices on the FTX exchange. Panel B reports the difference between futures and spot prices, which is referred to as the basis. Panel C plots implied default probabilities based on spot, futures prices and the average mean reversion coefficient, for threshold value $\underline{s} = 0$ in default state. Panel D plots average default probability over the sample period conditional on different values of $\underline{s}$ in the default state.

Figure 4: Event Study: USDT Peg Collapse May 2022



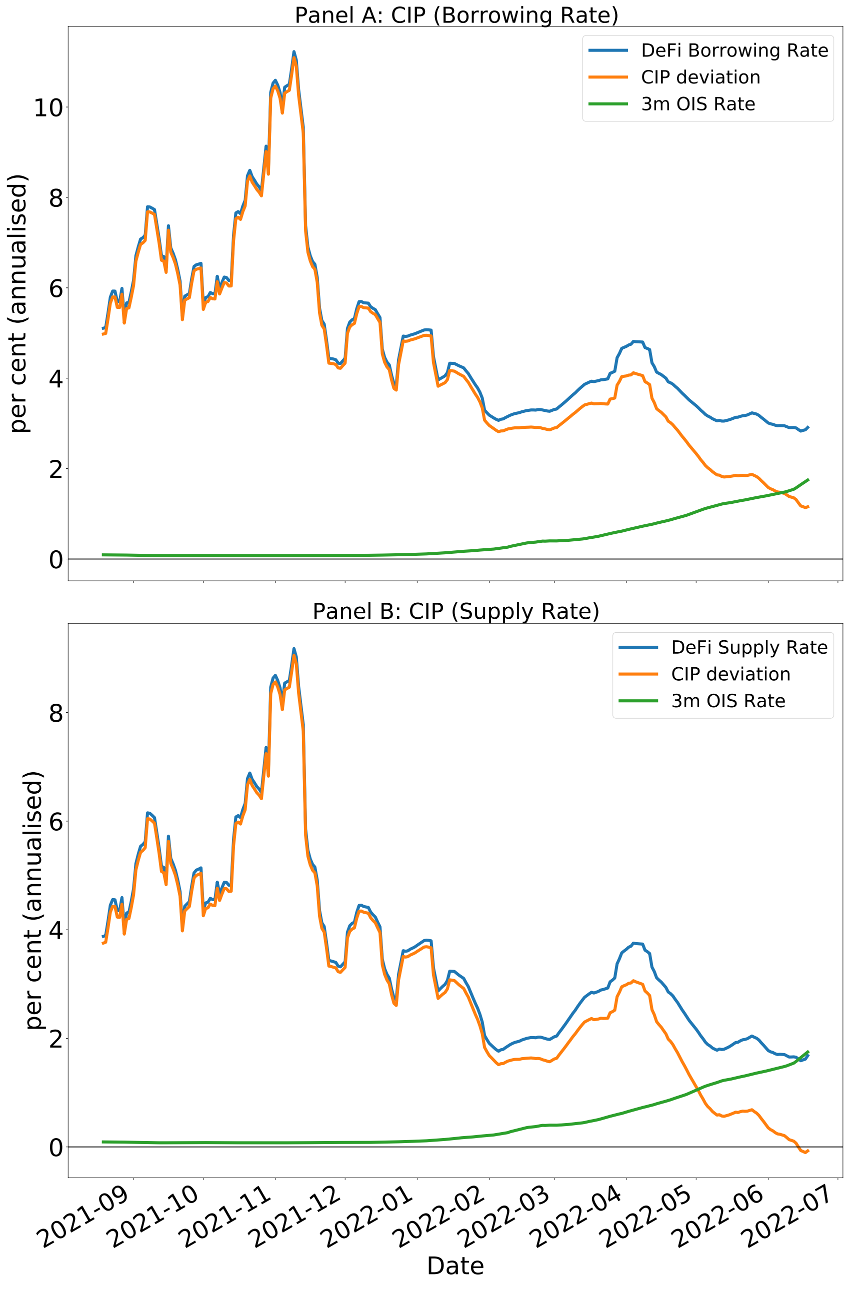
Note: The graph reports event study for various variables during a window of 1 week before and after the USDT peg collapse in May 2022. The vertical line is the day of USDT peg collapse, which is 12th May 2022. Panel A plots the USDT default probability. USDT spot prices, velocity and supply are reported in Panels B, C and E. Bitcoin volatility is reported in Panel D. USDT borrow and supply rates are reported in Panel F, which are value-weighted average of rates in Compound and Aavev2 based on the aggregate liquidity supplied in each protocol.

Figure 5: Event Study: USDC Crash March 2023



Note: Figure reports event study for various variables during a window of 1 week before and after the USDC peg collapse in March 2023. The vertical line is the day of USDC peg collapse, which is 11th March 2023. Panel A plots the USDC imputed default probability, based on observables of USDC velocity, redemptions and Bitcoin volatility. USDC spot prices, velocity and supply are reported in Panels B, C and E. Bitcoin volatility is reported in Panel D. USDC borrow and supply rates are reported in Panel F, which are value-weighted average of rates in Compound and Aavev2 based on the aggregate liquidity supplied in each protocol.

Figure 6: Money market, stablecoin rates and deviations of Covered Interest Rate Parity



Note: Figure plots USDT supply and borrow rates, USD money market (3m OIS) and CIP deviations. Panel A measures CIP deviations based on borrow rates, and Panel B measures CIP deviations based on supply rates. CIP deviations are equal to the difference between stablecoin and USD rates after hedging exchange rate risk with a futures contract. All rates are a 14 day rolling average, and annualized. The sample runs from 5 August 2021 to June 18th, 2022.

Tables

Table 1: Q1 2023 Tether Attestation: Consolidated Reserves report

Assets	**Amount (USD Billion)**	**% Balance Sheet**
US T-Bills	53.04	64.78%
Overnight Reverse Repo Agreements	7.50	9.17%
Term Reverse Repo Agreements	0.79	0.97%
Money Market Funds	7.45	9.08%
Cash and Bank Deposits	0.48	0.59%
Non-U.S. T-Bills	0.05	0.06%
Cash or Cash Equivalents Sub-Total (1)	69.31	84.65%
Corporate Bonds	0.14	0.17%
Precious Metals	3.39	4.14%
Bitcoin	1.50	1.83%
Other investments	2.14	2.62%
Secured loans	5.35	6.54%
Non-Cash or Cash Equivalents Sub-Total (2)	12.52	15.35%
Total (1)+(2)	81.83	100.00%

Note: This table presents Tether attestation by accounting firm BDO for Quarter 1 2023. Balance sheet breaks down all assets held by Tether into categories. For more details and the full attestation, see Tether's press release (link).

Table 2: Variables used in Regression Analysis

Variable	**Description**
s	Closing spot price of USDT in units of USD.
f	Closing future price of USDT in units of USD.
$f_t - s_t$	The difference between spot and future price of USDT, referred to as the futures-spot basis.
$\mathcal{P}_{baseline}$	The probability of default of USDT based on the baseline specification in equation (8), measured in percentage points.
$\mathcal{P}_{lin}$	The probability of default of USDT based on linear interpolation, measured in percentage points.
Velocity	The ratio of the value transferred (i.e., the aggregate size of all transfers) divided in the last year to date. It can be interpreted as the number of times that an average native unit has been transferred in the past 1 year.
σ_{BTC}	BTC volatility, calculated as the square root of the sum of square hourly returns over a daily interval, measured in percentage points.
$D_{Redemption}$	Takes value of 1 if there is a decline in the free float supply of USDT compared to the previous day, and 0 otherwise.
i_{USDT}^{borrow}	USDT borrow rate (annualized). Value-weighted average of USDT rates on Compound and Aavev2, measured in percentage points.
i_{USDT}^{supply}	USDT supply rate (annualized). Value-weighted average of USDT rates on Compound and Aavev2, measured in percentage points.
FG_{index}	Crypto fear and greed index measures market sentiment by analyzing factors such as volatility, market volume, and social media.
i_{USD}	USD 3 month OIS interest rate, measured in percentage points.

Table 3: Summary statistics

	Mean	Std	25%	50%	75%	Min	Max	Count
s	1.000	0.001	1.000	1.000	1.001	0.995	1.012	842
f	0.999	0.001	0.998	0.999	0.999	0.995	1.005	791
Basis	-0.002	0.001	-0.003	-0.002	-0.001	-0.012	0.004	791
$\mathcal{P}_{baseline}$	0.573	0.459	0.240	0.520	0.720	-0.000	2.160	791
$\mathcal{P}_{lin}$	0.621	0.506	0.240	0.600	0.771	-0.000	3.646	791
Velocity	48.072	7.834	40.917	44.580	56.405	38.000	63.105	842
$D_{Redemption}$	0.189	0.392	0.000	0.000	0.000	0.000	1.000	842
σ_{BTC}	3.284	1.922	2.128	3.041	3.892	0.000	16.599	842
i_{USDT}^{borrow}	4.911	3.221	3.321	3.979	4.891	2.244	36.808	318
i_{USDT}^{supply}	3.620	2.839	2.051	2.917	3.830	1.024	32.093	318
FG_{index}	48.385	26.032	24.000	44.000	73.000	6.000	95.000	842
i_{USD}^{OIS}	0.229	0.371	0.075	0.080	0.095	0.044	2.022	842
cip_{USDT}^{borrow}	4.426	3.423	2.858	3.632	4.589	0.269	36.571	317
cip_{USDT}^{supply}	3.139	3.057	1.582	2.575	3.540	-0.950	31.876	317

Table 4: Determinants of probability of default

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		$\mathcal{P}$ (baseline)				$\mathcal{P}$ (linear interpolation)		
Velocity	0.024***			0.024***	0.030***			0.028***
	(0.003)			(0.002)	(0.003)			(0.003)
σ_{BTC}		0.032***		0.033***		0.059***		0.058***
		(0.010)		(0.009)		(0.015)		(0.013)
$D_{redemption}$			0.230***	0.084*			0.362***	0.179***
			(0.050)	(0.045)			(0.068)	(0.052)
Intercept	-0.616***	0.469***	0.529***	-0.704***	-0.813***	0.427***	0.551***	-0.953***
	(0.116)	(0.039)	(0.023)	(0.114)	(0.147)	(0.048)	(0.023)	(0.145)
R-squared	0.174	0.019	0.039	0.202	0.208	0.052	0.080	0.287
Nr. obs.	791	791	791	791	791	791	791	791

Note: This table uses a regression analysis to identify determinants of USDT default probability. Columns (1) to (4) use the baseline value of devaluation risk estimated in equation (8). Columns (5) to (8) use a measure of devaluation risk based on linear interpolation of futures contracts. Both measures are measured in percentage points. $Velocity$ is the ratio of the value transferred (i.e., the aggregate size of all transfers) divided in the last year to date. It can be interpreted as the number of times that an average native unit has been transferred in the past 1 year. σ_{BTC} is the intra-day volatility of BTC, measured in percentage points. $D_{redemption}$ is equal to 1 if there is a decline in the free float supply of USDT compared to the previous day, and 0 otherwise. The sample specification is from February 28th, 2020 to June 18th, 2022. Newey-West standard errors, which adjust for heteroscedasticity and autocorrelation, are reported in parentheses. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level.

Table 5: Determinants of USDT interest rates

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	i^{USDT}_{borrow}				i^{USDT}_{supply}			
$\mathcal{P}_{baseline}$	1.254***			0.576*	1.109***			0.511*
	(0.482)			(0.347)	(0.427)			(0.301)
FG_{Index}		0.071***		0.057***		0.065***		0.051***
		(0.010)		(0.011)		(0.009)		(0.009)
i_{USD}			-2.219***	-0.802***			-2.085***	-0.817***
			(0.284)	(0.222)			(0.249)	(0.198)
Intercept	3.849***	2.136***	5.917***	2.558***	2.681***	1.088***	4.565***	1.566***
	(0.342)	(0.271)	(0.315)	(0.465)	(0.305)	(0.239)	(0.275)	(0.411)
R-squared	0.035	0.248	0.124	0.259	0.036	0.265	0.141	0.279
Nr. obs.	317	318	318	317	317	318	318	317

Note: This table uses a regression analysis to identify determinants of USDT interest rates. Columns (1) to (4) use the USDT borrowing interest rate as the outcome variable. Columns (5) to (8) use the supply interest rate. The outcome variable of USDT Interest rates are calculated as a weighted average of Aavev2 and Compound lending pools, based on the aggregate liquidity supplied in each pool. Independent variables include the measure of devaluation risk $\mathcal{P}_{baseline}$, the Crypto Fear and Greed Index, and 3 month USD OIS rates. All interest rates and the devaluation risk measure is in percentage points. The sample runs from 5 August 2021 to June 18th, 2022. Newey-West standard errors, which adjust for heteroscedasticity and autocorrelation, are reported in parentheses. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level

Table 6: USDT Spot, borrowing, lending rates and issuance changes around FOMC announcements

	(1) $\Delta\ i_{USDT}^{supply}$	(2) $\Delta\ i_{USDT}^{borrow}$	(3) Δ log (USDT Spot)	(4) Δ log(USDT Net supply)
Δi_{USD}	-0.272	-0.289	-0.269**	-3.491**
	(2.119)	(1.826)	(0.133)	(1.372)
$FOMC_{dummy}$	-0.398	-0.303	-0.002	0.028
	(0.331)	(0.278)	(0.010)	(0.135)
$FOMC_{dummy} \times \Delta$	-11.587	-9.695	1.021	-30.571
	(13.409)	(10.882)	(0.816)	(26.140)
Intercept	0.010	0.008	-0.000	0.313***
	(0.138)	(0.119)	(0.002)	(0.029)
R-squared	0.000	0.000	0.005	0.024
Nr. obs.	317	317	841	841

Note: This table regresses USDT spot price changes on a set of independent variables. $FOMC_{dummy}$ is the dummy variable, which takes a value equal to 1 if it is a day with FOMC announcement, and 0 otherwise. Δi_{USD} is the change in USD interest rate. $FOMC_{dummy}*\Delta i_{USD}$ is the interaction variable between $FOMC_{dummy}$ and Δi_{USD}. Changes in USDT supply are measured in Billions USD. All interest rates are measured in percentage points. The USDT spot price change is measured in USD. Newey-West standard errors, which adjust for heteroscedasticity and autocorrelation, are reported in parentheses. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level.

Internet Appendix to

"Stablecoin Devaluation Risk"

(Not for publication)

Appendix

Appendix A: Stablecoin risk management solutions

A.1 Private sector solutions

One possibility for minimising devaluation risk is real-time audits by a third party proof-of-reserve system. Third party verification of stablecoin collateral at a block-time frequency would provide more transparency on the value of collateral. Real-time auditing can also mitigate the risk of an issuer absconding with funds held off-chain by providing an early alert.

An example is the proof of reserve system provided by the blockchain firm Chainlink.[20] Chainlink conducts automated audits designed to help prevent systemic failures in DeFi applications. A stablecoin that uses Chainlink's proof of reserve is TrueUSD. On February 23rd, 2023, TrueUSD (TUSD) partnered with Chainlink to verify its minting of new stablecoin tokens in real time.

Figure A1 is a schematic. First, Network Firm (an accounting firm) initiates a call for USD-reserve data from TUSD's escrow bank accounts. Network Firm is an oracle, an entity that brings data from off the blockchain (off-chain) data sources, such as the reserves held by TrueUSD in bank accounts. It then transfers this onto the blockchain for use by smart contracts, which are auto-executing code. The use of oracles is necessary because smart contracts running on the Ethereum blockchain cannot access information

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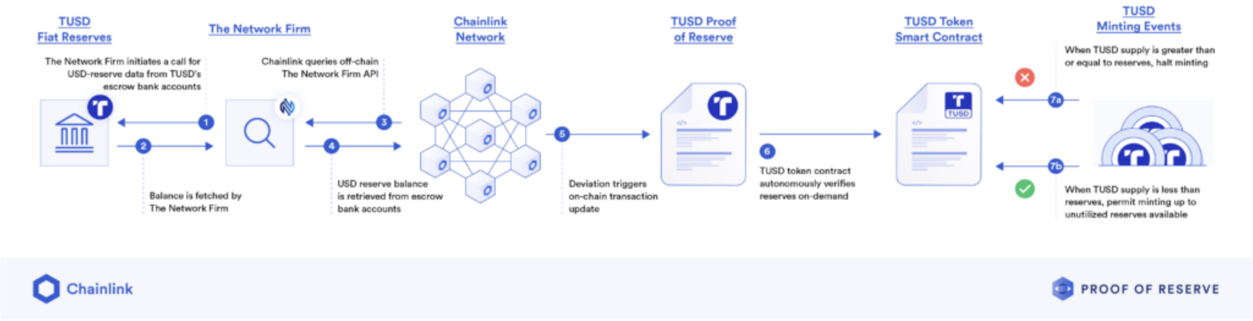
[20] (link)

stored outside the blockchain network.

Figure A1: Chainlink Proof of Reserve



Note: Schematic documents the proof of reserve for TUSD minting events. In the first step, the Network Firm (An accounting firm) initiates a call for USD-reserve data from TUSD's escrow bank accounts. Chainlink queries the Network Firm API to determine the balance from escrow bank accounts. This triggers an update on the blockchain. The TrueUSD smart contract is hard wired to only mint TUSD tokens when the supply is less than reserves held off-chain.

Once the new balance of reserves held in escrow accounts is verified, Chainlink triggers an update on the blockchain. The TrueUSD smart contract, which is auto-executing, mints or burns tokens based on the change in the value of reserves it receives from Chainlink's proof of reserve. In particular, minting of new tokens can only occur once Chainlink verifies that the reserve balances held at the escrow accounts have increased. This proof of reserve system addresses some of the factors creating stablecoin devaluation risk. First, it ensures that the minting of new tokens is tied to reserves and enforces full collateralization at all times. There can still be a run on the stablecoin if investors want out, but there will now be sufficient reserves to meet all redemption requests at par in all states of the world. And since reserves are sufficient to meet redemption requests, the risks of a run are likely to be less.

Second, this is a significant improvement over the existing transparency measures of the largest stablecoins Tether and USDC, which provide attestation reports at monthly or quarterly frequencies. Auditing of assets in block-time by a proof-of-reserve system is at a much higher frequency.

Third, investors can more readily verify the liquidity and riskiness of the assets held by the issuer. If the issuer holds U.S. Treasury securities, the CUSIPs of those individual Treasuries can be verified by the oracle.

A concern is oracle risk, in other words, insufficient quality or misreporting of data received by the oracle on reserves held in escrow accounts. Chainlink requires multiple oracles to achieve consensus on the value of reserves held by the issuer.[21] At the time of writing in May 2023, 16 different companies (and oracles) validate the reserves held by TrueUSD. Chainlink only updates the level of reserves held by TrueUSD when there is consensus among the oracles on the network.

Third-party auditing is only as a reliable as the third-party auditor, in this case Chainlink. Questions about the reliability of such auditors have given rise to calls for government regulation, to which we now turn.

A.2 Government regulations

Recent analysis by the Bank of England suggests a regulatory framework for mitigating stablecoin devaluation risk (BOE, 2021).[22] It points to the need for capital requirements, for the issuer to maintain a sufficiently high fraction of high-quality liquid assets (HQLA) in its reserve portfolio. Second, it suggests that the central bank can provide liquidity support to meet redemptions. This can be provided through access to the central bank discount window facilities used by banks. Third, central banks can provide arrangements for stablecoin users to access their funds in the event that a stablecoin fails. This can be through providing full or partial insurance of customer holdings.

One suggestion is for issuers to be required to meet the capital requirements imposed by Basel regulations on internationally active banks (Catalini and Shah, 2021; Liao, 2022). Some will argue that stablecoin issuers, or at least some of them, have already moved in

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[21] In technical parlance, Chainlink introduces the concept of decentralized oracle networks. This avoids the risk of a centralized entity controlling an oracle or potentially manipulating the smart contract. For more details we refer readers to `https://blog.chain.link/what-is-the-blockchain-oracle-problem/`

[22] For more information, refer to the BOE report on stablecoins `https://www.bankofengland.co.uk/paper/2021/new-forms-of-digital-money`

this direction. For example, Liao and Caramichael (2022) show that USDC has a historically high level of HQLA based on liquidity coverage ratio calculations. The authors find that USDC has at least two times the amount of HQLA as traditional banks, when benchmarked against historical gross outflows over a 30-day ahead period.

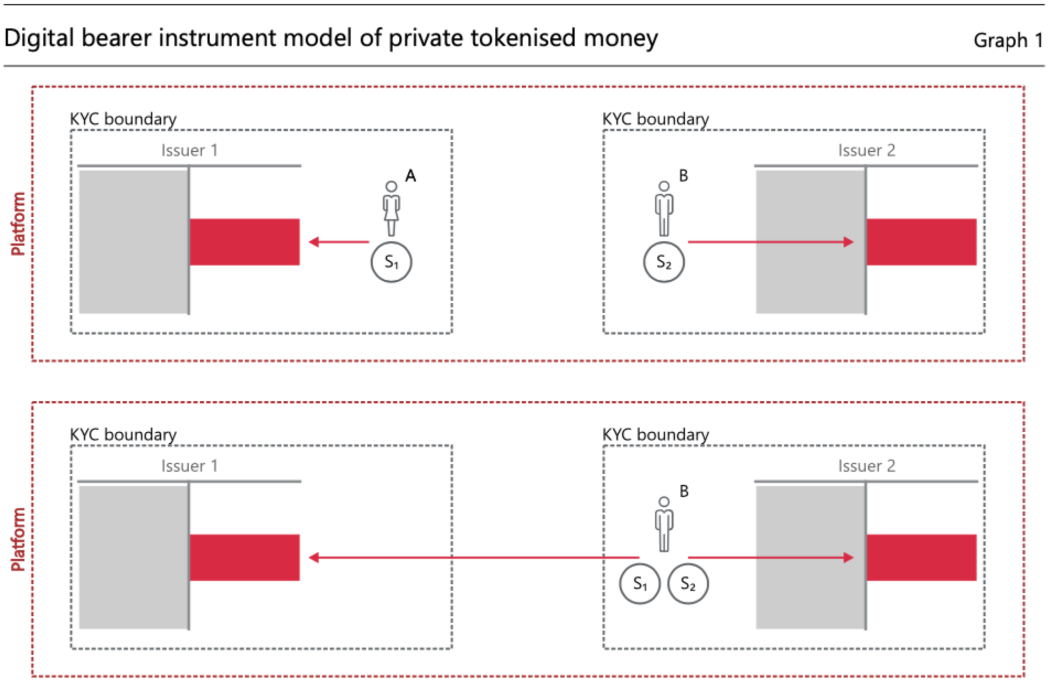
A.3 Alternative stablecoin designs

Policy-makers have suggested alternative arrangements to address stablecoin devaluation risk. These alternatives, namely tokenized deposits and reserve-backed tokens, aim to enhance the stability and reliability of existing stablecoin designs.

A.3.1 Tokenized Deposits

Stablecoins as currently designed follow the bearer instrument model (Figure A2). In this case, transfers between users (individuals A and B in the Figure) can occur without the issuer's consent, allowing the new holder to become the owner of the issuer's liability. Tokens circulate as transferable financial assets with market prices that may fluctuate. Exchange rates can deviate from par due to settlement frictions, and their stability largely depends on the credibility of the issuer's promise. The maintenance of singleness in value is contingent not only on the creditworthiness of the issuer but also on shared confidence in the value of the money.

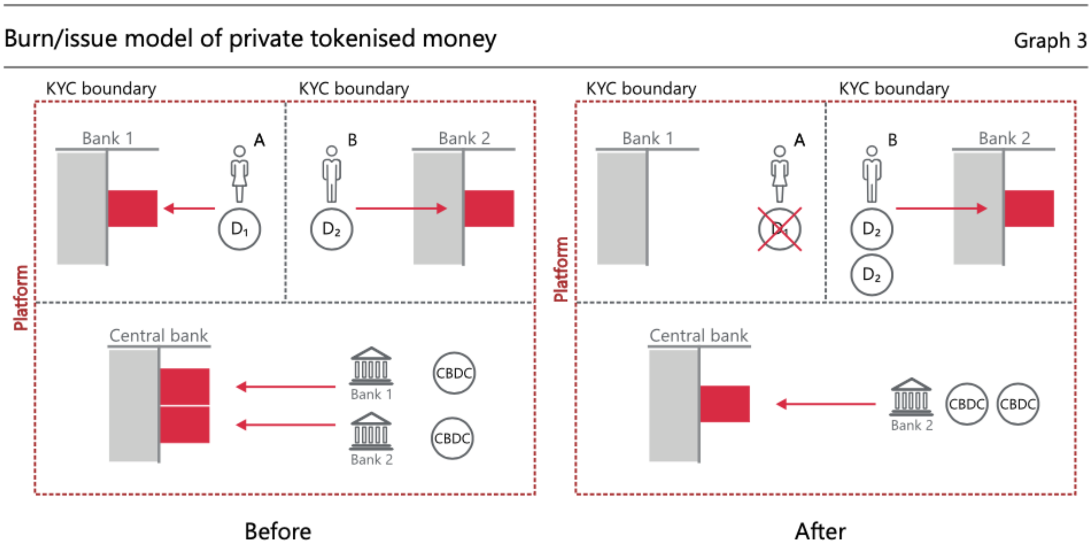
Figure A2: Bearer Instrument Model



Source: Garratt and Shin (2023)

In contrast, Tokenized deposits, as proposed by Garratt and Shin (2023), present a model where private money tokens act as a transferable claim on the issuer, functioning without updating the issuer's balance sheet during regular transfers. This model stipulates that tokens representing an issuer's liability are not directly transferable outside the Know Your Customer (KYC) boundary, and follows a non-bearer instrument model, as shown in Figure A3. Payments involve debiting the sender's account, crediting the receiver's account, and settling on the central bank's balance sheet. Within the same issuer's platform, customers can transfer tokens amongst themselves, addressing singleness concerns. This payment method modifies liabilities between banks and customers without introducing credit exposures across institutions. Central bank digital currency (CBDC) ensures settlement in central bank money, eliminating doubts about exchange value and maintaining singleness. In summary, Tokenized deposits are proposed as a solution to achieve singleness, offering an alternative to the bearer instrument model currently used by stablecoins.

Figure A3: Tokenized Deposit model



Source: Garratt and Shin (2023)

A.3.2 Reserve-Backed Tokens

Reserve-backed tokens (RBT), as discussed by Goel (2024), allow issuers to hold asset reserves with a central bank, enhancing peg stability and obligating the issuer to function as a narrow bank. This structure also facilitates easier redemption processes. The overall risk associated with RBTs depends on the transfer model, particularly if tokens are traded in secondary markets where they can deviate from par.

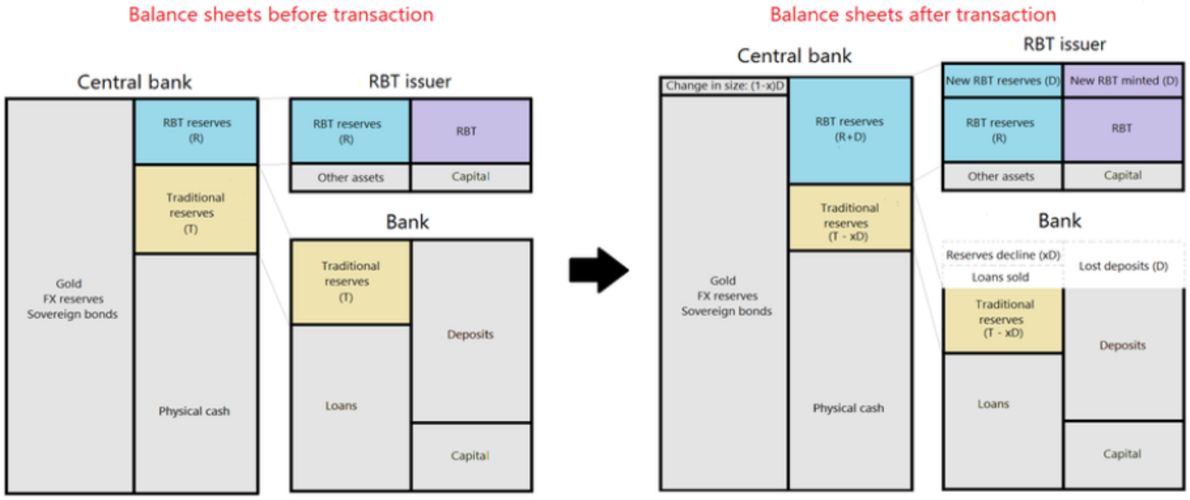
Figure A4 illustrates the creation of RBT using the balance sheets of the issuer and central bank before and after the transaction. When an issuer creates new tokens, they are supplemented by traditional reserves held with the central bank. As users switch from holding deposits with a private bank to holding them with an RBT issuer, there is a corresponding contraction in the bank's balance sheet.

RBTs offer several advantages, including reducing the impact on balance sheets during redemptions, ensuring issuer independence from custodians, and mitigating risk through full backing by safe assets. Additionally, the simplified structure of RBTs facilitates more effective regulation, ensuring compliance with financial standards and improving overall market integrity.

The Bank of England also discusses a related scenario where stablecoin issuers hold central bank digital currency (CBDC), the ultimate HQLA, as reserves. In exchange for granting access to these reserves, the central bank could audit the stablecoin issuerâs balance sheet and impose capital and liquidity requirements. Holding CBDC reserves increases the likelihood that stablecoin providers can maintain the value of their tokens at par, as they would have sufficient funds to process redemptions (Martin, 2022). If reserves are inadequate, the issuer could borrow from the central bank against high-quality but illiquid collateral, with customer holdings potentially guaranteed up to a specified limit. In this scenario, the central bank effectively regulates the stablecoin issuer similarly to banks, as recommended by Gorton and Zhang (2023). However, if a stablecoin issuer is regulated as a narrow bank, it is unclear how it could compete with existing fractional reserve banks. If regulated like existing banks, the primary difference might be its deposit base and transactions technology.

In conclusion, both tokenized deposits and reserve-backed tokens address devaluation risks associated with current stablecoin designs. Tokenized deposits ensure the singleness of value within a platform, while RBTs provide enhanced stability through central bank-backed reserves.

Figure A4: RBTs Balance Sheet



Note: An illustration of how the various balance sheets could adjust when bank deposits are converted to RBTs.

Source: Goel (2024)

Appendix B: Interest Rate Determinants

Table A1: Determinants of USDT interest rates-Compound

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		i_{borrow}^{USDT}				i_{supply}^{USDT}		
$\mathcal{P}_{baseline}$	1.413***			0.868***	1.218***			0.741***
	(0.401)			(0.294)	(0.351)			(0.254)
FG_{Index}		0.061***		0.047***		0.054***		0.041***
		(0.008)		(0.009)		(0.007)		(0.007)
i_{USD}			-1.828***	-0.710***			-1.683***	-0.693***
			(0.235)	(0.219)			(0.205)	(0.197)
Intercept	3.693***	2.522***	5.712***	2.669***	2.321***	1.232***	4.110***	1.441***
	(0.238)	(0.212)	(0.254)	(0.333)	(0.215)	(0.187)	(0.219)	(0.297)
R-squared	0.081	0.326	0.154	0.358	0.079	0.342	0.170	0.376
Nr. obs.	317	318	318	317	317	318	318	317

Note: This table uses a regression analysis to identify determinants of USDT interest rates. Columns (1) to (4) use the USDT borrowing interest rate as the outcome variable. Columns (5) to (8) use the supply interest rate. The outcome variable of USDT Interest rates are from lending protocol Compound. Independent variables include the measure of devaluation risk $\mathcal{P}_{baseline}$, the Crypto Fear and Greed Index, and 3 month USD OIS rates. All interest rates and the devaluation risk measure is in percentage points. The sample runs from 5 August 2021 to June 18th, 2022. Newey-West standard errors, which adjust for heteroscedasticity and autocorrelation, are reported in parentheses. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level

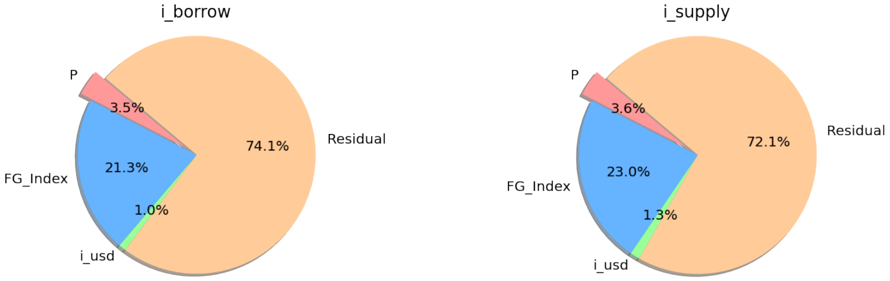
Table A2: Determinants of USDT interest rates-Aavev2

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	i^{USDT}_{borrow}				i^{USDT}_{supply}			
$\mathcal{P}_{baseline}$	1.212*			0.415	1.075*			0.376
	(0.712)			(0.566)	(0.625)			(0.487)
FG_{Index}		0.081***		0.067***		0.074***		0.060***
		(0.016)		(0.017)		(0.014)		(0.014)
i_{USD}			-2.543***	-0.867***			-2.420***	-0.928***
			(0.425)	(0.323)			(0.371)	(0.281)
Intercept	3.957***	1.833***	6.139***	2.420***	2.947***	0.970**	4.958***	1.639**
	(0.515)	(0.430)	(0.479)	(0.753)	(0.450)	(0.378)	(0.417)	(0.657)
R-squared	0.014	0.135	0.069	0.138	0.014	0.147	0.081	0.153
Nr. obs.	317	318	318	317	317	318	318	317

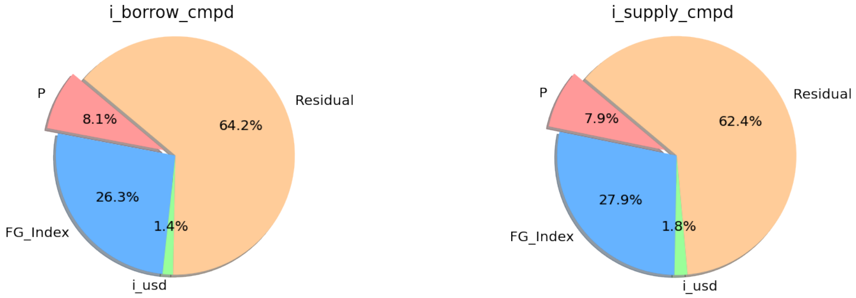
Note: This table uses a regression analysis to identify determinants of USDT interest rates. Columns (1) to (4) use the USDT borrowing interest rate as the outcome variable. Columns (5) to (8) use the supply interest rate. The outcome variable of USDT Interest rates are from lending protocol Aavev2. Independent variables include the measure of devaluation risk $\mathcal{P}_{baseline}$, the Crypto Fear and Greed Index, and 3 month USD OIS rates. All interest rates and the devaluation risk measure is in percentage points. The sample runs from 5 August 2021 to June 18th, 2022. Newey-West standard errors, which adjust for heteroscedasticity and autocorrelation, are reported in parentheses. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level.

Figure A5: Interest rate determinants-ANOVA

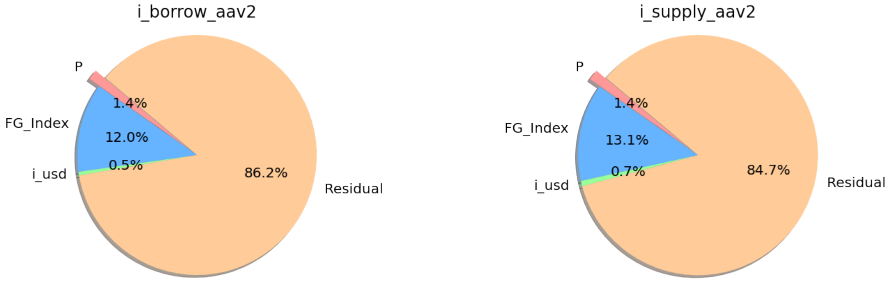
Panel A: Value-weighted interest rates



Panel B: Interest rates - Compound



Panel C: Interest rates - Aavev2



Note: Figure shows ANOVA for determinants of interest rates. Panel A uses value-weighted interest rates based on liquidity supplied to Compound and Aav2. Panel B uses Compound borrow and supply rates, and Panel C uses Aav2 borrow and supply rates. Independent variables include the measure of devaluation risk $\mathcal{P}_{baseline}$, the Crypto Fear and Greed Index, and 3 month USD OIS rates. The sample runs from 5 August 2021 to June 18th, 2022.