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# The Financial Stability Implications of Digital Assets

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**OVERVIEW**

- This article considers the potential vulnerabilities associated with the digital asset ecosystem, adapting the Federal Reserve's framework for assessing financial stability risks in the traditional financial system.
- In particular, it examines the potential channels through which stress in crypto-asset markets could be transmitted to the traditional financial system and ultimately disrupt the real economy.
- The authors argue that, to date, the contribution of digital assets to systemic risk has been limited, given that the digital ecosystem is relatively small and not a major provider of financing and payment services to the real economy.
- However, the observed fragility in the digital asset space is associated with vulnerabilities that could destabilize the broader financial system if the digital ecosystem becomes more systemic.

In recent years, financial activity associated with digital assets has grown significantly, with periods of exponential growth and multiple precipitous crashes. Not only have digital asset prices experienced sharp increases and declines, but these asset price dynamics have been accompanied by the failure of firms in the digital asset ecosystem, resembling the dynamics around financial crises in the traditional financial system. These developments have raised concerns among regulators and policymakers about the financial stability implications of digital assets (Brainard 2022; Goldsmith Romero 2022; Financial Policy Committee 2022; Buch 2023). The goal of this article is to give an overview of the financial stability risks associated with the digital asset ecosystem.

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Our overview adapts the Federal Reserve's framework for assessing systemic risk in the traditional financial system to the digital asset ecosystem. The Federal Reserve's framework distinguishes between vulnerabilities and shocks. Shocks are sudden or surprising events that hit the financial system, whereas financial vulnerabilities are the factors that may amplify negative shocks to the financial system, as we discuss in the next section. Our focus is on the financial vulnerabilities that explain the fragility of the crypto system observed in its short history. In addition, we focus on the potential contribution of the digital asset ecosystem to systemic risk: the likelihood of widespread disruptions to the provision of financing and payment services that can have serious negative consequences for the real economy. Therefore, we examine the potential channels through which stress in the crypto system can be transmitted to stress in the traditional financial system and ultimately disrupt the real economy.

The Federal Reserve's framework identifies broad categories of vulnerabilities that can help assess systemic risk in the traditional financial system. First, vulnerabilities from valuation pressures capture the possibility of outsized drops in asset prices. Second, leverage vulnerabilities capture the amplification of shocks, given that the use of leverage reduces the ability of investors to absorb even modest adverse shocks without selling assets, cutting back on lending, or defaulting. Third, vulnerabilities from funding risk capture the risk of large, sudden withdrawals of funds—a situation commonly referred to as a run. In addition, as emphasized in the literature, there are vulnerabilities from interconnections, which capture the possibility that interactions among financial vulnerabilities can create spillovers and further amplify adverse shocks. For example, an outsized drop in the price of Bitcoin may lead to amplified losses for leveraged investors, who might be forced to sell Bitcoin, amplifying the initial price decline. Similarly, losses on an intermediary's crypto investment can prompt its creditors to withdraw funds on a large scale, forcing the intermediary to sell crypto assets, also amplifying the initial decline in price.

We argue that, to date, the contribution of digital assets to systemic risk has been limited, given that the digital ecosystem is relatively small and is not a major provider of financing and payment services to the real economy. As a result, stress experienced in the digital ecosystem has had limited spillovers to the traditional financial system. However, as we discuss below, the observed fragility of the digital asset ecosystem is associated with financial vulnerabilities in different sectors of the crypto ecosystem that could destabilize the broader financial system in the future, were the digital ecosystem to become more systemic. Note that the statistical close for this analysis was June 2023.

Section 1 provides an overview of the digital asset ecosystem. Our analysis distinguishes between crypto assets, which have market-determined prices, and stablecoins (SCs), which aim to maintain a stable value. In terms of sectors, we consider separately centralized crypto lenders, centralized crypto exchanges (CEXs), and "decentralized finance" (DeFi). Centralized crypto lenders are intermediaries that take funds from customers and invest them in the digital ecosystem, mostly via loans. CEXs facilitate crypto-asset trading, as well as the exchange of traditional currency against crypto assets. These exchanges are typically part of larger crypto conglomerates that provide many other financial products and services. Finally, DeFi refers to the provision of financial products and services using automated protocols.

In our view, the main vulnerability from crypto assets is the buildup of valuation pressures, since these assets are prone to sizable price declines that can be amplified in the digital ecosystem. For instance, Bitcoin prices fell by more than 70 percent following their peak in November 2021 and experienced declines of similar magnitude after their previous peaks in 2017, 2013, and 2011. Vulnerabilities from valuation pressures are amplified by the self-contained nature of the ecosystem that mostly supports speculation and arbitrage across multiple crypto assets, leaving investors exposed to a common source of risk. In other words, the price of crypto assets is explained by a single factor (Hu, Parlour, and Rajan 2019; Liu and Tsyvinski 2021; Ferroni 2022).

We argue that most sectors of the digital ecosystem contribute to financial vulnerabilities from funding risk. First, some SCs have already experienced destabilizing runs, for example, TerraUSD in May 2022 and Iron in June 2021 (Adams and Ibert 2022; Anadu et al. 2023; Liu, Makarov, and Schoar 2023). Moreover, even SCs that we assess as being less fragile contribute to vulnerabilities from funding risk as we will discuss later in the article. Second, several centralized crypto lenders, upon a sequence of adverse shocks in 2022, failed after large withdrawals from their depositors (Patel and Rose 2023). Third, as part of complex crypto conglomerates, CEXs have experienced runs when investors perceive that their investment funds have been diverted within the conglomerate, as in the collapse of FTX in November 2022. Fourth, DeFi protocols have also experienced runs, as in the collapse of the Terra platform, which has been attributed to a run on its Anchor protocol and its decentralized SC TerraUSD (see Box 1 and Liu, Makarov, and Schoar [2023]).

In addition, the use of leverage by crypto investors appears widespread, amplifying investors' exposure to shocks to crypto-asset prices and the feedback loop between leverage and crypto-asset prices. The use of leverage is facilitated by both centralized firms and DeFi protocols. Similarly, the use of leverage is facilitated by traditional asset brokerages and exchanges, all of which enable derivatives and margin investments in crypto assets.

Moreover, all sectors within the crypto ecosystem are highly interconnected, with the aforementioned vulnerabilities amplifying one another and rendering the crypto system very fragile against the occurrence of adverse shocks. In the short history of digital assets, several high-profile projects have failed, and key institutions have found themselves facing liquidity issues and insolvency. As we review below, this was the case with the stablecoin TerraUSD, the centralized crypto lender Celsius, the centralized exchange FTX, and the DeFi protocols associated with the Terra platform, among others.

The lack of a strong and cohesive regulatory framework for digital assets also amplifies these vulnerabilities. Many features of the digital asset ecosystem are designed to avoid regulation or do not fit neatly into existing regulatory frameworks. For instance, when digital asset companies are registered as legal entities, they are often domiciled in non-Group of Twenty (G-20) countries. In addition, controlling influence can be dispersed or can rely on arrangements without a clear legal status. For example, decentralized autonomous organizations (DAOs), where the decision-making process is typically governed by proposals that are voted on by holders of governance tokens, do not have a clear legal status in all U.S. states.[1]

To date, stress in the digital ecosystem has had limited spillovers to the traditional financial system. However, our discussion reveals that crypto intermediaries need financial services offered by traditional intermediaries, linking the financial vulnerabilities that we have described in the digital system with financial vulnerabilities in the traditional financial system. Traditional financial institutions that take deposits from SC issuers and CEXs are a key link between these two systems. Given the fragility of the crypto ecosystem, the demand by crypto firms for bank deposits and money market instruments can exhibit large fluctuations, elevating vulnerabilities from funding risk at traditional banks and other money market investment vehicles.[2] In fact, the failure of Signature Bank and Silvergate Bank in March 2023 has been linked to their reliance on deposits from crypto firms (Tierno 2023). Nonetheless, the overall contribution of the digital asset ecosystem to systemic risk is hard to gauge owing to the short history of digital assets, the reliance on unaudited financial statements in this ecosystem, and other data gaps.

This article is at the intersection of two strands of the literature. First, it contributes to the literature that assesses financial stability risk. One approach is to stress test a set of key institutions to measure systemic risk. For example, Hirtle et al. (2016) and Bassett and Rappoport (2022) present frameworks to stress test the banking sector. Another approach is to gauge the contribution of each intermediary to systemic risk by the amount by which an intermediary is undercapitalized when the system experiences financial stress (Acharya, Engle, and Richardson 2012; Acharya et al. 2017; Brownlees and Engle 2017). Finally, Adrian, Covitz, and Liang (2015) and the Board of Governors of the Federal Reserve System (2018) propose distinguishing between vulnerabilities and shocks to monitor financial stability in the traditional financial system. Here we follow this latter approach and adapt it to gauge the contribution to systemic risk from digital assets.

Second, this article contributes to the literature that studies the financial stability implications of digital assets. In this nascent literature, some studies consider a particular sector of the digital asset ecosystem. One set of papers focuses on the financial stability risks from stablecoins (Gorton et al. 2022; Bertsch 2023; Ma, Zeng, and Zhang 2023; Liu, Makarov, and Schoar 2023; Anadu et al. 2023). Another set of papers focuses on decentralized finance, or DeFi (Schär 2021; Aramonte, Huang, and Schrimpf 2021). Relative to these studies, we discuss the financial stability implications considering the broader digital asset ecosystem. Other analyses have considered a broader view of the digital asset ecosystem but with a specific focus. For example, Consultative Group of Directors of Financial Stability (2023) describes the financial stability risks from digital assets focusing on the implications for emerging market economies.

The rest of the article is organized as follows. Section 1 provides a short overview of the digital asset ecosystem and a description of the way we adapt the Federal Reserve's framework for assessing financial stability. The sections following describe financial stability vulnerabilities associated with crypto assets (Section 2), stablecoins (Section 3), centralized crypto lenders (Section 4), centralized crypto exchanges (Section 5), and DeFi (Section 6). A case study of the TerraUSD collapse in May 2022 and its repercussions in digital and traditional markets is described in Box 1. Section 7 describes the interconnections of the digital asset and the traditional financial systems. Finally, Section 8 offers some conclusions.

## 1. Digital Assets and Financial Stability

### 1.1 The Digital Asset Ecosystem

For our analysis, we focus on the set of digital assets implemented using cryptographic techniques, or crypto assets, and the activities that take place on the networks that support these assets. As a result, our study encompasses payments, trading, borrowing, and lending with digital assets. Moreover, our analysis spans not only crypto assets such as Bitcoin but also the broader digital ecosystem, which we briefly review in this section.

The creation and transfer of crypto assets require a network of computers that maintain a database of transactions and ownership, or a ledger, using a distributed technology, where every agent connected to the network keeps a separate copy of the ledger. To maintain a database using distributed ledger technology, these networks use a consensus algorithm to reach agreement on which transactions are valid. The participants in the consensus algorithm are usually called validators. A common way in which these distributed ledgers are structured involves the use of time-stamped blocks, known as blockchains. Bitcoin and Ethereum are the two best-known networks using blockchain technology. Bitcoin was the first of these networks, introduced in 2008 and designed as the ledger for a payment system with limited programmability.[3] In 2014, Ethereum introduced the concept of a programmable blockchain that can execute a broader set of programs, referred to as smart contracts. At the time of writing, more than 190 blockchain networks were actively used.[4] Until 2022, both Bitcoin and Ethereum used a proof-of-work consensus algorithm to validate transactions. In September 2022, Ethereum transitioned its network to use a proof-of-stake consensus algorithm.

Most networks using blockchain technology have a "native" crypto asset designed to function with that particular blockchain. Native tokens are used as payment instruments in these blockchains and are used to give agents an incentive to adhere to the network protocol. For example, Ether (ETH), the native crypto asset of the Ethereum blockchain, is used to settle transactions on the Ethereum network and to pay the fees associated with these transactions (referred to as gas fees). Bitcoin (BTC), the native asset of the Bitcoin blockchain, and Ether are the largest crypto assets by market capitalization (see Section 2).

Blockchains that allow for richer programming environments are host to a number of non-native crypto assets, referred to as tokens. These tokens can serve multiple functions. One type of non-native asset is a stablecoin (SC), which is designed to maintain a stable value and is discussed in Section 3. Another type of non-native crypto asset is a governance token, which gives holders the right to participate in the decision making of a platform or protocol. Other crypto-asset tokens give the holder the right to access some specific services, such as Binance Coin (BNB) and FTX Token (FTT), which gave their users a discount on trade fees at the Binance and FTX exchanges, respectively. Finally, non-native crypto assets are also used to represent nonfungible tokens (NFTs), which are individually unique and have been used to represent assets such as art, collectibles, and real estate.

Despite their similarities, different networks use different protocols, precluding the seamless transfer of information and assets between these networks. Similarly, the transfer of information and assets between the digital ecosystem and the traditional financial system is a challenge, with an emergent set of institutions that aim to facilitate the investment in crypto assets by the general public. Among these institutions are centralized crypto lenders, or lending platforms, discussed in Section 4. Within the crypto ecosystem, these intermediaries are structured most similarly to banks, in the sense that they take deposits from customers—in the form of both digital and traditional assets—and use these deposits to make loans to institutions that participate in the digital economy.

Another set of institutions that enable investment in crypto assets by the general public are centralized crypto exchanges discussed in Section 5. CEXs facilitate the trading of crypto assets in a manner similar to that of traditional exchanges, by keeping an order book to match buyers and sellers. The order book lists buy and sell orders by their price, allowing a buyer (seller) to choose the lowest (highest) available price in the list. The term "centralized" relates to the fact that CEXs act as a central agent facilitating transactions and that transaction records are held by this central agent, as opposed to being held "on-chain," that is, using distributed ledger technology. Furthermore, CEXs are typically part of larger crypto conglomerates, also discussed in Section 5. In addition to trade execution, these crypto conglomerates can provide many other financial products and services, such as custody, brokerage, settlement, clearing, the listing of crypto derivatives, and venture capital and hedge fund investments. By contrast, in the traditional financial system, these services are offered by separate entities. Moreover, many of these conglomerates operate in ways to avoid financial regulation and do not report fully audited financial statements, making their operations highly opaque.

In addition to allowing blockchains to host non-native assets, programmability enables the hosting of smart contracts: software code intended to automatically execute when predetermined terms and conditions are met. Smart contracts can be used to automate the provision of financial products and services such as lending, savings, payments, and trading, with the potential to replace traditional financial intermediaries. The use of smart contracts for the provision of these services is referred to as "decentralized finance," or DeFi, which we discuss in Section 6. The term "decentralized" relates to the fact that smart contracts replace the central agent, or intermediary, and that data are recorded and shared using blockchains, or more generally distributed ledger technologies.

DeFi protocols allow users to lend, borrow, trade, provide market liquidity, write insurance contracts, and raise capital (Carapella et al. 2022). One important DeFi protocol category is liquidity provision. For example, the Lido protocol allows users to lock their ETH in order to participate in the consensus algorithm and earn the rewards associated with their locked assets, while at the same time obtaining another token called a staked Ethereum (stETH) that can be traded in the Ethereum blockchain, that is, this token is not locked. Another important category of DeFi protocols is bridges, which allow users to lock their crypto assets in one blockchain and retrieve an equivalent crypto asset in another blockchain. One of the most-used bridges is the wrapped Bitcoin protocol, which allows users on the Bitcoin blockchain to lock their BTC and obtain an equivalent token on the Ethereum chain called wrapped Bitcoin (WBTC). Similar to bridges, liquid staking protocols are another popular type of DeFi algorithm. Staking protocols are another popular type of DeFi application, giving users a liquid token in exchange for locked crypto assets.

In the DeFi space, the governance of smart contracts is typically administered by decentralized autonomous organizations (DAOs). In a DAO, the decision-making process is governed by proposals that are voted on by its members. There are different models for DAO membership, but a commonly used model in DeFi is to consider as members the holders of governance tokens—which are tradable—and give members votes in proportion to their holdings of these tokens. An example of such an organization is MakerDAO, which governs the DAI stablecoin and where membership is determined by the holdings of the Maker (MKR) governance token.

Last, in Section 7 we review the connections between the traditional financial system and the digital ecosystem. These connections stem from both the provision of financial services across these systems and the direct exposures created by cross-system positions. For example, some traditional banks offer deposits to firms in the digital financial system and traders can buy traditional financial assets that give them exposure to the digital economy, such as future contracts on Bitcoin and Ether listed by the CME Group.

## 1.2 Assessment of Financial Stability

A traditional financial system is considered stable when systemic risk is limited; that is, there is a limited chance for widespread disruptions to the provision of financing and payment services that can cause serious negative consequences to the real economy (IMF-FSB-BIS 2016; Board of Governors of the Federal Reserve System 2018). Therefore, a financial system is stable if households, communities, and businesses can rely on obtaining financing and accessing payment services even when the system is hit by adverse shocks. Similarly, the digital ecosystem may be regarded as stable if users can rely on being able to buy and sell their digital assets, on obtaining financing, and on executing payments using crypto assets. However, disruptions to the digital financial system may or may not lead to serious negative consequences for the real economy and would need to do so to render risks to the digital ecosystem as systemic.

To assess the risks to financial stability associated with digital assets, we adapt the Federal Reserve's framework to monitor financial stability in the traditional financial system, which distinguishes between vulnerabilities and shocks (Adrian, Covitz, and Liang 2015; Board of Governors of the Federal Reserve System 2018). Shocks are sudden or surprising events that hit the financial system, making them inherently difficult to predict. By contrast, financial vulnerabilities—the factors that may amplify negative shocks to the financial system—build up or recede over time, making them easier to monitor.[5] Thus, the framework analyzes how potential adverse shocks could be amplified by different vulnerabilities and how these vulnerabilities may interact to create additional amplification. The Federal Reserve monitors vulnerabilities in four broad categories: valuation pressures; leverage in the financial sector; leverage in the nonfinancial sector; and funding risk while also considering the possibility that interactions among these vulnerabilities can further amplify adverse shocks. In addition, Adrian, Covitz, and Liang (2015) also recommend monitoring complexity and interconnections within the financial system.

Valuation pressures aim to capture the possibility of outsized drops in asset prices, which could be amplified in the financial system. In fact, sudden declines in asset prices may be amplified in financial markets, since they weaken agents' balance sheets and may force additional asset sales and further price declines (Geanakoplos 2003, 2010; Shleifer and Vishny 2011; Brunnermeier and Sannikov 2014; Haddad and Muir 2021). Research suggests that valuation pressures are associated with investors' risk appetite—the willingness of investors to take on risk. Asset price drops have been more likely when asset prices are high relative to expected discounted cash flows or historical norms (Campbell and Shiller 1988; Case and Shiller 2003; Cochrane and Piazzesi 2005; Shiller 2015). In addition, nonprice measures of risk appetite that proxy for investors' sentiment have been shown to influence stock prices, with stocks of younger, unprofitable, high-volatility, non-dividend-paying, and growth companies being more sensitive to investor sentiment (Baker and Wurgler 2007). Valuation pressures are amplified when they are fueled by the use of leverage, especially when the maturity of the assets is longer than the maturity of the liability financing these assets.

Leverage refers to the use of debt to finance the purchase of an asset, and it captures two important sources of the amplification of shocks in the financial system. One source is the amplification of asset returns when debt is used to finance asset purchases. When the value of debt does not change with the price of the asset, the borrower's return on investment is a multiple of the asset return, increasing the borrower's exposure to a given shock in asset prices. The other source is the co-movement of leverage and asset prices: When uncertainty is low, leverage and asset prices rise; when uncertainty is high, leverage and asset prices fall (Geanakoplos 2003, 2010; Fostel and Geanakoplos 2008; Adrian and Shin 2014). This co-movement is further amplified when the maturity of the debt is shorter than the maturity of the asset being financed.

Funding risk captures the risk to intermediaries of facing large, sudden withdrawals of the funds they borrow to finance their activities, a situation commonly referred to as a run. Facing a run, intermediaries may need to sell assets quickly, pushing asset prices low, thereby incurring substantial losses and potentially even becoming insolvent. The risk of a run is associated with the commitment to repay borrowed funds, irrespective of the evolution of prices for the assets invested, and the difficulty of liquidating long-term assets on short notice–that is, their illiquidity. So, funding risk is intimately related to liquidity and maturity transformation, which describes mismatches between the ease with which a financial institution can sell its assets and the ease with which its creditors can withdraw their funding, or a mismatch between the terms of assets and liabilities.

Banks are subject to funding risks, crystallizing in the form of bank runs, but nonbank intermediaries are also subject to funding risk. In fact, during the global financial crisis (GFC), the initial shock was amplified by the dramatic pullback of lenders from the markets for sale and repurchase agreements (repos) and asset-backed commercial paper (Gorton and Metrick 2012; Acharya, Schnabl, and Suarez 2013). More recently, in March 2020, redemptions from bond funds and money market funds (MMFs) amplified the effect of the initial COVID-19 shock, contributing to the need for policy interventions (Falato, Goldstein, and Hortaçsu 2021; Li et al. 2021). Deposit insurance and the provision of emergency liquidity by central banks are key protections against this vulnerability in the traditional banking system.

Going beyond the four broad categories in the Federal Reserve framework, and as recommended by Adrian, Covitz, and Liang (2015), we also consider vulnerabilities from interconnectedness and complexity. Interconnectedness aims to account for the amplification of stress in the financial system from the interrelationships among intermediaries. These interrelationships may arise from different channels. First, intermediaries can be directly interconnected through counterparty relationships, such as payment obligations, debt, or derivative contracts (Eisenberg and Noe 2001; Acemoglu, Ozdaglar, and Tahbaz-Salehi 2015; Giglio 2014). Direct interconnections increase the contribution to systemic risk of large intermediaries with many counterparty relationships and of longer intermediation chains. Second, intermediaries may be indirectly interconnected if they are exposed to similar shocks to their earnings or their balance sheets.[6] Indirect exposure to asset markets by interconnected agents creates potential interconnections among these markets. Third, direct and indirect interconnections may interact. For example, Chang and Chuan (2021) investigate contagion when intermediaries have counterparty and common asset exposures. Finally, interconnections can be brought about by critical market infrastructures. When an infrastructure that cannot be easily replaced is compromised or fails to function as expected, adverse consequences can be significant.

Complexity can also contribute to amplifying financial shocks, since more complex systems may increase the uncertainty of counterparty exposures and more complex financial products may have more uncertain payouts. New financial products and services may also increase systemic risk, since the lack of data makes the assessment of risks more complex and may introduce new interconnections that might not become apparent until the system is hit by adverse shocks.

Although shocks are inherently difficult to predict, the history of traditional financial systems offers additional insights into the types of shocks that disrupt the provision of financial services. In addition, the digital asset ecosystem has had numerous realizations of adverse shocks—which we describe throughout this article—that have been amplified by the financial vulnerabilities described above. First, sharp drops in the price of crypto assets have been amplified by liquidations and fire sales both in CEXs and DeFi protocols. Second, many SCs, centralized crypto lenders, and CEXs have experienced runs that have spilled over to other areas of the digital asset ecosystem. Third, defaults of hedge funds, centralized lenders, and CEXs have also created negative feedback loops throughout the system.

In addition to the aforementioned shocks, we consider shocks stemming from operational risk, including cyber risks, given that particular features of the digital ecosystem give more prominence to these risks and they can be amplified by the previously mentioned vulnerabilities. Operational risks are always a concern in relation to financial services involving digital assets. For instance, the greater speed of automated execution reduces the response time for interventions that could prevent fire sales or other destabilizations (Allen 2022). In addition, decentralized governance can hinder rapid action to mitigate stress or to implement regulations aimed at reducing financial vulnerabilities. Moreover, in the digital ecosystem, operational risk is compounded by the prevalence of fraud, scams, hacks, and bugs, and it is exacerbated by automation and decentralization. Inaccurate or misleading representations and disclosures increase the risk of fraud, and the lack of a strong and cohesive regulatory framework for digital assets creates legal uncertainties.[7]

Some caveats are in order. First, in the novo digital space, financial vulnerabilities might crystallize in new forms relative to the short history of this space and the longer history of crises in the traditional financial system that we draw on for our analysis. In fact, how financial vulnerabilities can amplify shocks only becomes evident after the fact (Adrian, Covitz, and Liang 2015). This is particularly the case in this space as new structures and products transform risks in novel ways, which can lead participants to neglect some risks (Gennaioli, Shleifer, and Vishny 2013). Second, this framework is more judgmental relative to using stress tests or other gauges of systemic risk. For instance, using data and a stress test framework, we could assess the contribution of the digital sector to systemic risk. Alas, data and model requirements place this approach beyond the scope of our analysis. Alternatively, the academic literature proposes other frameworks to measure systemic risk and the contribution of different intermediaries. For example, the contribution of each intermediary to systemic risk can be measured by the amount by which an intermediary is undercapitalized when the system experiences financial stress (Acharya, Engle, and Richardson 2012; Acharya et al. 2017; Brownlees and Engle 2017). Despite our framework being more judgmental, Aikman et al. (2017) show how this framework can be used to quantify systemic risk, summarizing the information on a wide array of indicators of financial fragility, which may include systemic risk indicators derived from the results of stress tests or as proposed in the academic literature.

## 2. Crypto Assets

Crypto assets are digital assets that use cryptographic techniques to prove ownership (see Section 1.1). In this section we review the financial stability implications of these assets, excluding SCs, which we review in Section 3. We argue that the main financial vulnerabilities from crypto assets are the buildup of valuation pressures and interconnectedness, since these assets are prone to sizable price declines that can be amplified in the digital ecosystem. Vulnerabilities from valuations are amplified by the other financial vulnerabilities associated with the different parts of the crypto ecosystem described in this article. The salient risk of large price declines makes the crypto ecosystem unstable, but thus far, stress in the market for crypto assets has had limited spillovers to the traditional financial system. Were the crypto system to grow larger and become more connected with the traditional financial system, vulnerabilities from crypto-asset valuations could create stronger spillovers to traditional financial markets and contribute to systemic risk (see the discussion in Section 7).

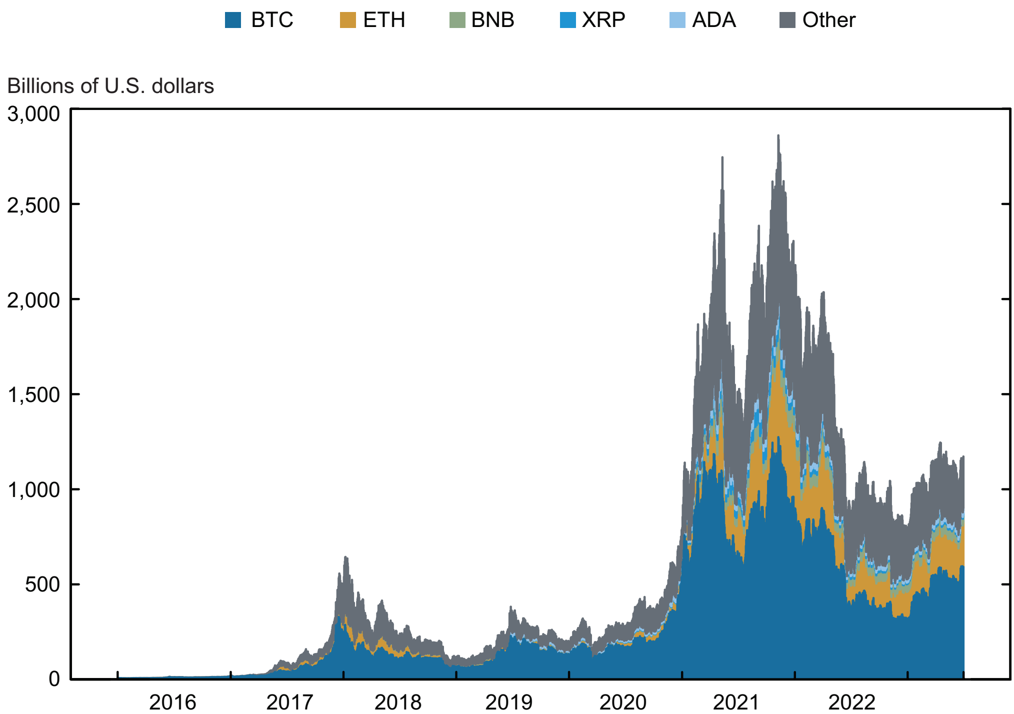
Valuation pressures are signaled by prices that are elevated relative to the asset's fundamental or intrinsic value, which can be measured, for example, by discounting the asset's future expected cash flows. At present, native crypto assets do not have associated cash flows, so some observers have argued that their fundamental value is zero and that they ought to have a price equal to zero. The lack of cash flows represents a key challenge for the assessment of valuation pressures related to crypto assets (see Appendix 1).

To gauge the valuation dynamics of crypto assets, we present the market capitalization of a broad sample of crypto assets in Chart 1.[8] Market capitalization corresponds to the total supply of the asset multiplied by its current market price. The market capitalization of crypto assets experienced very rapid growth in late 2020 and early 2021, hitting a first peak above $2.5 trillion for the total market capitalization in May 2021 and reaching an all-time high of $2.8 trillion in November 2021. Crypto assets rose sharply in value during 2020 and 2021—a period of historically low interest rates—and began to fall in value as central banks began to raise interest rates to fight elevated inflation. As of June 2023, the crypto asset with the largest market capitalization was Bitcoin (BTC), with a market capitalization of $592 billion. The second largest, Ether (ETH), had a market capitalization of $237 billion. They were followed by Binance Token (BNB), XRP the native crypto asset of the XRP Ledger, and Cardano (ADA), with market capitalizations of $37 billion, $25 billion, and $10 billion, respectively. As of June 2023, the market capitalization of all the crypto assets reported in Chart 1 was down almost 60 percent from its peak in November 2021.

### 2.1 Financial Vulnerabilities from Crypto Assets

We argue that the main financial vulnerability from crypto assets corresponds to the buildup of valuation pressures. First, valuation pressures in crypto assets are underscored by the recurrent large declines in the price of BTC and other crypto assets (Chart 1). In fact, BTC fell by more than 70 percent from its peak in November 2021 to May 2022 and experienced declines of similar magnitude after its previous peaks in 2017, 2013, and 2011. Similarly, holders of NFTs have found themselves unable to recoup their initial investments upon selling their tokens and, in some instances, have taken significant losses.[9]

Chart 1
## Total Market Capitalization of Crypto Assets



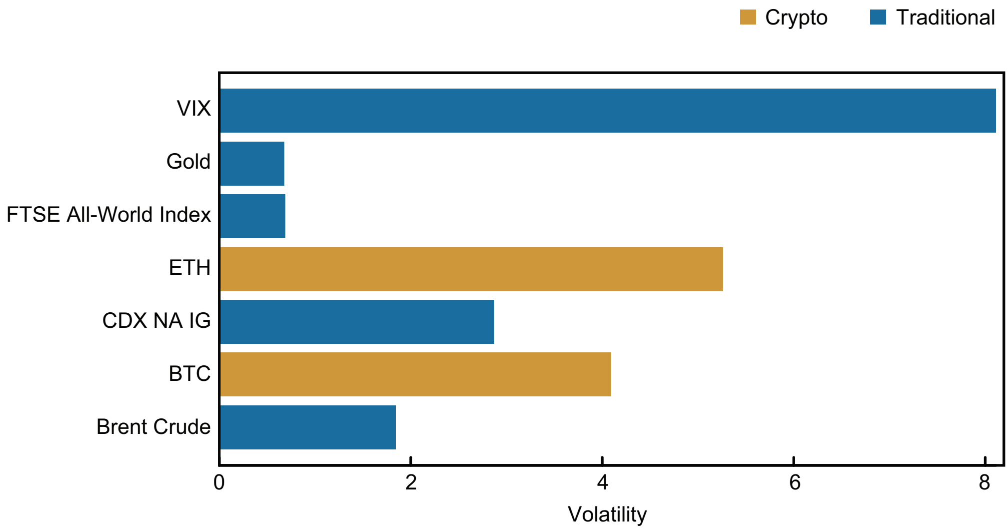

Source: Coinmetrics.

Notes: BTC is the ticker symbol for Bitcoin, ETH for Ether, BNB for Binance Token, XRP for the native crypto asset of the XRP ledger, and ADA for Cardano. The values are daily measures.

The large price swings of crypto assets are reflected in high realized volatility for this asset class. Chart 2 compares the volatility of crypto assets with traditional assets. BTC and ETH display volatilities that are higher than those of most traditional assets in normal periods, defined as periods where neither the traditional nor the crypto market experiences stress. Moreover, during periods of traditional market stress, crypto assets can be as volatile as traditional assets, and during periods of crypto stress, these assets are much more volatile than traditional assets.

Second, the evidence points to a significant role of risk appetite in driving crypto-asset prices. As discussed in Section 1.2, valuation pressures have been shown to be associated with investors' risk appetite. Research suggests a large role for investors' sentiment driving the returns of assets that represent equity in firms that are younger or do not pay dividends (Baker and Wurgler 2007). In addition, the use of social media platforms, such as Reddit and X (formerly Twitter), by traders of crypto assets might increase the likelihood of asset price bubbles and crashes, since it accelerates the speed of dissemination of information and trading ideas. Some researchers have argued that the fast dissemination of narratives associated with asset returns has amplified asset returns during both booms and crashes (Shiller 2017). A popular narrative among crypto enthusiasts has been that crypto assets are a hedge against inflation. Yet, as shown in Chart 1, the

Chart 2
Volatility of Crypto and Traditional Assets in Normal Periods




Source: Authors' elaboration based on Bloomberg and CryptoCompare.

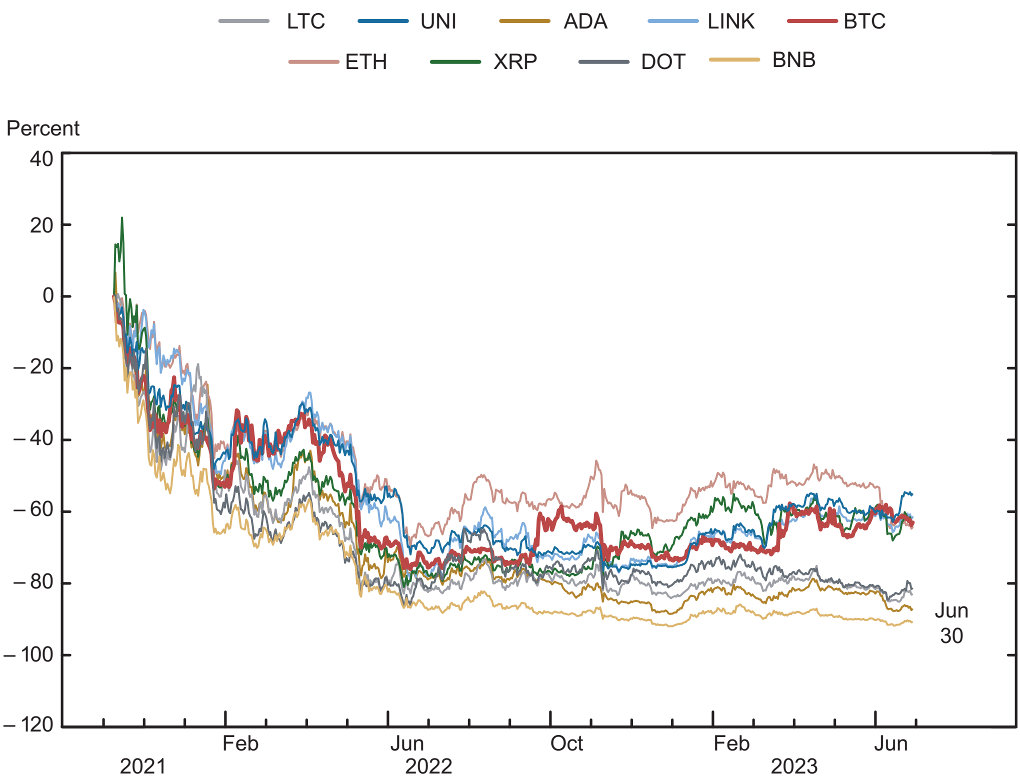
Notes: Normal period spans Feb. 1, 2018, to Jan. 31, 2020. VIX corresponds to the CBOE index of implied volatility of the U.S. stock market. CDX NA IG corresponds to the Markit CDX contract associated with 125 of the most liquid North American entities with investment grade credit ratings. BTC is the ticker symbol for Bitcoin, and ETH is the ticker symbol for Ether. We thank Christopher Anderson and Sara Saab, who shared with us their analysis of the crypto-asset market.

crypto-asset class performed poorly from late 2021 following the increase in inflation, which was accompanied by higher interest rates and a change in risk sentiment in traditional markets.

Moreover, research suggests that most of the variation in the prices of crypto assets is associated with a common factor, and only a small fraction of price movements are associated with the idiosyncratic characteristics of individual crypto assets (Hu, Parlour, and Rajan 2019; Liu and Tsyvinski 2021; Ferroni 2022). In fact, after BTC reached its all-time high in November 2021, the prices of major crypto assets all followed a similar downward trajectory as illustrated in Chart 3. Over the past few years, the returns on BTC have been strongly correlated with the returns on other crypto assets. A high correlation between crypto assets and the low explanatory power of idiosyncratic factors suggest a large role for risk appetite in driving the prices of these assets.

Furthermore, we argue that crypto assets introduce significant vulnerabilities from interconnectedness. First, crypto assets create direct interconnections between counterparties, since these assets are used for making payments and securing debt, and as a reference asset in derivative contracts. For example, the use of crypto assets as collateral creates negative feedback loops between vulnerabilities from valuation pressures and leverage. In fact, ETH, BTC, and WBTC are commonly used as collateral in digital financial transactions. When the price of BTC drops, it causes large losses for leveraged investors. As the value of these investments approaches the value of the corresponding debt, creditors may liquidate crypto-asset collateral, amplifying the initial price

Chart 3
Performance of Major Crypto Assets since Bitcoin's All-Time High




Source: CryptoCompare.

Notes: ADA is the ticker symbol for Cardano, LINK for Chainlink, BTC for Bitcoin, BNB for Binance Token, LTC for Litecoin, UNI for Uniswap, ETH for Ether, XRP for the native crypto asset of the XRP Ledger, and DOT for Polkadot. The values are daily measures.

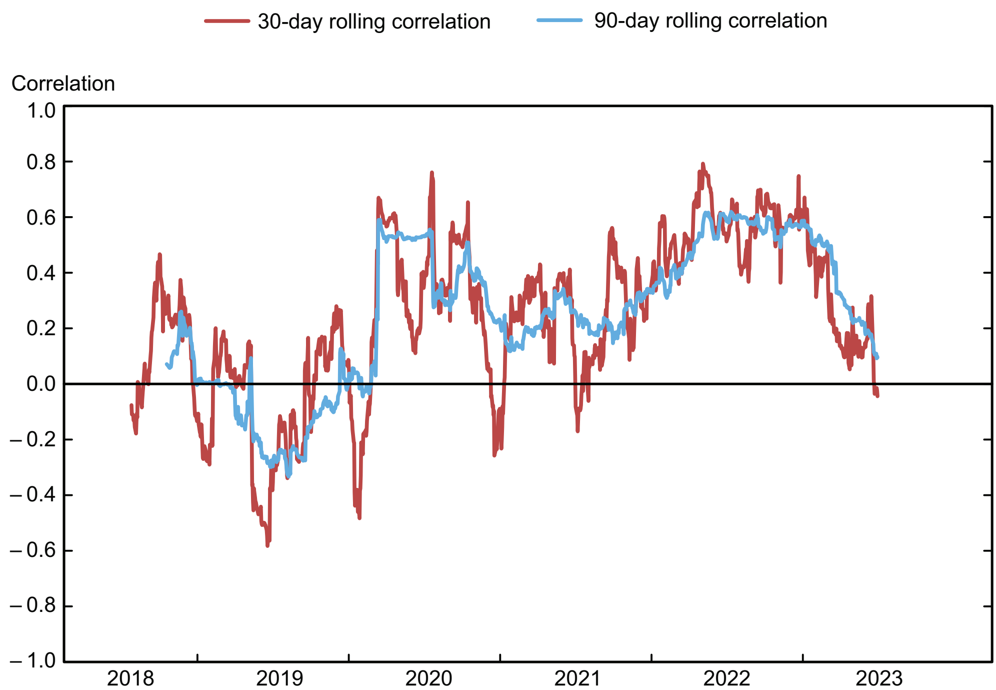
decline. Second, crypto assets create indirect interconnections through common exposures throughout the digital ecosystem. Moreover, the degree to which crypto-asset prices move together implies that crypto-asset investors are indirectly interconnected even if they are exposed to different crypto assets (Ferroni 2022). These common effective exposures limit the ability of crypto intermediaries to share liquidity risk. Were crypto-asset prices to drop, it might trigger short-term creditors to withdraw funds from investments with such an exposure, such as (centralized and decentralized) crypto lenders and exchanges, as happened in the Terra crash (see Box 1). With most firms having similar exposures to crypto-asset prices, the ability of these firms to provide insurance against liquidity risk will be limited, and they may be forced to sell crypto assets in a downturn, amplifying the initial price decline. Finally, the networks that support crypto-asset activities are not easy to replace, making them critical market infrastructures.

It is worth noting that relative to traditional assets, crypto assets seem more exposed to downside risks. As in traditional asset markets, a decline in asset prices could be triggered by a reversal in investors' risk appetite. Additionally, new technologies could render incumbent crypto assets obsolete, or new regulations or tax provisions could be unfavorable. For example, quantum computing could undermine the cryptographic techniques used to maintain the security of current networks that support crypto assets (Webber et al. 2022). Further, light regulation could increase the exposure of crypto-asset prices to price manipulation and operational risk. Notorious examples of price manipulation are the so-called "pump and dump" schemes. In these schemes, agents coordinate to bid up the price of a targeted crypto asset before selling it at a profit. Thousands of tokens, mainly those with small market capitalizations but also several major tokens, have been the target of these schemes, although the prevalence of such schemes has decreased over time (Hamrick et al. 2021). In terms of operational risk, crypto assets seem to be associated with a higher incidence of fraud, scams, hacks, and bugs associated with digital networks. These operational events could cause declines in crypto-asset prices, and these declines could be amplified and create negative feedback loops when vulnerabilities from funding risk and leverage are elevated. For instance, if agents were to lose confidence in the soundness of an intermediary, creditors might withdraw funds from the intermediary, forcing the fire sale of crypto assets. Finally, the light regulation in crypto-asset markets raises the specter of market manipulation (Auer, Frost, and Vidal Pastor 2022).

Despite the fact that valuation pressures contribute to making the digital ecosystem very unstable, we argue that such pressures and the interconnectedness associated with crypto assets, until now, have made a limited contribution to systemic risk. In fact, the large price declines of Bitcoin and other crypto assets from previous peaks in 2021, 2017, 2013, and 2011 did not cause widespread disruptions to the provision of financial services in the real economy. One channel through which the valuation pressures of crypto assets can spill over to the traditional markets is contagion. To inspect this channel, we calculate the correlation of crypto assets with traditional assets over time. Chart 4 displays the correlation of Bitcoin with the S&P 500 index over rolling windows of 30 and 90 days. The 90-day correlations between these assets started close to zero at the beginning of 2017 but have been much higher lately, displaying higher correlations around the onset of the COVID-19 pandemic and in 2022 as central banks increased rates to bring inflation down. This pattern is apparent in correlations with other traditional financial assets as well and suggests that crypto assets are highly susceptible to changes in risk sentiment in traditional financial markets, rather than the other way around.

Nevertheless, as the crypto ecosystem grows larger and becomes more interconnected with the traditional financial system, vulnerabilities from crypto assets could spill over into traditional financial markets (see the discussion in Section 7).

Chart 4
Rolling Window Correlations of Bitcoin Prices and the S&P 500 Index



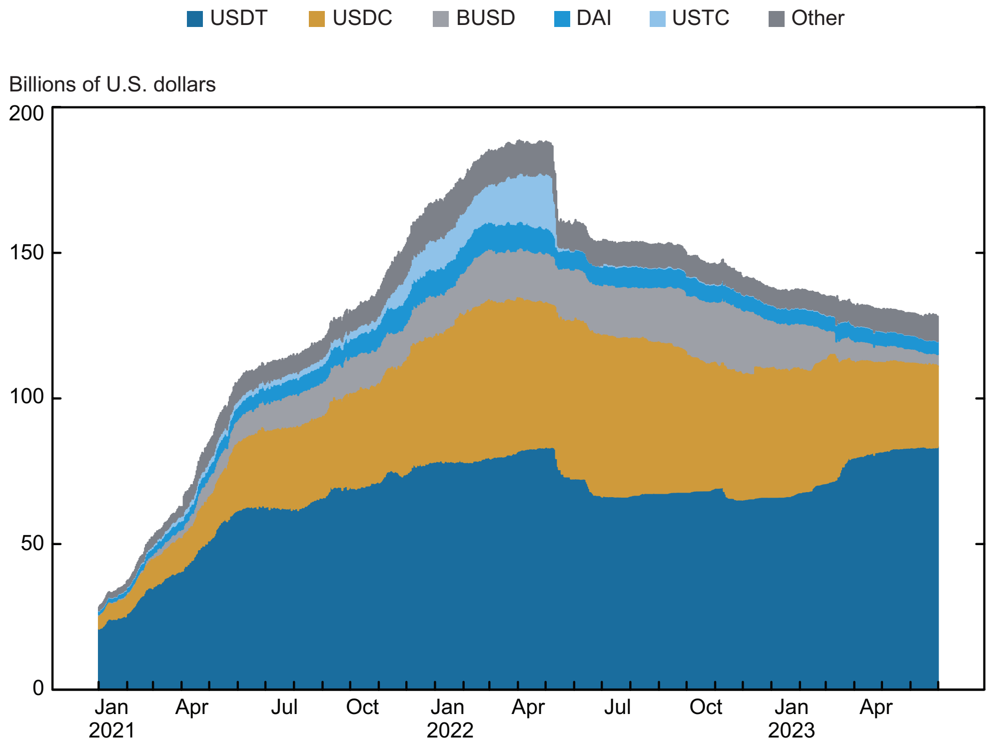

Sources: CryptoCompare and S&P Dow Jones Indices LLC, S&P 500 [SP500], retrieved from FRED, Federal Reserve Bank of St. Louis, https://fred.stlouisfed.org/series/SP500.

## 3. Stablecoins

SCs are digital assets that aim to maintain a stable value relative to a reference asset—typically the U.S. dollar. We argue that the main financial vulnerabilities from SCs are funding risk and interconnectedness. In fact, some SCs have already experienced destabilizing runs, such as TerraUSD, which collapsed in May 2022 (see Box 1). Moreover, even the SCs that we assess as being less fragile appear subject to runs. Further, as detailed in this and subsequent sections, SCs create interconnections that can amplify shocks in the digital ecosystem and have the potential to spill over into the traditional financial system. As a result, SCs appear to contribute not only to the instability of the digital ecosystem but also to systemic risk. Nonetheless, financial stability risks from SCs and the amplification mechanisms of such risks through vulnerabilities in the crypto ecosystem are hard to gauge owing to the short history of SCs, the reliance on unaudited financial statements, and other data gaps.

The market capitalization of SCs has experienced rapid growth in recent years, with the five major SCs depicted in Chart 5 growing from $27 billion at the beginning of 2021 to a peak of

Chart 5
## Market Capitalization of Major Stablecoins

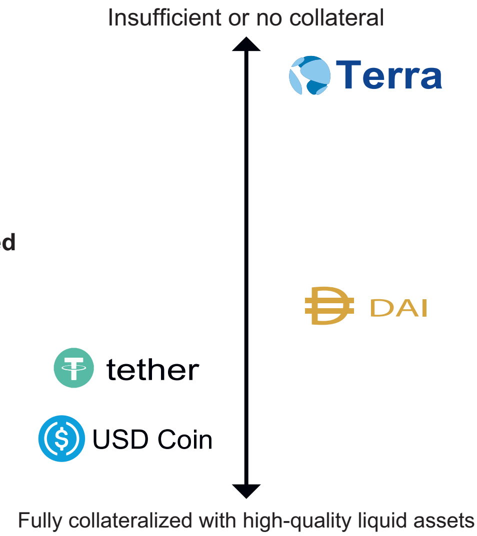



Source: DeFi Llama.

Notes: USDT is the ticker symbol for Tether, USDC for USD Coin, BUSD for Binance USD, DAI for the stablecoin issued by MakerDAO, and USTC for TerraUSD. The values are daily measures.

$178 billion on April 2022. The growth of SCs in 2021–22 coincided with the broader growth of the crypto-asset markets and DeFi. By contrast, from the collapse of TerraUSD in May 2022 to the end of June 2023, the market capitalization of the other four major SCs in the chart declined by a little over 25 percent. As shown in Chart 5 as of the end of June 2023, the largest stablecoin by market capitalization was Tether (USDT), with a market capitalization of $83 billion, almost back to its peak of $84 billion reached in May 2022 before the collapse of TerraUSD. The second largest stablecoin was USD Coin (USDC), with a market capitalization of $28 billion. They are followed by DAI, the stablecoin issued by MakerDAO, and Binance USD (BUSD), with market capitalizations of $4.4 billion and $4.2 billion, respectively. The fifth SC presented in the chart is TerraUSD (USTC), which experienced a run that reduced its market capitalization from a peak of more than $18 billion at the end of April 2022 to $120 million at the end of June 2023 (see Box 1). Appendix 2 provides further background material on stablecoins.

Exhibit 1
**Key Design Features of Stablecoins**




Note: Adapted from Gabriele (2021).

## 3.1 Financial Vulnerabilities from Stablecoins

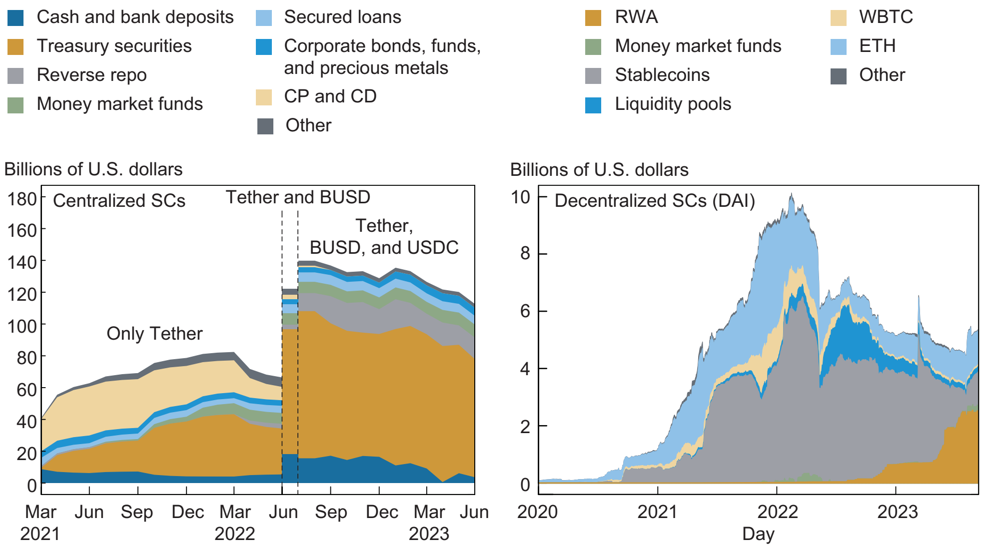
We argue that the main financial vulnerabilities from SCs are run risk and interconnectedness. In fact, SCs are marketed as being stable and pegged to their reference asset, creating the perception that users can redeem them on demand for the reference asset. However, in practice, SC issuers may impose restrictions on redemptions, leaving users that want to liquidate their SCs with only the option to trade them in secondary markets.[10] The perception that SCs can be redeemed on demand is enough for them to create vulnerabilities from liquidity and maturity transformation, since SC reserve assets could be illiquid or have longer maturities.

Different SCs have different designs aimed at maintaining their peg, which can affect their susceptibility to runs. SCs can be partitioned according to two key distinguishing features, as shown in Exhibit 1: their degree of centralization, shown along the horizontal axis, and their degree of collateralization, shown on the vertical axis.

The first key design dimension is their degree of centralization of governance. Some SCs, like Tether, USDC, or BUSD, are issued by a single entity with a centralized governance structure. By contrast, DAI and TerraUSD have decentralized governance structures and are issued and administered using smart contracts. In the latter case, issuance and redemptions are carried out by a smart contract that follows preset rules that can be modified by the corresponding DAO. For example, changes in the eligible collateral for creating or minting DAI are voted on by the holders of the MKR governance token. Coordination problems at DAOs, given their decentralized governance structure, create higher vulnerabilities from decentralized SCs, all else being equal, since it is harder for a DAO to respond promptly to sudden changes in market conditions not contemplated in their smart contract rules.

Chart 6

## Stablecoin Reserves by Asset Categories




Sources: Authors' elaboration based on SC issuer attestations for Tether, BUSD, and USDC and Dune for DAI. For Tether, see https://tether.to/en/transparency/. For BUSD, see https://paxos.com/busd-transparency/. For USDC, see https://www.circle.com/en/transparency.

Notes: CP is commercial paper. CD is certificate of deposit. SC is stablecoin. ETH is the ticker symbol for Ether and WBTC is the ticker symbol for wrapped Bitcoin. RWA stands for real-world assets.

The second key design dimension is the degree of collateralization (shown in the vertical axis of Exhibit 1). Given the lack of standardization or regulation, SC issuers have been able to use assets of different quality to back SCs. At one extreme, SCs fully backed by central bank reserves would be resilient to runs. But holding central bank reserves requires an account at the central bank, which is generally limited to regulated depository institutions. Among centralized SCs, Tether, USDC, and BUSD hold traditional assets as collateral, the grade of which has varied over time, as we describe next. At the other extreme, there are SCs that are backed by low-quality collateral or by no collateral at all, as represented by the vertical axis in the exhibit. Among decentralized SCs, DAI is an algorithmic SC designed to be overcollateralized, while Terra (or TerraUSD for its dollar SC) is an algorithmic SC that was designed with no collateral.[11]

A closer inspection of the reserves backing major SCs reveals that, over time, they have increased the grade of their reserve assets. For the major centralized SCs—BUSD, Tether, and USDC—we combine information from their self-reported, unaudited financial statements to study the evolution of their reserves.[12] As shown in Chart 6, since 2021 the grade of reserve assets has improved, with a shift away from commercial paper and toward Treasury securities and reverse repos (see left panel). Cash and bank deposits represented an important share of assets, but their importance diminished in the second quarter of 2023. For the largest decentralized SC—DAI—we use blockchain information to study the evolution of its reserves. The right panel of Chart 6 shows that while in 2020 most DAI was backed by ETH, the composition of its reserves shifted to SCs in 2021 and the beginning of 2022. During 2022, crypto assets associated with liquidity pools, which we describe in Section 6, comprised an important share of reserve assets, whereas in the first half of 2023, real-world assets (RWA), such as Treasury securities, became a larger share of its reserve assets.

Despite the improvement in collateral quality since 2021 for major SCs, we argue that these major SCs still represent funding risk vulnerabilities. As of June 2023, these SCs display different risk exposures on their reserve assets. For example, about 15 percent of Tether's reserves comprise risky assets, such as corporate bonds, precious metals, Bitcoin, other investments, and secured loans, making Tether riskier than most prime MMFs, a sector that experienced destabilizing runs in 2008 and 2020 (Anadu et al. 2023). By contrast, USDC reports only safe assets as collateral. Yet, USDC de-pegged when Silicon Valley Bank failed in March 2023, since some of its cash was held as bank uninsured deposits at this bank.

The ease of switching between SCs with reserves of different perceived quality can amplify run risks from more fragile ones, since more resilient SCs provide a convenient instrument to run to in a period of stress. In fact, shortly after the TerraUSD collapse and when based on self-reported, unaudited financial statements, Tether held lower-grade reserves compared with USDC, Tether saw redemptions of around $10 billion, while USDC saw a little more than $4 billion of new inflows (Chart 5).[13]

It is worth emphasizing that triggers for a run on SCs can arise from different sources. On the one hand, a drop in the price of the collateral assets or a lack of trust in the custodian of those assets could trigger a run.[14] On the other hand, the trigger for a run could be a sudden lack of confidence in the SC, which could be self-fulfilling and might be the result of a speculative or short sellers' attack on the SC analogous to those that threaten currency pegs.

Further, we argue that SCs create interconnections that can amplify shocks in the digital ecosystem and have the potential to spill over into the traditional financial system. Since SCs underpin the crypto ecosystem, a run on an SC can create negative feedback loops via the SC's relationships with DeFi applications and crypto-asset prices. Moreover, SCs are commonly deposited and borrowed in DeFi, commonly used to trade for other crypto assets in decentralized exchanges, and often touted as earning yields in excess of bank deposits (Gorton et al. 2022). For instance, if an SC loses its peg, DeFi platforms that operate using that SC may become stressed. In this case, users will withdraw funds from lending platforms and borrowers will see their rates increase rapidly, which would transmit stress to both decentralized and centralized exchanges, and ultimately to other cryptocurrencies. In fact, in the case of the demise of the Terra platform, the collapse of the TerraUSD stablecoin, whose market capitalization of about $18 billion evaporated, was accompanied by a decline of $25 billion in the total value locked (TVL) in the Terra blockchain associated with its DeFi applications, such as Anchor and Mirror, with knock-on effects on Terra investors and their counterparties (see Box 1).

In addition, for SCs collateralized by traditional financial assets ("off chain"), a run could lead to liquidations and fire sales of the collateral assets. If a sizable share of holders rushed to sell or redeem a large SC such as Tether or USDC, it could not only create instability in the digital asset ecosystem but also disrupt certain markets in the traditional financial system, since SC issuers would have to dispose of their reserve assets quickly to meet redemptions. These disruptions would likely be more severe in the case of SCs with less liquid reserve assets, such as corporate bonds and commercial paper. Until 2022, Tether was reportedly one of the largest holders of commercial paper in the world.[15]

# 4. Centralized Crypto Lenders

Centralized crypto lenders, or lending platforms, are intermediaries that take funds from customers and invest them in the digital ecosystem, mostly via loans. We argue that the main financial vulnerabilities from these lenders are leverage, funding risk, and interconnectedness. In fact, after a sequence of adverse shocks in the digital ecosystem in 2022, several large lending platforms failed, and these failures contributed to amplifying and further spreading financial stress within the digital ecosystem, with thousands of retail depositors losing their investments with centralized crypto lenders.

At their peak in late 2021, major lending platforms managed assets worth tens of billions of dollars. For example, Celsius Network, a major crypto lender, had over $28 billion worth of assets under management.[16] Another lender, BlockFi, had roughly $10 billion.[17] Voyager had $5.9 billion worth of assets on its platform.[18] Genesis held just under $1 billion of investor assets.[19] Together these firms held funds on behalf of millions of customers, but account balances were concentrated in a small number of accounts (Patel and Rose 2023). All of these four major crypto lenders declared bankruptcy following the collapse of the Terra platform and its Anchor protocol. Appendix 3 provides further background information on centralized crypto lenders.

## 4.1 Financial Vulnerabilities from Centralized Crypto Lenders

We argue that centralized crypto lenders create vulnerabilities from leverage, run risk, and interconnectedness. These different vulnerabilities also feed back into one another, amplifying the effects of adverse shocks to lending platforms.

Leverage vulnerabilities from these platforms are compounded by several aspects of the digital ecosystem. In practice, these platforms have operated with little capacity to absorb losses, reducing their resiliency to withstand even a small shift in crypto-asset prices or the default of a small creditor. For example, Celsius reportedly operated with an assets-to-equity capital ratio of 19:1, compared with a ratio of 9:1 for a group of publicly traded banks.[20]

In addition, most large centralized crypto lenders have had inadequate risk management practices, with elevated concentrations in risk to counterparties and to the digital system. As discussed in Section 2, crypto assets are prone to sharp declines and tend to co-move, increasing the likelihood of experiencing concurrent losses for lending platforms, both directly through their investment in digital assets and indirectly through the increased probability of failure of their borrowers. When lending platforms extend large loans to a small number of borrowers, it increases their risk of insolvency in the event of a counterparty default. For example, Voyager Digital made loans to one counterparty Three Arrows Capital (3AC), representing more than half of its loan book and more than twice its total capital. Similarly, Genesis' two largest borrowers were 3AC and Alameda Research, a hedge fund associated with FTX. Finally, the amount and quality of the collateral backing loans seemed inadequate given the limited capacity to absorb losses. For instance, BlockFi had extended $1.8 billion in loans against $1.2 billion in collateral, leaving an unsecured exposure.[21]

Centralized crypto lenders generate elevated vulnerabilities from funding risk, since their assets cannot be liquidated easily, while their liabilities could be withdrawn on demand. In fact, the failure of several of these platforms was preceded by runs on their liabilities, with all of the bankruptcies mentioned above occurring after these lenders saw withdrawals of at least 10 percent of their total liabilities (Patel and Rose 2023).

All else equal, funding risk from lending platforms is higher than that from traditional lenders given the absence of liquidity requirements and the lack of access to government liquidity backstops. Moreover, elevated vulnerabilities from leverage and valuation pressures heighten funding risk. Elevated leverage increases the likelihood that the value of lenders' assets will fall below the value of their liabilities, triggering customers to withdraw their funds. As customers rush to withdraw funds, lending platforms may be forced to sell crypto assets at distressed prices to meet redemptions. Distressed crypto-asset sales can have a larger effect on prices when valuation pressures are elevated. These dynamics create a negative feedback loop and spillovers to other investors exposed to crypto-asset prices.

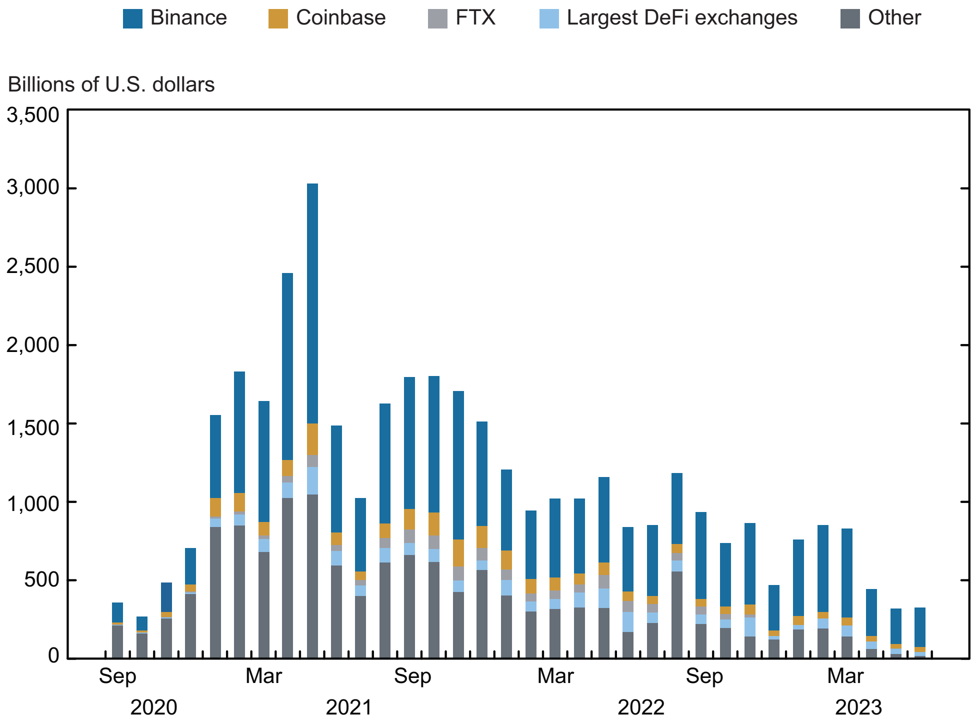
One mitigant to funding risk is that, in practice, lending platforms could suspend withdrawals. For example, when the crypto-focused hedge fund 3AC defaulted on its loan from Voyager, Voyager responded by suspending withdrawals and securing an emergency line of credit. Nonetheless, Voyager ultimately could not remain solvent and declared bankruptcy. By contrast, one factor that amplifies vulnerabilities from funding risk at crypto lenders are the high yields offered to depositors in normal times, since they leave little room to increase interest rates to mitigate fund withdrawals in times of stress.

Centralized crypto lenders also create vulnerabilities from interconnectedness, through their direct lending to institutional investors in the digital ecosystem and their broker-dealer activities. For example, after the Terra platform crashed, these lenders were forced to sell collateral assets at fire-sale prices, contributing to further dislocations in the markets for crypto assets. Popular trades using USDC-USDT and stETH-ETH unraveled, forcing funds such as 3AC to liquidate their positions as well, leading to further drops in the price of crypto assets. These dynamics led 3AC to default on its loans from Voyager and Genesis, creating additional losses for centralized crypto lenders, contributing to their eventual bankruptcy.

## 5. Centralized Crypto Exchanges and Crypto Conglomerates

Centralized crypto exchanges, or CEXs, facilitate crypto-asset trading and the exchange of traditional currency and crypto assets.[22] We argue that CEXs contribute to vulnerabilities owing to interconnectedness both within the crypto ecosystem and between this ecosystem and the traditional financial system. In addition, CEXs facilitate the use of leverage by crypto investors. Moreover, CEXs are typically part of larger crypto conglomerates that provide many other financial products and services. As part of complex crypto conglomerates, CEXs have experienced runs when investors perceive that their investment funds have been diverted within the conglomerate, as in the collapse of FTX. Given the relationship of CEXs with intermediaries in the traditional system, the run risk at CEXs creates funding risk for traditional intermediaries, contributing to systemic risk. Nonetheless, the contribution of CEXs to financial stability risks is hard to gauge, due to the short history of these exchanges, the complexity of crypto conglomerates, the reliance of such entities on unaudited financial statements, and other data gaps.

Chart 7
Trading Volume for Selected Exchanges




Source: CryptoCompare.

Note: The values are monthly measures.

As of June 2023, two of the largest CEXs (Binance and Coinbase) had daily trading volumes of $12 billion and $2 billion, respectively, and accounted for the bulk of all crypto-asset trading volumes (Chart 7). These volumes are quite small when compared with volumes on the largest traditional exchanges.[23] However, as we show in Chart 7, CEXs have come to dominate the trading volumes for crypto assets relative to DeFi exchanges (which we discuss below in Section 6). The failure of FTX, which at the time was a highly significant player and the third largest CEX, has also contributed to the increasing concentration of crypto trading volumes.

## 5.1 Financial Vulnerabilities from Centralized Crypto Exchanges and Conglomerates

CEXs contribute to the degree of interconnectedness within the digital asset ecosystem, both by providing trade execution and by providing additional business lines such as custody, brokerage, lending, market-making, settlement and clearing, and proprietary trading either directly or through affiliated entities. In traditional securities markets, these services are provided by separate entities, each with specific regulations and a high degree of oversight. The sprawling nature of CEX conglomerates can contribute to contagion throughout the crypto ecosystem, since a shock to one of the various business lines might undermine a CEX's ability to provide capital and liquidity to the various others.

Another way that CEXs create interconnections within the digital asset ecosystem is by operating investment funds that finance the development of new crypto projects and investing in existing crypto assets. Disclosures regarding the size and composition of these investment portfolios are generally opaque, which limits the degree to which investors can gauge CEXs' risk exposures. As an example, prior to its collapse, FTX operated a venture fund with a portfolio that was reportedly valued at $2 billion.[24] As the collapse of FTX illustrated, a stress event at a major CEX can result in rapid forced liquidations of these holdings, which could be highly disruptive to crypto-asset markets.

CEXs also facilitate the use of leverage by crypto investors. The exchanges provide leverage in the crypto ecosystem through their facilitation of margin lending and their offering of "leveraged tokens," a type of derivative product that gives consumers leveraged exposure to the underlying asset.[25] CEXs offer derivatives and often allow leverage exceeding 100 times. However, the extent of the leverage these exchanges allow in the digital asset ecosystem is opaque, given their off-chain operating model and a lack of oversight and financial disclosures.

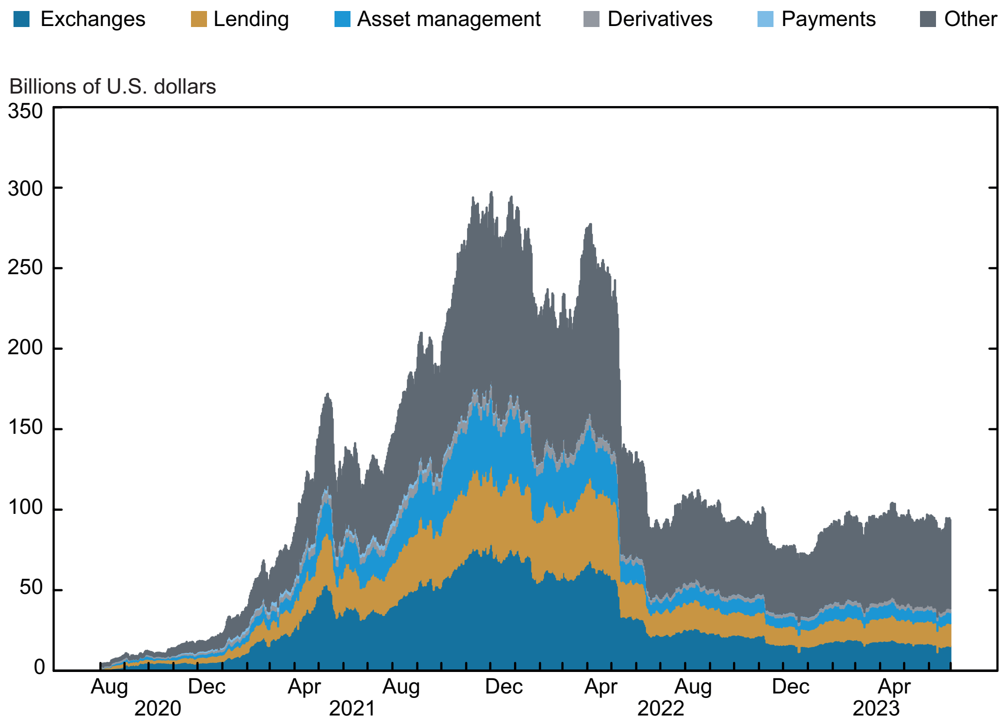
The complexity of crypto conglomerates and the lack of segregated accounts at CEXs create vulnerabilities from funding risk. Account holders can withdraw investments at any time, stressing a CEX's ability to source both crypto and traditional assets to meet these withdrawals. In the absence of regulations, CEXs have commonly operated without keeping customers' assets in segregated accounts, creating a mismatch between the CEX's holdings and customers' withdrawal demands. Other activities of the crypto conglomerate can increase the risk of CEX investments, which can make the value of the holdings drop below the value of the customers' investments. Just the perception that a CEX might not have enough assets to meet withdrawal demands can be enough to create funding risk. Customers, expecting that a CEX's assets would not be enough, could withdraw their investment, causing a run. The collapse of FTX illustrates the run dynamics. In late November 2022, a series of viral social media posts related to FTX's financial condition triggered $6 billion of withdrawals over a period of just 72 hours.[26] In response to the run, FTX suspended user withdrawals on its platforms and filed for bankruptcy shortly thereafter.

Funding risk at CEXs creates interconnections between the digital asset ecosystem and the traditional financial system. Since CEXs facilitate the exchange of traditional currencies with crypto assets, these exchanges need to maintain accounts denominated in traditional currencies to meet withdrawals. As we discuss in Section 7, CEXs have used deposit accounts at partner banks for this purpose, contributing to the volatility of partner banks' deposit base. That is, the funding risk at CEXs in the digital asset ecosystem elevates funding risk at traditional banks that take deposits from these exchanges, contributing to systemic risk.

## 6. DeFi

Decentralized finance (DeFi) refers to the provision of financial products and services using smart contracts on the networks that support digital assets.[27] We argue that DeFi applications create vulnerabilities from interconnectedness in the digital asset ecosystem, from the provision of leverage and from funding risk as discussed above. In fact, the collapse of the Terra platform and its homonymous SC has been attributed to a run on its Anchor protocol and its decentralized SC, TerraUSD, as discussed in Liu, Makarov, and Schoar (2023). These vulnerabilities

CHART 8
Total Value Locked by Category on DeFi Platforms




Source: DeFi Llama.

Notes: Total value locked is the overall value of assets committed to a decentralized finance (DeFi) protocol. This metric includes governance tokens staked in the protocol, staked tokens where one of the coins in the pair is the governance token, and borrowed coins in lending protocols. Certain tokens are double-counted across protocols. The values are daily measures.

contribute to systemic risk within crypto, but DeFi protocols are relatively small in the aggregate (see Chart 8) and generally lack direct connections with traditional financial institutions.

DeFi applications experienced explosive growth in 2021 as venture-capital-backed DeFi projects proliferated and attracted users with the promise of outsized returns and the potential to gain exposure to rapidly appreciating crypto assets (Chart 8). However, the collapse of Terra and its associated DeFi platforms severely curtailed user deposits across DeFi protocols and seems to have hampered growth of these platforms through June 2023.

## 6.1 Financial Vulnerabilities from DeFi

Like banks and the centralized crypto lenders discussed in Section 4, DeFi lending protocols facilitate maturity transformation, introducing funding risk. Loans in DeFi lending protocols typically have indefinite terms and floating rates, and borrowers can repay at any time. Depositors can withdraw funds at any time, provided there are sufficient assets in the pool. DeFi lending protocols mitigate maturity mismatches by incorporating algorithms that vary the interest rates on loans or deposits in order to attract deposits or offer incentives to repay loans. So long as users respond to the incentives implied by the interest rates, run risks can be mitigated or managed by the DeFi protocol. However, in the event of a shock that undermines confidence in the DeFi protocol, automated price processes may be insufficient to prevent runs.

Users of DeFi lending protocols are also directly and indirectly exposed to a form of liquidity risk, which can also contribute to runs. If a particular crypto asset has been fully loaned out, no depositor may withdraw that crypto asset from the protocol—and no borrowers can take loans in that crypto asset—until existing loans are repaid or new deposits are added to the pool. If depositing is unattractive and borrowers are unable or unwilling to repay their loans, depositors would have to rely on the liquidation of collateral to recover their assets.[28] Users would withdraw funds before the balance of a crypto asset in the protocol drops to zero, precipitating a run. The collapse of the algorithmic stablecoin TerraUSD, as we discuss in the box below, was initiated by a run on the SC and amplified by a liquidity crunch in one of the DeFi lending protocols, Anchor.

Another vulnerability related to funding risk for many DeFi lending protocols is collateral rehypothecation**.** Many DeFi protocols allow for collateral to be posted for use on a different DeFi platform as collateral for an additional loan. As in the traditional financial system, rehypothecation can create a collateral chain requiring multiple transactions to unwind. In a stress event, a user attempting to avoid an automated margin call may trigger a rapid unwinding of positions across different platforms if the collateral has been repeatedly rehypothecated. The selling required to unwind rehypothecation may trigger additional automated margin calls, resulting in a cascading pattern of selling (see Infante and Vardoulakis [2021] for runs by collateral providers in the traditional financial system).

Another prominent financial vulnerability that DeFi protocols present is the interconnectedness that they create within the crypto-asset economy. As the collapse of TerraUSD illustrates, more than 100 DeFi platforms operated on the Terra blockchain, and the collapse of TerraUSD immediately impaired the functioning of each of these entities, in addition to contributing to a volatility shock affecting the entire crypto economy.

Vulnerabilities from interconnectedness are amplified by several features of DeFi protocols. First, DeFi lending protocols facilitate borrowing against depository receipts. Certain DeFi protocols accept digital depository receipts from other protocols as collateral for loans. For example, users may receive tokens for providing liquidity to DeFi exchanges. These liquidity-provider tokens from DeFi exchanges can be used as collateral in DeFi lending protocols (and borrowed value from lending protocols can then be re-deposited elsewhere). Second, bridges are a channel for transmitting stress between different blockchains (Berenzon 2021).

The relative ease with which users can obtain leverage on DeFi platforms also contributes to vulnerabilities from leverage. Borrowers' use of DeFi loans to buy crypto assets increases the risk that they will not have the ability to absorb even modest losses when hit by adverse shocks.

Several other novel risks are embedded in various DeFi protocols that amplify vulnerabilities. First, the absence of circuit breakers and price bands heighten the risk of a flash crash.[29] Second, the automated liquidation mechanisms shared by several DeFi protocols amplify vulnerabilities from valuation pressures. On a DeFi lending platform, if a borrower's collateral value falls below a required threshold, a third party may buy out the position, "liquidating" it by repaying the loan and seizing equivalent collateral plus a "liquidation bonus" (Qin et al. 2021). These liquidations can have a persistent effect on crypto-asset prices, leading to further liquidations (Lehar and Parlour 2022).

Third, DeFi protocols are subject to blockchain congestion risk that can amplify vulnerabilities from funding risk and valuation pressures. The smooth operation of DeFi protocols generally requires that blockchains process transactions promptly and at low cost. During periods of high trading volumes, limits on blockchain processing speeds can result in delays in processing transactions or higher transaction fees, giving investors further incentives to run pre-emptively and reducing the price after fees that investors would offer for assets. Congestion on blockchains can result in additional liquidations, since borrowers seeking to recollateralize their positions may be delayed. Fourth, bridges have been a key source of technical weakness as the targets of many successful cyberattacks that can be transmitted through multiple networks.

Finally, another novel risk is "oracle risk." Many DeFi protocols require price information for many operations, such as valuing collateral. Oracles are the channel through which a protocol accesses information on a different network, including the traditional financial system. The manipulation of an oracle's information can be enough to activate vulnerabilities from valuation pressures or funding risk.

Box 1

### The Terra Collapse: A Case Study in Interconnectedness

TerraUSD was an algorithmic stablecoin designed to maintain a 1:1 peg to the U.S. dollar, despite not maintaining reserves to back the coins it issued. In early May 2022, TerraUSD was the third largest stablecoin, with a total market capitalization of $18 billion. While TerraUSD could be used on more than 100 DeFi platforms on the Terra blockchain, most of the activity on the Terra network was on a single DeFi peer-to-peer lending and borrowing protocol, Anchor, which offered deposit yields of close to 20 percent. To maintain its peg, TerraUSD used an arbitrage relationship with Terra's native crypto asset, Luna. Luna is an unbacked crypto asset with a free-floating market value, and at its peak in April 2022 was trading for over $116, with a total market capitalization of around $40 billion.

TerraUSD's market value, Luna's price, and the total value locked (TVL) on Anchor grew rapidly from early 2021 through May 2022. However, the entire Terra ecosystem collapsed in less than a week. On May 8 and 9, TerraUSD liquidity dried up across multiple DeFi protocols and crypto exchanges, causing the price of TerraUSD to decline below $0.70. In response, there was a rush to redeem TerraUSD in exchange for newly issued Luna, rapidly driving down the price of both, resulting in a loss of about $60 billion in valuation that week, as seen in Charts 1A and 1B (see also Liu, Makarov, and Schoar [2023]). Terra's collapse illustrates the fragility and interconnectedness of the crypto ecosystem.

Terra's collapse contributed to stress throughout the crypto ecosystem. Terra's founder reportedly sold $2.4 billion worth of Bitcoin trying to maintain TerraUSD's peg before its eventual collapse.[a] Additionally, Terra users rapidly withdrew crypto assets from the Terra blockchain, particularly stETH, used as loan collateral on the Anchor protocol. These events led to direct pressure on the prices of major crypto assets. The rapid decline in crypto-asset prices (for example, Bitcoin's price declined by about 60 percent between April and June) led to margin calls, sell-offs, and liquidations.

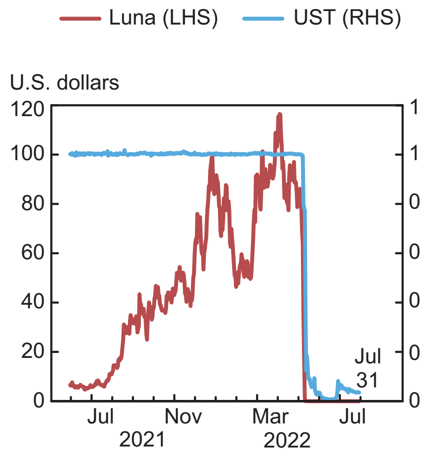
Crypto hedge fund Three Arrows Capital (3AC), which at its peak reportedly had over $18 billion in assets under management, was heavily invested in Terra/Luna.[b] In June, following

*(Continued)*

Box 1 (Continued)

Chart 1A

Luna and TerraUSD Prices

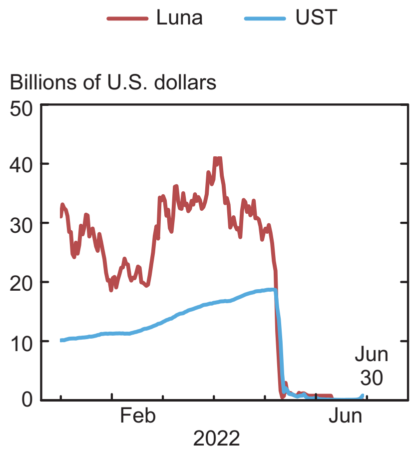



Source: CoinGecko.

Note: UST is TerraUSD.

Chart 1B

Luna and TerraUSD Market Capitalization




Source: CoinGecko.

Note: UST is TerraUSD.

the Terra crash, 3AC was ordered to begin liquidations and filed for bankruptcy under Chapter 15.[c] Voyager Digital, a publicly traded centralized crypto exchange and lender with about $6 billion in assets and about $250 million in total equity as of March 31, 2022, reported that 3AC defaulted on a loan worth about $660 million.[d] The decline in crypto-asset prices that followed the Terra crash and broader stress in crypto markets led Celsius, another centralized crypto lender, to file for Chapter 11 bankruptcy protection.[e]

[a] Christiaan Hetzner, "Luna Foundation Guard Has Now Dumped $2.4 Billion from Its Bitcoin Reserves in Failed Attempt to Defend TerraUSD Peg," Yahoo!, May 16, 2022. https://www.yahoo.com/video/luna-foundation-guard-now-dumped-145139063.html.

[b] Will Canny, "FSInsight Accuses Three Arrows Capital of Running a 'Madoff-Style Ponzi Scheme,'" CoinDesk, June 28, 2022. https://www.coindesk.com/business/2022/06/28/research-firm-fsinsight-accuses-three-arrows-capital-of-running-a-madoff-style-ponzi-scheme/.

[c] Hamza Shaban, "Three Arrows Capital Falls into Liquidation after Crypto Crash," *Washington Post*, June 29, 2022. https://www.washingtonpost.com/business/2022/06/29/three-arrows-liquidation-crypto/.

[d] Yueqi Yang, "Voyager (VOYG) Reveals $660 Million Exposure to Three Arrows Capital (3AC)," Bloomberg, June 22, 2022. https://www.bloomberg.com/news/articles/2022-06-22/voyager-discloses-660-million-exposure-to-troubled-crypto-fund.

[e] See Kate Rooney and Paige Tortorelli, "Embattled Crypto Lender Celsius Files for Bankruptcy Protection," CNBC.com, July 13, 2022. https://www.cnbc.com/2022/07/13/embattled-crypto-lender-celsius-informs-state-regulators-that-its-filing-for-bankruptcy-imminently-source-says-.html. See also Ryan Browne and Arjun Kharpal, "Crypto Lender Celsius Pauses Withdrawals; Bitcoin Slides," CNBC.com, June 13, 2022. https://www.cnbc.com/2022/06/13/crypto-lender-celsius-pauses-withdrawals-bitcoin-slides.html.

## 7. Interconnectedness with the Traditional Financial Sector

Despite the instability of the digital financial system we have described, the contribution of the crypto ecosystem to systemic risk depends on the likelihood that adverse shocks to this system can disrupt the provision of financing and payment services to the real economy, as described in Section 1.2. Since the direct provision of financial services from the crypto system to the real economy remains limited at the time of writing, the main concern for systemic risk is how interconnected the crypto and traditional financial sectors are. In this section, we describe the interconnections between the digital asset ecosystem and the traditional financial system that were revealed by shocks to these systems and how these interconnections are expected to evolve with the development of the digital ecosystem. Despite the crypto industry's claim that it is the future of finance, our discussion reveals that crypto intermediaries still need financial services offered by traditional intermediaries, linking the financial vulnerabilities that we have described in the digital system with financial vulnerabilities in the traditional financial system. Our discussion is organized by the types of institutions in the traditional financial systems, including banks, asset managers, brokerages, exchanges, and public and private companies.

### 7.1 Traditional Banks

Banks have offered deposit accounts and money market instruments in traditional currency primarily to two groups of crypto firms. First, as we discussed in Section 3, SC issuers until recently invested an important share of their reserves in bank deposits.[30] In addition to bank deposits, other SC reserve assets are invested in money market instruments used by banks to obtain financing. SC issuers have large investments in reverse repos, which banks can use to borrow against their holdings of U.S. Treasury securities (see the left panel of Chart 6).[31] Other categories of SC reserves can also include assets that are issued by traditional banks like commercial paper and certificates of deposit, but these asset classes have fallen in importance. Second, as discussed in Section 5, CEXs hold bank deposits backing the balances of traditional currencies in customers' accounts and as part of their other business lines.

Given the fragility of the crypto ecosystem, demand by crypto firms for bank deposits and money market instruments can exhibit large fluctuations, elevating vulnerabilities from funding risk at traditional banks. In fact, the failure of some commercial banks in March 2023 has been linked to their exposure to the digital asset system (Tierno 2023).

Silvergate Bank, a commercial bank with more than $15 billion in assets at the end of the third quarter of 2022, voluntarily wound down its operations in March 2023. This bank offered crypto-asset-collateralized loans and operated the Silvergate Exchange Network to facilitate real-time payments among crypto clients, taking deposits from the main SC issuers and large CEXs, including FTX. The "risk off" dynamic in the crypto industry in 2022 brought about a reduction in Silvergate's deposits from crypto customers from an average of $12 billion in the second quarter of 2022 to only $3.8 billion at the end of 2022 (Silvergate Capital Corporation 2022, 2023a). Despite the fact that crypto-asset-collateralized loans did not lead to losses or forced liquidations, these dynamics led to large losses and the wind-down of operations (Silvergate Capital Corporation 2023b).

Signet was another real-time payment system for crypto clients offered by Signature Bank, a commercial bank with $110 billion in assets at the end of 2022. This bank experienced a bank run, with depositors withdrawing 20 percent of deposit balances on Friday, March 10, 2022, and regulators closed the bank on Sunday, March 12 (Board of Governors of the Federal Reserve System 2023). These developments, together with the failure of SVB during the same week, contributed to a broader loss of confidence in commercial banks, leading government agencies to take decisive actions to support the flow of credit to households and businesses, including guaranteeing the uninsured deposits at SVB and Signature Bank (Board of Governors of the Federal Reserve System 2023). The failure of these banks could have been amplified in the traditional financial system and the digital asset system had the government agencies not taken these actions. Deposit withdrawals from commercial banks accelerated as confidence was lost, leading eventually to the failure of First Republic Bank, a commercial bank with more than $200 billion in assets at the end of 2022. In addition, after it was revealed that $3.3 billion of the reserves backing USDC were deposits at SVB, this stablecoin de-pegged, dropping to less than 88 cents before it became clear that these deposits would be guaranteed (Tierno 2023).

We argue that interconnections between funding risk in the traditional and digital systems are expected to remain in place, even if the structures that create these links change. For example, MakerDAO has proposed to tokenize real-world assets and issue loans using these tokens as collateral (Di Prisco 2021). As of the time of writing, MakerDAO holds approximately $2 billion in short-term Treasury securities backing DAI. In addition, JPMorgan has expressed interest in tokenizing U.S. Treasury securities and shares of money market funds to use as collateral in DeFi, which could become a channel for transmitting stress from crypto-asset markets to the U.S. Treasury market.[32] The use of tokenized real-world assets as collateral in decentralized finance protocols amplifies vulnerabilities owing to automatic liquidations (see Section 6).

In addition to the links created by bank deposits and money market instruments, several banks invest in crypto-asset-related companies. Leverage vulnerabilities from banks and the potential for elevated valuation pressures in the crypto sector can raise financial stability concerns about these investments. Blockdata (2022), a relatively new analytics firm, has estimated that Standard Chartered, BNY Mellon, Citi, and UBS have each invested more than $250 million in crypto companies. According to these estimates, these investments represent no more than 1.5 percent of Tier 1 capital at these banks.

## 7.2 Traditional Asset Managers, Brokerages, and Exchanges

Asset managers have created different investment products that give investors exposure to crypto assets. A leading example is Grayscale, a Canadian company that sponsors the Grayscale Bitcoin Trust, which invests solely in Bitcoin and issues shares that trade in over-the-counter markets in Canada. In addition, Grayscale provides analogous trusts investing in Ether and Solana, as well as a DeFi index product. Similarly, exchange-traded funds linked to cryptocurrency prices have been approved by regulators in Canada and Australia.

In addition, several retail brokerages (including Fidelity and Robinhood) have begun to offer access to crypto markets. For example, Fidelity allows crypto accounts for trading BTC and ETH and has made crypto investment available in 401k retirement accounts.[33]

Finally, traditional exchanges have begun to list financial products tied to crypto assets. For example, the Chicago Mercantile Exchange offers both Bitcoin and Ethereum derivative contracts, including futures and options (CME Group 2017).

As more asset managers, brokerages, and exchanges offer access to cryptocurrency investments, indirect interconnections from common exposures to crypto assets increase. In addition, these traditional institutions can facilitate leveraged trading via derivatives or margin accounts, amplifying vulnerabilities from crypto-asset valuations. If crypto-asset prices drop sharply, margin calls, asset fire sales, and account liquidations could follow.

Moreover, clients' investments in crypto assets expose these traditional asset managers, brokerages, and exchanges to novel risks. If blockchain accounts are hacked and digital assets are lost, these institutions may still be liable for returning assets to their customers. To meet these obligations, these institutions would have to sell some of their own assets, potentially contributing to the transmission of stress to other sectors of the financial system.

## 7.3 Venture Capital Firms and Hedge Funds

In both 2021 and 2022, venture capital firms invested more than $30 billion in crypto-asset-related firms but investments declined to around $5 billion in the first half of 2023.[34] The limited partners in these venture capital funds are usually pension funds, university endowments, nonprofit foundations, and finance companies. Many mainstream hedge funds have also launched dedicated crypto divisions.[35]

Vulnerabilities from funding risk are lower from hedge funds and venture capital funds, since these entities can have long-term capital commitments. Nevertheless, when such firms invest in digital assets, DeFi, or their derivatives, they expose their investors to valuation pressures in crypto assets and can amplify vulnerabilities from leverage at hedge funds. The most prominent example of these risks was the collapse of FTX, which had raised over $2 billion from investors such as BlackRock, Tiger Asset Management, Sequoia Capital, and Paradigm. In a short amount of time in November 2022, FTX became insolvent, and its value was marked down to zero, representing significant losses for many of its investors.[36] Hedge funds exposed to these losses can transmit the stress to other markets in which they invest.

## 7.4 Public and Private Companies

A growing number of publicly traded companies have crypto assets on their balance sheets. The largest publicly traded company with significant exposure to crypto assets is Coinbase, which was publicly listed in 2021. As of the first quarter of 2022, Coinbase held more than $200 billion worth of crypto assets from its custodial, brokerage, and market-making services (Coinbase 2022). Besides Coinbase, public companies such as MicroStrategy have significant holdings of crypto assets on their balance sheets. As of June 30, 2023, MicroStrategy had about $4.5 billion worth of Bitcoin holdings, about $205 million of which were purchased with a Bitcoin-collateralized loan. Tesla and Square have also held Bitcoin, although Tesla announced on July 20, 2022, that it sold 75 percent of the Bitcoin it had purchased, adding $936 million to its balance sheet.[37]

Companies that invest in the digital asset ecosystem expose themselves to the volatility of the system, leading to potential losses. For instance, Tesla reported a $204 million loss on its Bitcoin investments for the fiscal year ending in 2022, whereas Coinbase stock dropped more than 70 percent between its initial public offering in April 2021 and June 2023. These losses may affect more traditional activities of the company, leading potentially to reduced purchases, output, or—in extreme cases—default or bankruptcy. If the exposures to digital assets are large enough, negative shocks to these prices could have spillover effects to companies' creditors, suppliers, and customers.

## 8. Conclusion

This article offers an overview of the financial stability risks associated with the digital asset ecosystem. We focus on the vulnerabilities that explain the fragility of the crypto ecosystem and the vulnerabilities that can amplify and transmit stress in the crypto ecosystem to stress in the traditional financial system.

We contend that the observed fragility of the digital asset ecosystem is associated with the buildup of valuation pressures from crypto assets, funding risk from most sectors of the digital ecosystem, the common use of leverage by crypto investors facilitated by both different sectors of the crypto ecosystem and some sectors of the traditional financial system, and a highly interconnected crypto ecosystem. In addition to these financial vulnerabilities, the fragility of digital assets seems to be amplified by the lack of a strong and cohesive regulatory framework and some novel risks.

However, we argue that, to date, the contribution of digital assets to systemic risk has been limited, given that the digital ecosystem is relatively small and is not a major provider of financing and payment services to the real economy, and given that stress in the digital system has had limited spillovers to the traditional financial system.

We expect our article to serve as a resource for those who want an overview of the digital asset ecosystem with a focus on financial stability and to promote further research in this area.

# Appendix 1: Assessment of Valuation Pressures Related to Crypto Assets

At present, native crypto assets do not have associated cash flows, presenting a key challenge for the assessment of valuation pressures related to crypto assets. Even in the absence of cash flows, investors might be willing to pay positive prices for native crypto assets (see, for instance, Cochrane [2017]). First, they could expect that other investors will be willing to pay more for the asset in the future, as in a typical asset bubble. One common narrative is that this valuation motive is stronger for Bitcoin than other cryptocurrencies, given the scarcity created by its cap on total coin supply and its long-lived nature. Second, investors might expect that the assets would generate cash flows in the future, in which case they would be willing to pay for the asset depending on their assessments of the likelihood and the size of these future payments. Some investors might view future asset repurchases as akin to future cash flows. Finally, investors might hold these assets if they are needed to perform some activities, like settling transactions on the ledger, or if they are needed to engage in risky activities that can generate financial returns, like staking and lending.[38]

To the extent that some of the fundamental value accrues from the value of the network itself, the variation in the supply of native crypto assets introduces an additional complication. Different protocols have different rules for putting bounds on issuance, effectively limiting the supply of these assets. For instance, the Bitcoin network requires the solution of difficult cryptographic puzzles to mint new coins from a finite potential total supply, whereas, in the Ethereum network, there is no explicit cap on the total supply, but new coins are only minted under certain conditions, like to reward validators.

The valuation of non-native crypto assets is similarly challenging, since benefits from asset ownership may come in the form of voting rights for proposals on a DAO or perks such as discounts on trading fees, for which it is difficult to assess a monetary value. It is similarly challenging to assess the valuation of NFTs representing digital art and collectibles. Moreover, the use of tokens to represent traditional assets, which would be easier to value, remains fairly limited.

# Appendix 2: Background on Stablecoins

Within the crypto ecosystem, SCs facilitate trading, borrowing, and lending of crypto assets, and enhance the transferability of funds across blockchains by providing a reference asset with a stable value. This property is desirable as a medium of exchange in the crypto ecosystem, given the relatively large fees involved in exchanging crypto assets and traditional assets. Similarly, as we discuss in Section 6, DeFi applications essentially operate using SCs.

Proponents of SCs argue for their potential to become a widely used medium of exchange within and outside of the digital ecosystem. At present, their use remains largely confined within the crypto ecosystem, and they are not widely used to facilitate wholesale or retail payments across the traditional economy. But things could change rapidly if adoption of this technology accelerates or if an existing payment provider adopts this technology.[39]

If SCs are to become a medium of exchange available to the general public outside of the crypto ecosystem, they might spur more competition in the traditional payment systems. Whether such competition will translate into a welfare gain is still an open question. New payment system providers are already promoting competition, although they mostly cater to the banked population. For the unbanked population, realizing these gains from enhanced competition depends on digital wallets being available without relying on bank accounts and traditional payment systems. In addition, SCs that are quoted in different currencies might lower the costs of cross-border payments for both retail and wholesale transactions. Whether the technology underpinning SC transfers can realize such gains depends on how much it can save on the costs of the current settlement systems for cross-border payments.[40]

Detractors of SCs highlight their fragility, as exemplified by the collapse of TerraUSD in May 2022 and the previous failure of other SCs like Iron in June 2021 (see, for example, Adams and Ibert [2022], and Liu, Makarov, and Schoar [2023]). Weakly regulated SCs may be subject to runs and generate negative spillovers across the digital ecosystem and traditional money markets. An additional consideration introduced by the wide use of SCs may be that the provision of bank credit would be reduced without a corresponding increase in credit provision through DeFi. The extent to which the wide use of SCs could reduce the aggregate provision of credit will depend to a large degree on how SCs manage their reserves. Credit provision would be less affected if, for instance, SC reserves were used to fund banks through deposits or other money market instruments, or if SC issuers included banks, which could effectively offer tokenized deposits.[41]

# Appendix 3: Background on Centralized Crypto Lenders

Of all the intermediaries in the digital ecosystem discussed in this article, centralized crypto lenders or lending platforms are structured most similarly to banks, in the sense that they take deposits from customers and use these deposits to make loans. Although centralized crypto lenders accept various assets as deposits, these are typically exchanged for crypto assets and held in wallets maintained by the lender, who, in return, promises to pay customers a fixed yield on these assets. Lenders often promise their customers that their funds will be available on demand.[42] However, the accounts offered by lending platforms, in practice, have functioned very differently than bank deposits. Customers often transferred "all rights and title" to their digital assets once they put them on a crypto lender's platform.[43] In addition, upon bankruptcy of a lending platform, customers have been generally considered to be unsecured creditors. Further, crypto lenders have not been eligible for the same government liquidity backstops as traditional banks, such as Federal Deposit Insurance Corporation (FDIC) insurance and discount window loans, given that they have not have commercial bank status.

In spite of these drawbacks, lending platforms have attracted customers' deposits by offering higher yields than alternatives in the traditional financial system. For example, in March 2022, Celsius users earned an average yield of 5 percent, and up to 17 percent in some cases, compared to less than 1 percent interest paid by banks, on average, during the same period.[44]

A distinctive feature of lending platforms is that they invest in crypto assets and extend loans denominated in or secured by these assets. Among their most notable assets are loans denominated in traditional currencies or digital assets to institutions that participate in the digital ecosystem, like hedge funds, market makers, trading firms, exchanges, digital asset miners, and decentralized finance protocols. In addition to lending activities, centralized crypto lenders can engage in broker-dealer activities. For example, one notable lending platform was "permitted to use the assets in its sole discretion, including rehypothecating those assets (e.g., using those assets as collateral to take out additional loans)" to generate yield.[45]

As mentioned in the main text, the top four lending platforms managed assets worth tens of billions of dollars at their peak. All four of these major firms have gone bankrupt, with Celsius and Voyager having declared bankruptcy in July 2022, BlockFi having declared bankruptcy in November 2022, and Genesis having declared bankruptcy in January 2023. A fifth lending platform, Nexo, exited the U.S. market and paid a $45 million fine after being sued by multiple state governments and investigated by the Securities and Exchange Commission.[46]

# Appendix 4: Background on Centralized Crypto Exchanges

Centralized crypto exchanges facilitate the trading of crypto assets in a manner similar to that of traditional exchanges, by keeping an order book to match buyers and sellers. When using a CEX, users typically do not retain custody of their crypto assets and instead might rely on the CEX for the custody of these assets. In addition to facilitating the exchange between different crypto assets and SCs, CEXs enable users to exchange these assets for traditional currencies and to hold investment balances in traditional currencies, connecting the digital ecosystem and the traditional financial system.

Unlike regulated financial exchanges, CEXs also offer a broad range of additional financial products and services beyond facilitating trading execution, including custody, margin lending, prime brokerage (for institutions), and writing and listing crypto derivatives. For instance, in addition to being the largest crypto-asset exchange, Binance issues a major SC (BUSD), developed a major blockchain, with its associated crypto asset (BNB), and has invested in other third-party crypto projects (including the failed TerraUSD stablecoin) via its venture capital entity Binance Labs. In addition, Binance Labs has acquired the data aggregator CoinMarketCap and held minority stakes in rival CEX FTX, as well as in the news agency Forbes. Similarly, Coinbase, via its venture capital subsidiary Coinbase Ventures, also owned a stake in FTX and is a founding member of the consortium that develops stablecoin standards, including for USDC, the second-largest SC by market capitalization (see Section 3). Finally, before its failure, FTX bought a U.S. broker-dealer in 2021. Moreover, Sam Bankman-Fried, one of the founders and major shareholders of FTX, was also an owner of quantitative trading firm Alameda Research, founded decentralized exchange Serum, and acquired a stake in the traditional brokerage Robinhood.[47]

In addition, many CEXs operate in ways that avoid financial regulation and do not report fully audited financial statements, making information regarding the operation of these various ancillary business lines highly opaque. Further, unregulated digital asset firms do not commonly keep customer assets segregated from the firms' operating funds (Goldsmith Romero 2022). This opacity and lack of account segregation increase the risk that a dishonest or unprofessional exchange operator may confiscate or lose the funds (Schär 2021). As an illustration, one aspect of FTX's collapse was the fact that the firm allegedly used customer deposits to support bets made by Alameda Research, an affiliated hedge fund investing in crypto assets.[48]

# Appendix 5: Background on Decentralized Finance

Decentralized finance protocols are generally designed to facilitate automated peer-to-peer transactions with minimal or zero third-party intermediation. Each DeFi protocol is unique and together they provide a large number of financial services and products. However, most DeFi protocols involve exchanging or lending crypto assets, and many of these share certain common design features such as the use of liquidity pools into which users can deposit, withdraw, or trade assets, and in which interest and exchange rates are set algorithmically.

DeFi lending protocols allow depositors to pool assets and earn interest generated from the proceeds of loaning those assets to borrowers. In DeFi lending protocols, depositors receive a "utility token" representing their share of the "liquidity pool" and any accrued interest. Anonymous borrowers generally overcollateralize their loans. Usually, borrowers on DeFi lending protocols pledge crypto assets as collateral in exchange for loans denominated in stablecoins, allowing users to access liquidity without selling crypto assets.[49]

Many DeFi platforms involve a process called staking, which is necessary to secure proof-of-stake (PoS) blockchains. Many proof-of-stake blockchains such as Ethereum require their users to lock their native tokens (ETH in this case) in order to participate in the consensus algorithm. This locking process is called "staking" and allows users to earn yield for their stake, but it simultaneously prevents the native tokens from being used in other DeFi protocols or being sold. While, a priori, this is a trade-off that ETH users face when deciding whether to stake or not, there are important DeFi protocols like Lido that act as an intermediary. When users deposits an ETH with Lido, they obtain both the rewards from staking and a new token called "staked Ethereum" (stETH), which they can use in other DeFi protocols. Therefore, staking platforms are similar to lending platforms, but users pledging crypto assets are compensated from the blockchain validation fees that their assets help support, and not from interest payments.

# Notes

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[1] The state of Wyoming granted legal status to DAOs (see https://www.wyoleg.gov/Legislation/2021/SF0038), and the state of Vermont and the Virgin Islands have enacted DAO laws in some form (see https://ethereum.org/en/dao/).

[2] In January 2023, federal bank regulatory agencies issued a crypto-asset guidance, highlighting the risks associated with the digital asset ecosystem, including the risk for volatile deposit outflows stemming from the fragility of the ecosystem and run risk from SCs. Moreover, the guidance also cites the concentration risk stemming from the interconnectedness within the ecosystem, and the risk from fraud, legal uncertainties, and the lack of a strong and cohesive regulatory framework. See Board of Governors of the Federal Reserve System, Federal Deposit Insurance Corporation, and Office of the Comptroller of the Currency (2023).

[3] It is worth noting that the Bitcoin blockchain has had limited programmability via the Bitcoin script programming language and that recent enhancements facilitate the execution of basic smart contracts. However, relative to other networks, Bitcoin continues to offer less flexibility to design smart contracts, and decentralized applications have been developed using other networks that can interoperate with Bitcoin (see, for example, Kimmell [2021]).

[4] Estimate based on the population of blockchains reported by DeFi Llama. For the full list, see https://defillama.com/chains. Accessed April 22, 2023.

[5] An additional advantage of the focus on vulnerabilities is that policies can be designed to address the vulnerabilities identified, making it more likely that the system will be able to continue to function effectively in the face of adverse shocks.

[6] For instance, Greenwood, Landier, and Thesmar (2015) and Duarte and Eisenbach (2021) develop indicators of fire sale vulnerabilities from banks' common asset exposures.

[7] For example, in the case of the bankruptcy of Celsius, there was legal uncertainty about whether customers' deposits would be treated as senior debt claims or as other unsecured debt claims.

[8] Chart 1 excludes SCs, which we discuss in Section 3.

[9] Christiaan Hetzner, "Death of the NFT? CryptoPunk Bought for $1 Million Sells for $139,000 Just 6 Months Later," *Fortune*, May 9, 2022. https://fortune.com/2022/05/09/death-of-cryptopunk-nft-bayc-bored-apes-yuga-larva/.

[10] The trading of SCs in secondary markets may attenuate run risk, as argued by Jacklin (1987) for the case of bank deposits. However, Ma, Zeng, and Zhang (2023) argue that the fixed redemption value offered by SC issuers to a small set of arbitrageurs creates incentives for traders to run in secondary markets.

[11] DAI and Terra employ a set of rules, expressed in software code, that aim to maintain exchange rate stability by dynamically matching the supply of SCs with the demand. In the case of DAI, these rules specify that, to create or mint one dollar of DAI, a user needs to deposit more than one dollar of crypto assets into a vault, and these vaults can be liquidated when the value of the collateral drops below a certain threshold. This mechanism keeps DAI overcollateralized in the absence of large price swings. In the case of Terra, these rules considered the exchange of Terra for Luna, the native crypto asset of the Terra blockchain. In this sense, Luna was akin to the collateral backing the Terra SC. See Baughman et al. (2022) for more details on different stabilization mechanisms for stablecoins.

[12] We create end-of-the month pro-forma total assets on the balance sheet for major SCs as follows. For BUSD, we consider the last attestation of the month to be the end-of-the-month assets. For Tether, we linearly interpolate the end-of-quarter attestations to monthly frequency. And for USDC, we simply use its end-of-the month attestations.

[13] The potential introduction of a central bank digital currency can further amplify run risks from fragile SCs by providing an alternative that may be perceived as the most resilient. See Infante et al. (2022) and references therein.

# Notes (Continued)

[14] In essence, SCs are a form of privately produced money, much like bank deposits, which are intrinsically fragile. In fact, bank deposits, before the advent of deposit insurance, experienced frequent runs. Deposit insurance protects depositors up to the legal limit and is granted to depository institutions, which are subject to supervision and regulation and enjoy access to emergency liquidity and Federal Reserve services. Insurance, supervision and regulation, and access to emergency liquidity are the three pillars of public support for deposits to function as money. The President's Working Group on Financial Markets, the Office of the Comptroller of the Currency, and the Federal Deposit Insurance Corporation (2021) have recommended that SC issuance and related activities of redemption and maintenance of reserve assets be carried out by entities that are insured depository institutions.

[15] Siddharth Venkataramakrishnan and Joe Rennison, "Tether's Commercial Paper Disclosure Places It among Global Giants," *Financial Times*, June 10, 2021. https://www.ft.com/content/342966af-98dc-4b48-b997-38c00804270a.

[16] See https://www.prnewswire.com/news-releases/celsius-integrated-tezos-301444427.html. Accessed May 23, 2022.

[17] See https://www.sec.gov/litigation/admin/2022/33-11029.pdf. Accessed May 25, 2023.

[18] See https://www.coindesk.com/layer2/2022/07/12/behind-voyagers-fall-crypto-broker-acted-like-a-bank-went-bankrupt/. Accessed May 23, 2022.

[19] See https://www.sec.gov/litigation/complaints/2023/comp-pr2023-7.pdf. Accessed May 27, 2023.

[20] Eliot Brown and Caitlin Ostroff, "Behind the Celsius Sales Pitch Was a Crypto Firm Built on Risk," *Wall Street Journal*, June 30, 2022. https://www.wsj.com/articles/behind-the-celsius-sales-pitch-was-a-crypto-firm-built-on-risk-11656498142.

[21] See htps://blockfi.com/blockfi-transparency-report-Q2-2022. Accessed May 25, 2023.

[22] Appendix 4 provides further background on centralized exchanges.

[23] See http://www.nasdaqtrader.com/Trader.aspx?id=DailyMarketSummary. Accessed May 25, 2023. Note: Daily trading volumes may include wash trading (see, among others, Aloosh and Li [2022]; Chen, Lin, and Wu [2022]; and Cong et al. [2022]).

[24] See https://www.prnewswire.com/news-releases/ftx-launches-2-billion-ventures-fund-hires-former-lightspeed-partner-amy-wu-301461078.html. Accessed May 25, 2023.

[25] Leveraged tokens each represent a basket of perpetual contract positions. The price of a leveraged token moves along with price changes in the perpetual contract market, and the leverage level moves up and down accordingly.

[26] Tom Wilson and Angus Berwick, "Crypto Exchange FTX Saw $6 Bln in Withdrawals in 72 hours," Reuters, November 8, 2022. https://www.reuters.com/business/finance/crypto-exchange-ftx-saw-6-bln-withdrawals-72-hours-ceo-message-staff-2022-11-08/.

[27] For more details on DeFi, see Appendix 5.

[28] For example, borrowers may have no intention of repaying a loan used to extract higher-quality assets in exchange for lower-quality collateral (for example, borrowing stablecoins collateralized by the protocol's own governance token).

[29] Nick Baker, "How Crypto Exchanges Could Stop Flash Crashes If They Wanted To," Bloomberg, October 22, 2022. https://www.bloomberg.com/news/articles/2021-10-22/crypto-exchanges-can-stop-flash-crashes-if-they-want-will-they#xj4y7vzkg.

[30] Before the FTX bankruptcy, these deposits were substantial. As of the end of the third quarter of 2022, reported cash holdings, mostly held as bank deposits, were $6.1 billion for Tether, $9.2 billion for USDC, and $1.9 billion for BUSD. More recently, as of the end of June 2023, SC issuers have reduced their reported cash holdings, with $91 million at Tether, $2.7 billion at USDC, and $8.4 million at BUSD.

[31] For instance—as of June 30, 2023—Circle reported $18.4 billion worth of repo agreements backing USDC, and Paxos reported $4.1 billion worth of repo agreements backing BUSD. Tether is an exception here, reporting only $577 million in repo agreements; instead, Tether reported holdings of $55.8 billion in U.S. Treasury securities.

## Notes (Continued)

[32] Ian Allison, "JPMorgan Wants to Bring Trillions of Dollars of Tokenized Assets to DeFi," CoinDesk, June 11, 2022. https://www.coindesk.com/business/2022/06/11/jpmorgan-wants-to-bring-trillions-of-dollars-of-tokenized-assets-to-defi/.

[33] See https://www.fidelity.com/crypto/trading. Accessed October 31, 2023. For a description of 401K retirement plans, see Rob Wile, "Fidelity Lets Companies Offer Bitcoin in a 401(k), but Financial Advisers Warn It's a Risky Bet," NBC News, May 22, 2022. https://www.nbcnews.com/business/consumer/bitcoin-401k-fidelity-financial-advisers-warn-risk-cryptocurrencies-rcna29099.

[34] See https://www.galaxy.com/insights/research/crypto-and-blockchain-venture-capital-q3-2023/. Accessed October 20, 2023.

[35] Gregory Zuckerman, "Mainstream Hedge Funds Pour Billions of Dollars into Crypto," *Wall Street Journal*, March 9, 2022. https://www.wsj.com/articles/mainstream-hedge-funds-pour-billions-of-dollars-into-crypto-11646808223.

[36] Jihye Lee, "Sequoia Capital Marks Down Its Investment in FTX to $0," CNBC, November 10, 2022. https://www.cnbc.com/2022/11/10/sequoia-capital-marks-down-its-ftx-investment-to-0.html. Accessed October 2, 2023.

[37] Robert Wall, "Tesla Sells 75% of Its Bitcoin Purchases," *Wall Street Journal*, July 20, 2022. https://www.wsj.com/livecoverage/tesla-earnings-q2-2022-elon-musk-live/card/tesla-sells-75-of-its-bitcoin-purchases-tgkMdMf1EHDvdniqHu8S.

[38] Cong, Li, and Wang (2021) and Wang, Yang, and Zhang (2023) develop models where crypto assets have positive value as they serve to settle transactions in a network where users can acquire specialized services. In these models, the value of crypto assets aggregates the heterogeneous transaction demands by users of the platform.

[39] After the statistical close of this article at the end of June 2023, PayPal launched its own stablecoin, PayPalUSD. While the circulation of PayPalUSD was limited initially, PayPal announced that PayPalUSD can be used through both Venmo and cryptocurrency wallets, which may increase its use going forward.

[40] For details on frictions to cross-border payments, see Financial Stability Board (2020).

[41] The potential for bank credit disintermediation from SCs could be similar to the potential for bank credit disintermediation from the introduction of a central bank digital currency (CBDC). Recent contributions to the literature on the potential effect of a CBDC argue that it could increase or decrease credit intermediation through banks, depending on its design features and the degree of market power in deposit markets (Andolfatto 2021; Keister and Sanches 2023; Chiu et al. 2023; Whited, Wu, and Xiao 2022).

[42] The Celsius terms of use stated that users could "request that Celsius return the borrowed Eligible Digital Assets and deliver any Rewards accrued from the Earn Service, by transferring such Eligible Digital Assets and Rewards to your external Virtual Wallet." See Celsius's terms of use available at https://celsius.network/terms-of-use. Accessed May 25, 2023. BlockFi stated that users could "request a withdrawal … of principal at any time" but that withdrawal limits may be applied at any time. See BlockFi terms of service, https://blockfi.com/interest-account-terms-existing-us. Accessed May 27, 2023.

[43] See Celsius's terms of use are available at https://celsius.network/terms-of-use. Accessed May 25, 2023.

[44] For the interest rates paid by banks, see https://fred.stlouisfed.org/series/SNDR. Accessed May 27, 2023. For Celsius rates, see Declaration of Alex Mashinsky to the U.S. Bankruptcy Court, Southern District of New York, Chapter 11 Case No. 22-10964 (MG) (2022).

[45] From Celsius bankruptcy filings. See Declaration of Alex Mashinsky to the U.S. Bankruptcy Court, Southern District of New York, Chapter 11 Case No. 22-10964 (MG) (2022).

[46] See U.S. Securities and Exchange Commission, "Nexo Agrees to Pay $45 Million in Penalties and Cease Unregistered Offering of Crypto Asset Lending Product," January 19, 2023, https://www.sec.gov/news/press-release/2023-11. Accessed March 5, 2023.

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[48] Vicky Ge Huang, Alexander Osipovich, and Patricia Kowsmann, "FTX Tapped into Customer Accounts to Fund Risky Bets, Setting Up Its Downfall," *Wall Street Journal*, November 11, 2022. https://www.wsj.com/articles/ftx-tapped-into-customer-accounts-to-fund-risky-bets-setting-up-its-downfall-11668093732.

[49] More than 90 percent of DeFi lending is denominated in SCs, while 75 percent of the collateral is denominated in volatile crypto assets. See International Monetary Fund (2022).

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