MEASURING DEFI RISK

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Abstract

Decentralized finance (DeFi) lending has grown from nonexistent in 2017 to nearly 45 billion US Dollars in total value locked[1] (TVL) across the three largest protocols (Aave, Compound, and Maker) in December 2021, before declining to nearly 14 billion USD in February 2023. Using cryptocurrency as collateral, the platforms match speculative margin trading with yield-seeking depositors lending coins pegged to the dollar (stable coins). Depositors receive claims guaranteed by a basket of collateral, akin to new stable coins. We develop a framework requiring only knowledge of aggregate deposits and borrowings to measure overall system risks to lenders and borrowers. Using evidence from major protocols, the measures identify an increase in system fragility beyond prudent levels around mid 2021, with a potential loss of peg for extreme variations in coin prices. Overall, the model offers an easily implementable aggregate risk metric capturing the perspectives of synthetic investors and offers early warning signals as the industry is moving from deposits guaranteed by collateral to fiat money.

Keywords: coin, cryptocurrency, stable, systemic, banking, loans, collateral, interest.

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[1]Total value locked (TVL) is the sum of all cryptocurrencies staked on a Defi platform, considering the value deposited and adjusting for the value loaned.

Decentralized finance DeFi lending allows owners of cryptocurrency assets to earn interest by depositing their assets into a lending pool, while borrowers access credit from the pool subject to depositing collateral.[2] In February 2023 the total value locked across the protocols Aave, Compound, and Maker, which account for almost 90% of the Defi lending market is nearly 14 billion USD from roughly 500 million USD in January 2020 and a peak of 45 billion USD in December 2021 (see Figure 1). Normally, lenders deposit stable coins (pegged to the dollar) in exchange for interest payments while borrowers borrow the coins, sell them in exchange for unpegged coins (such as bitcoin), depositing an amount greater or equal in unpegged coins into the pool as collateral.

The resulting lending pool is a margin investment account using collateralized debt in stable coin guaranteed with a sufficiently large reserve of unpegged coin. Lenders own tokens with a claim to recover their deposits, potentially converting deposits in stable coins guaranteed by audited dollar balances (e.g., USDC) into new stable coins in the form of deposit tokens in the platform guaranteed by a basket of cryptocurrencies (e.g., cUSDC). The collapse in the algorithmic coins Terra-UST in May 2022, with a circulating supply of 12 billion USD, has drawn renewed attention to the stability of tokens without dollar reserves. Another turmoil in the Defi lending market is the filing of bankruptcy by the crypto lender BlockFi following that of the crypto exchange FTX in November 2022, blaming it on the downturn in cryptocurrency prices during the summer 2022 and a defaulted loan of $680 million owed by FTX trading firm, Alameda research[3]. However, the risks of DeFi deposit tokens, which share some of the stabilization principles of algorithmic stable coins (i.e., they are guaranteed by a basket of cryptocurrencies), are not fully understood.

[2]See Meyer, Welpe and Sandner (2021) for a review of the recent literature.

[3]More details can be found through the following link to the related WSJ article https://www.wsj.com/articles/blockfi-files-for-bankruptcy-as-latest-crypto-casualty-11669649545

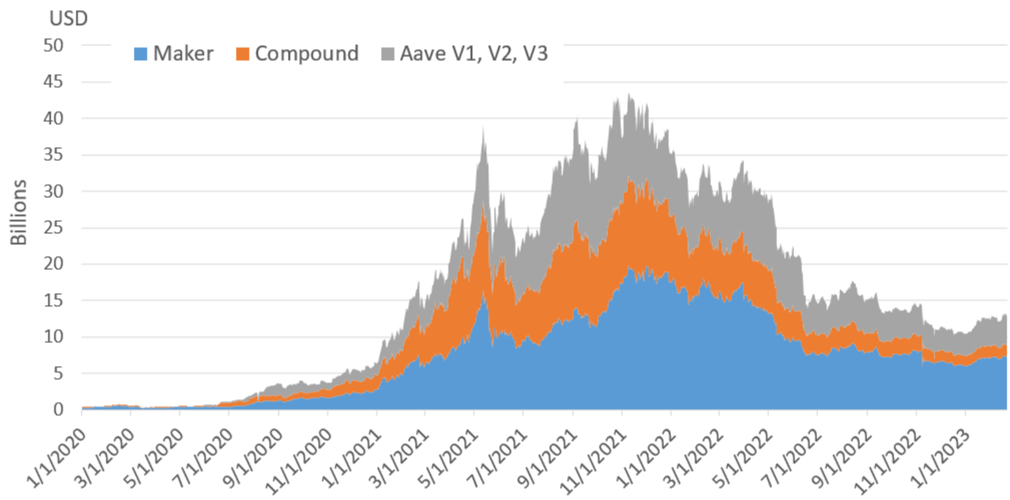

Figure 1: Sample of largest Defi lending protocols-data from DefiLlama

The objective of this article is to clarify the market structure matching lenders and borrowers, and quantify the risk of the pool as a function of downward changes in the value of coins. We develop a simple framework to assess the position of a pool relative to lenders and borrowers and derive two system risk measures: (i) the risk of liquidation for a synthetic margin borrower and (ii) the risk of collateral loss for a synthethic lender. The measures are implementable with aggregate public data on the borrowing and lending positions of major platforms without knowledge of investor-level leverage.[4]

The growing popularization of cryptocurrencies among investors presents several new challenges in the DeFi segment. DeFi deposits are perceived as products with low risk of default, because borrowers must submit more than the value of the loan in collateral and will be liquidated if the ratio of collateral cannot be maintained. Further, while platforms report deposits in each pool, the net position of a pool at any point in time, which can be a complex function of smart contracts linked to the pool, is not easily accessible. Unlike a traditional money fund, lending pools do not report a net asset value. Many depositors may face exposures to large declines in coin prices that would cause the value of collateralized assets in the pool to fall below the claims of depositors.

To set ideas, we describe below the characteristics of a DeFi loan. This type of loan is different from a traditional bank loan, where a lender deposits funds at the bank, receiving in exchange a claim on the

[4]Unfortunately, measuring investor-level leverage is difficult given the anonymity of wallets. Although wallet addresses and their content are public on the ledger, some wallets may represent exchanges and large investors have multiple wallets, making it infeasible to consolidate net positions at the investor level. This data limitation motivates the approach of this paper to measure risk at the institution level in terms of a synthetic lender matched to a synthetic borrower.

bank (or bank account) and the bank lends the funds to a borrower, receiving in exchange a claim on the borrower. This system is centralized because the lender and the borrower transact directly with the bank. By contrast, the objective of a DeFi loan is to match directly the borrower and the lender, automating the functions of the bank via a self-executing (or smart) contract.

This of course presents some challenges. Unlike a bank, a smart contract cannot evaluate soft information to measure credit risk. Therefore, DeFi loans are structured to dynamically manage risk of default. At initiation, the borrower must deposit more than the value of the loan as collateral, resulting in many cases in a ratio of a minimum of $1 of deposited assets for $.8 of loan, where .8 is the loan-to-value ratio and can vary across types of collateral. Most platforms normalize this ratio by multiplying by the liquidation threshold, denoting it the health factor: a borrower must maintain a health factor greater than one.

While, in principle, DeFi loans can be used to finance real investments, the transaction is not equivalent to a traditional bank loan. In a bank loan, the real investment serves as collateral. In a DeFi loan, other coins must serve as collateral for an amount greater than the loan, so that the borrower must hold balances in cryptocurrency greater than the loan. The loan will be liquidated as a function of changes in coin prices, not real estate prices. For this reason, the loans are mostly used to finance leveraged investment or arbitrages in other currencies, rather than purchases of real assets. As an example, suppose that the depositor believes that ether will increase relative to the dollar and, for expositional purposes, let us normalize the starting price of coins to 1 coin per dollar. The depositor borrows 2 USDC, a stable coin guaranteed by dollar deposits, and converts it into ETH, for a position 3 ETH and a liability of 2 USDC. The portfolio will appreciate if ETH increases relative to the dollar.[5]

The borrower may default if the collateral of 3 ETH is worth less than 2 USDC. The contracts use a stop-loss liquidation whereby, if the health factor falls below 1, the position becomes eligible for liquidation. Continuing on the example, suppose the value of ETH falls from 1 to .75. The health factor

[5]Stable coins, that is currencies pegged to a currency of reference with a fixed exchange rate, are critical building blocks of DeFi because they allow participants to borrow in units of a national currency and avoid liquidations due to the volatility of the borrowed assets. There are three main categories of stable coins, (1) coins backed by national currency or physical assets (e.g., Digix Gold Tokens, USD Coin), coins partially backed by basked of assets and by fiat (e.g., Tether, Diem), and coins backed with baskets of other cryptocurrencies (DAI). The latter category is the most popular in DeFi given that the process of pegging with a basket of cryptocurrencies is identical to a lending pool backing lenders' position with a basket of collateral deposits. Nevertheless, a pegged currency shares liquidity risks akin to a lending pool: the price of pegged currency can vary around the peg and a loss of confidence in the currency's collateral, if the value of the basket declines faster than the national currency, will lead to a loss of the peg.

falls to $(3 \times .75)/2 \times .8 = .9$ and the depositor will have to put more collateral or the position will be liquidated. Liquidators, i.e., other traders on the platform, can repay the loan up to the amount that restores the health factor to 1, and then claim the collateral at a price (the "oracle" price) set by the platform designed to aggregate current trading prices plus a liquidation premium, usually within 5% to 10%. With a premium of 5%, liquidators can repay 2 USDC, and claim $2 \times 1.05/.75 = 2.8$ ETH. The depositor is left with the balance of .2 ETH.[6]

However, liquidations do not offer a perfect protection for depositors. Liquidators incur trading spreads and gas fees when writing new transactions into the blockchain which can make liquidations unprofitable. In addition, transactions on the blockchain are not instantaneous nor are prices centralized in a single large exchange. If prices decreases before liquidators can repay the loan, e.g., as in the case of low liquidity or price jumps, the loan may only be partially repaid before all collateral is exhausted. To illustrate volatility risk, suppose that the price of ETH decreases to .5. Liquidators cannot repay the entire loan because this would require claiming a collateral of $2 \times 1.05/.5 = 4.2$ which is more than the 3 collateralized ETH. Instead, liquidators can claim the 3 ETH and reimburse x units of USDC so that $x \times 1.05/.5 = 3$, which corresponds to reimbursing approximately 1.43 USDC. The lending pool makes a loss of .57. To mitigate price risk, DeFi platforms use a lower preset liquidation threshold for collateral with greater volatility and incentivize liquidators by allowing them to seize the collateral at a discount (the bonus).

Related Literature. There has been little research in evaluating the risk of DeFi lending despite considerable interests in this area (Jensen and Ross 2020, Carter and Jeng 2021) - closest to our study, the studies below examine financial risks in DeFi platforms.[7]

[6]To avoid paying the liquidation bonus, some borrowers implement automated self liquidation code when their health factor falls below a certain value; note that this is not a default option or service in most DeFi protocols. Liquidations occur in situations of high market volatility and, given that the exchange process is not centralized, some traders may have a competitive advantage in trading faster and at better prices over an automated liquidation.

[7]There are other risks that are at least equally as important as price volatility (or financial) risk; while we note here, they are outside of the focus of our analysis. Many DeFi platforms issue governance tokens to change parameters of the protocol, or possibly the entire protocol - for example: Aave uses AAve tokens and Compound uses Compound tokens. Each token may gives voting rights. Many governance tokens are held by few investors, implying that governance votes are greatly centralized (Sun 2021, Zetzsche and Anker-Sorensen 2021, Zetzsche and Anker-Sorensen 2021), echoing concerns discussed for major coins (Gervais, Karame, Capkun and Capkun 2014). Another problem is the risk of hacking assets in the protocol. In October 2021, hackers diverted all of Cream Finance assets, for a total of $130 million by manipulating oracle prices for more illiquid coins - this event indirectly contributed to outflows in all other DeFi platforms. Hacking as well as the interaction between price manipulation and smart contracts present significant unsolved open issues in this area (Wang, Wu, Lin, Wu, Yuan, Zhou, Wang and Ren 2020, Chohan 2021, Scharfman 2022). Lastly, algorithmic stable coins guaranteed by a basket of unpeggeed coins (such as DAI) might lose their peg given sufficient market volatility or withdrawals akin to a bank run (Clark, Demirag

Saengchote (2021) describes the lending process at Compound, one of the most widely used loanable funds. He finds that DeFi borrowers are concerned about liquidation risk as evidenced by the positive relation between the daily loan amount and the three stable coins price volatility. However, he also finds that investors are more likely to re-deposit unpegged coins in response to market conditions while the supply of stable coins available for lending is relatively insensitive to volatility. Therefore, he conclude that yield farming via stable coins may shield the investor from market volatility. Our study builds on this evidence to construct measures of risk that depend on both borrowed funds and collateralized coins.

Also focusing on Compound, Perez, Werner, Xu and Livshits (2021) are the first to provide in-depth empirical analyses of liquidations. They find that (1) despite the increase in number of suppliers and borrowers over time, the total amount of funds supplied and borrowed remains extremely concentrated among a small set of participants; (2) the introduction of the COMP governance token spurred participants to borrow vastly more than before, with the total amount borrowed surpassing the total amount locked, (3) Due to excessive borrowing without a sufficiently safe amount of supplied funds, borrow positions now face a higher liquidation risk, such that a crash of 3% in the price of DAI could result in an aggregate liquidation value of over 10 million USD; and (4) liquidators have become more efficient over time, which can exacerbate liquidation risk.

Gudgeon, Perez, Harz, Livshits and Gervais (2020) use simulations to assess the systematic risk in DeFi lending protocols. They develop a stress-testing framework focusing on systematic insolvency risk due to financial contagion across crypto currencies within the system. They find that, with sufficient illiquidity a lending protocol, with a total debt of 400 million can become under-collateralized in 19 days. Using agent-based modeling and simulation to perform stress tests, Kao, Chitra, Chiang and Morrow (2020)) show that the Compound protocol can scale to a large market size and maintain a low probability of default when market conditions are volatile. Our analysis is also part of a growing literature evaluating the risk and returns in DeFi, which presents new opportunities for lending using smart (automatically-executing) contracts and savings stored in crypto assets. Aigner and Dhaliwal (2021) examine the risk taken by liquidity providers in a decentralized exchange (Uniswap): as for DeFi lending, liquidity providers in these platforms are exposed to volatility in prices since exchange prices are a deterministic function of supply and demand that, if insufficiently steep, may lead to a Gresham law in which

and Moosavi 2019, Clements 2021, Saengchote 2021, Catalini, de Gortari and Shah 2021); the fragility of algorithmic stable coins creates additional risks when held by DeFi liquidity suppliers.

coins with declining prices are traded into the exchange.

Finally, our approach is part of a growing literature that speaks to the benefits of emerging technologies to facilitate access to information and auditing. Dai and Vasarhelyi (2017) and Dai, Wang and Vasarhelyi (2017) show that public ledgers offer capabilites for fraud prevention by managing approvals and controls. Nguyen, Liang and Akoglu (2020) and Berberidis, Liang and Akoglu (2022) show how double-entry bookkeeping systems form a network structure with patterns that can be used to detect frauds. While our objective is more limited in scope, we offer queries that recover information about value locked in the smart contracts and which allow for a decomposition of the net position of claimants and depositors.

1 Conceptual Framework

We develop a simplified conceptual framework that will serve to lay out the key elements of DeFi loans. Consider two trading dates $t = 0, 1$, a lending pool and two traders A and B, a price path $(p_t)_{t=0,1}$ for ETH with initial price $p_0 = 1$ normalized to one dollar. The borrowing (lending) rates on ETH k_t^e (v_t^e) and USDC k_t^u (v_t^u). USDC is a stable numeraire coin with price of \$1 in both periods. Trading ends at the end of period 1 and the two traders convert their holdings into numeraire.

At date 0, trader A initially owns w_A USDC and trader B owns w_B ETH. Trader A is solely interested in yield, while trader B wishes to leverage a position in ETH. Trader A deposits w_A USDC into the lending pool in exchange for token tUSDC that can be redeemed for USDC. Note that tUSDC is a stable coins which, unlike USDC (which is guaranteed by an audited dollar deposit), is guaranteed by the basket of securities committed to the protocol. Trader B deposits w_B ETH as collateral and borrows θ USDC at a rate k_t^u and exchanges them for θ ETH. The purchased ETH is deposited in the pool to obtain additional interest-bearing tokens and can also be used as collateral. There is a liquidation threshold τ^b on ETH so that, to maintain a health factor above one, the ratio of collateral to borrowings must satisfy

$$h_0 \equiv \frac{w_B + \theta}{\theta} \tau^b \geq 1. \tag{1.1}$$

Most DeFi platforms use a variation on the following model to set borrowing and lending rates. The borrowing rate is a preset increasing convex function $k_t^x \equiv \phi_x(U_t^x)$, where we denote $x = e$ for ETH loans and $x = u$ for USDC loans and the utilization rate U_t^x is the ratio of borrowings to deposits in currency x. The "base rate" if no trader is borrowing is zero, so we set $\phi_x(0) = 0$. It follows that the borrowing interest on USDC loans is $k_0^u = \phi_u(\theta/w_A)$, while the borrowing interest on ETH loans is $\phi_e(0) = 0$.

The interest paid to lenders can then be recovered by equating the inflow of interest paid by borrowers to the outflow of interest by lenders. In the case of USDC loans,

$$w_A v_0^u - \theta k_0^u = 0, \tag{1.2}$$

that is, substituting the interest on USDC loans $k_0^u = \phi_u(\theta/w_A)$, the interest paid to lenders on the USDC loan is

$$v_0^u = \frac{\theta\phi(\theta/w_A)}{w_A}. \tag{1.3}$$

Unlike in traditional lending, the spread $k_0^u - v_0^u$ does not represent a commission earned by an intermediary. DeFi protocols do not set rates that equate supply and demand, and there are usually more lenders than borrowers. The spread reduces the rate received lenders if there are fewer borrowers, as if borrowers were to randomly pick a lender.

Consider next the ETH price p_1 at date $t = 1$. The health factor h_1 of trader B is now given by

$$h_1 \equiv \frac{(w_B + \theta)p_1}{\theta(1 + \phi(\theta/w_A))}\tau^b. \tag{1.4}$$

There are two possible scenarios:

1. If the health factor in (1.4) remains greater than one, trader B's health factor is adequate and no collateral is put for liquidation. The loan is fully repaid with traders A and B achieving ending balances $w'_A = w_A + \theta\phi(\theta/w_A)$ and $w'_B = (w_B + \theta)p_1 - \theta(1 + \phi(\theta/w_A))$, respectively.

2. If the health factor falls below 1, liquidators can repay up to 1 USDC, and receive in exchange $(1 + \pi)/p_1$ ETH in collateral per unit of repayment, where π is a ETH liquidation premium fixed in the protocol. This implies two subcases:

2.a. If the loan and premium can be paid in full with the collateral, that is,

$$(w_B + \theta)p_1 \geq \theta(1 + \phi(\theta/w_A))(1 + \pi), \tag{1.5}$$

trader B is liquidated and keeps only the remaining collateral. Trader A achieves the same terminal wealth as in scenario 1 while trader B achieves a lower $w'_B = (w_B+\theta)p_1 - \theta(1+\phi(\theta/w_A))(1+\pi)$ reduced by the premiums paid to liquidators.[8]

2.b. If the price of ETH p_1 falls more so that the loan can no longer be fully repaid, i.e., inequality (1.5) no longer holds, liquidators can repay x units of USDC loan (cum interest) and claim up to the available collateral. Assuming that liquidators claim the maximum available collateral, the total loan repayment will be

$$(1 + \pi)x = (w_B + \theta)p_1, \tag{1.6}$$

implying that $\theta(1 + \phi(\theta/w_A)) - \frac{w_B+\theta}{1+\pi}p_1$ remains unpaid to the lending pool. After impairment, trader A converting the tokens can recover

$$w'_A = w_A - \theta + \frac{w_B + \theta}{1 + \pi}p_1 < w_A + \theta\phi(\theta/w_A), \tag{1.7}$$

while trader B loses their entire investment.

Note that the tokens of trader A in the lending pool are not risk-free if scenario 2b has non-zero probability. The lending pool has a standard debt-like risk and return profile: constant for prices of ETH satisfying (1.5) but, otherwise, if trader B defaults, tracking the value of a portfolio of ETH and USDC. The critical price level

$$\underline{p}_1 = \frac{\theta(1 + \phi(\theta/w_A))(1 + \pi)}{w_B + \theta} \tag{1.8}$$

where (1.5) is met at equality, i.e., such that the net assets in the pool are no longer sufficient to guarantee the claim of trader A, are the basis of our risk measure.

[8] Many DeFi platforms have scripts that allow the depositor to automatically repay the loan once the loan becomes eligible for liquidation, thus avoiding the premium π. With these "voluntary" liquidation calls, the loan is fully repaid and scenario 2a is equivalent to scenario 1.

2 Risk Measures

We are now ready to state a general model to obtain a risk assessment of the eco-system. There are two trading periods $t = 0, 1$ and $j \in [-J, J]$ coins. We denote $j \leq 0$ as stable coins whose value is pegged to USD. Each coin has an initial price normalized to one, and value at $t = 1$ is denoted p_j. There are $i \in [1, I]$ traders with a date $t = 0$ portfolio given by θ_{ij}. A portfolio $\theta_{i,j} < 0$ indicates that trader i is short on coin j. Each coin has its own liquidation threshold τ_j and premium π_j. Given that we will be interested in instantaneous risks in the system (one or two days), we omit interest rates as they are negligible on a daily basis relative to price changes.

The total deposits D_j and borrowings B_j in coin j are given by:

$$D_j = \sum_{i=1}^{I} 1_{\theta_{ij} \geq 0} \theta_{ij} \tag{2.1}$$

$$B_j = \sum_{i=1}^{I} 1_{\theta_{ij} < 0} |\theta_{ij}|. \tag{2.2}$$

Unfortunately, the true risk of the system, defined as the risk that deposits are unpaid, depends on many factors that are unobservable, such as the joint distribution of future coin prices and individual net position as well as leverage on investor-level margin accounts. To address this, we develop two synthetic measures of risk that can be computed with available aggregate deposits and borrowings and can be interpreted in terms of a general coin price level.

The measures are designed to capture risk from the perspective of the two types of synthetic traders described in section 1: type A seeks yield by investing only in the $j \leq 0$ stable coins while type B seeks capital appreciation by borrowing the $j \leq 0$ stable coins and trading the remaining $j > 0$ coins. Note that these are not meant to be a literal representation of a trader but an aggregate of the two main motives for using DeFi. Type B is an aggregate representation of many smaller traders with different levels of leverage who, individually, might not purchase the market portfolio of all unpegged coins. In practice, some traders may be combinations of the types, seeking a mix of yield and coin appreciation. As we consider a risk measure for each type of synthetic trader, a mixed trader would have a risk at an intermediate level between the two risk measures.

Hereafter, we operationalize risk as a proportional reduction in all unpegged coin prices that would cause a specific negative event (to be defined later on). A risk measure of zero means that coin prices would have to fall to zero value for the event to trigger, while a risk measure of one or above means that coin prices at the current level (100% of current prices) trigger the event.

The first risk measure captures a liquidation event by the type B trader. Assuming that coin prices decrease by a factor p_I, type B's health factor is

$$h \equiv \frac{p \sum_{j>0}(D_j - B_j)\tau_j}{\sum_{j\leq 0} B_j}, \tag{2.3}$$

where the numerator is defined by the net wealth after the price change weighted by the collateral requirement τ_j. Our interest is in the maximum price change such that the health factor falls below one. Solving (2.3) in p after setting $h = 1$, the first risk measure is defined by

$$R_I \equiv \frac{\sum_{j\leq 0} B_j}{\sum_{j>0}(D_j - B_j)\tau_j} \tag{2.4}$$

and captures the overall price change that can lead to liquidation by the synthetic type B investor.

From the perspective of the type A depositor, most liquidations need not imply default because the loans are over-collateralized with $\tau_j \in (0, 1)$. Hence, we consider a second measure capturing the price change such that type B trader is no longer able to repay the loan. After a forced liquidation, the value of the portfolio of type B trader is

$$p \sum_{j>0}(D_j - B_j) - \sum_{j\leq 0} B_j(1 + \pi_j), \tag{2.5}$$

where the first term is the value of the portfolio prior to liquidation and the second term is the repayment amount plus bonus to liquidators. Solving for p so that (2.5) remains positive,

$$R_{II} \equiv \frac{\sum_{j\leq 0} B_j(1 + \pi_j)}{\sum_{j>0}(D_j - B_j)} \tag{2.6}$$

is the point at which type B may not longer be solvent and, therefore, loans may become under collateralized.

Note that this decomposition is different from the common approach which consists in measuring the overall ratio of borrowing to lending to assess the leverage of a synthetic investor. This approach implies by construction a ratio lower than one and may be problematic because lenders and borrowers are different traders with different risk exposure. Put differently, even if lending is significantly greater than borrowing at a point in time, such lending would drain quickly should there be collateral losses in the lending pool: our risk measures attempt to capture aggregate excess collateral deposited by borrowers against commitments to lenders.

3 Empirical Analysis

We compute the measures daily from April 1st 2021 to February 15th 2023 for the protocols Compound and AAve V2 and from April 1st 2021 to May 18th 2022 for the protocol Aave v1, which was subsequently deactivated, with a total of 40,889 daily token-level observations.[9] The Aave and Compound protocols are among the largest in DeFi lending. Detailed information about lending and borrowing is obtained from the Ether blockchain from the 'c' tokens issued by Compound and 'a' tokens generated by AAve (e.g., aUSDC or cUSDC). These tokens are issued when funds are deposited into the protocol.[10] We do not include as stable coins any coin backed exclusively by a portfolio or other unpegged cryptocurrencies, which is consistent with the definition in the new proposed U.S. legislation S.3970 on stable coins. Further, our purpose here is to evaluate the risk of non-repayment of an asset whose value is exogenous to the crypto currencies, so this classification rules out coins guaranteed by a basket of coins such as Terra USD or DAI. We consider these coins as regular crypto assets.[11]

We find that the risk measures became briefly elevated in July 2021, where, at peak, R_I was greater than one and an additional loss of roughly $1 - R_{II} \approx 30\%$ in coin prices would have compromised the deposited collateral. DeFi deposits consolidated over the following four months. Another peak, but less severe, appeared in November 2022 with the risk measure R_I indicating that a crash of at least $1 - R_I \approx 18\%$ would compromise the position of borrowers. This peak occurred in the same period as

[9] These protocols experienced major changes in 2020 and early 2021 due to the opening of new markets and changes to details of the protocol in response to stress events (e.g., available markets, coins available for trading, and risk parameters). For this reason, we start the sample after protocols became more homogenous. For example, early 2021, protocols altered their oracle prices and updated liquidation procedures to address events with low liquidity or risks of price manipulation. For simplicity, we do not incorporate the other large DeFi protocol Maker. Maker functions with a different model: borrowers deposit assets in exchange for a stable coin (DAI) that they can sell on the market, so that lenders are owners of the DAI coin.

[10] Queries are publicly available at https://dune.com/queries/[query number], as queries 462944, 462941, 463938 and 462905. These queries are available to use and modify, with reference to the current study.

[11] On June 17th 2022, Maker suspended the DAi Direct Deposit Protocol (D3M) which allowed the minting of new DAI to offset the increase in interest rate given additional borrows in DAI on the platform. This decision was in response to about 100 million DAI having been borrowed by Celsius, a platform currently facing severe liquidity issues.

the collapse of FTX, which was caused by a liquidity crisis of the company's token, FTT. Even though the FTT token isn't used in the Compound and Aave protocols, FTX's collapse has had an impact on the Defi lending market as evidenced by the subsequent bankruptcy of the crypto lender BlockFi, partly due to a defaulted loan of nearly $680 million owed by FTX. An indirect effect of the FTX collapse on the Aave and Compound platforms that may explain the peak observed in November 2022 in Figure 2, could be a significant withdrawal by certain depositors (following the event) to avoid potential loss. For example, with respect to the Compound protocol, our data indicate a decrease in the total amount of deposit from $2.3 billion on November 8 (three days prior to the FTX bankruptcy) to $1.8 billion on November 14 (three days following the FTX bankruptcy), representing nearly 22% decrease in a six-day window. Regarding the Aave V2 protocol, a 10% decrease in the total amount deposited can be found in the same period. However, we observe a consolidating trend of these two protocols since January 2023. We conclude that, Defi positions had historically been at high levels of fragility and that at current levels, the risk is moderate relative to daily variation in coin prices. However, Defi positions remain vulnerable to a crash or a return to pre-covid crypto valuations. Note that the risk measures allow for continuous monitoring of this exposure. Next, we explain changes to risk in terms of events relevant to

Figure 2: Plots of computed R_I and R_{II} - Daily

the market for cryptocurrency as well as external financial and macroeconomic shocks. To this effect, we use the general performance of a crypto currency basket, macroeconomic factors, such as inflation and unemployment, and financial factors, such as the yield curve and the value-weighted equity market.

The statistical model is stated below:

$$R_i^t = \beta_{0,i} + \beta_{1,i}\text{NCI}_t + \text{Controls} + \epsilon_{i,t}, \tag{3.1}$$

where R_i^t denotes R_I or R_{II}. The explanatory variables are NCI, the value-weighted level of the coin index NCI supplied by Nasdaq. The set of control variables includes : inflation, unemployment rate, gold price, spread between the 3-month and the 10-year treasury yields, level of the CRSP value-weighted equity index, Chicago Board Options Exchange volatility index, and Schwab inflation-indexed bond. The results of our estimates, presented in table 1, suggest that a decrease of the NCI index by $1,000$ leads to a decrease in R_I by roughly 0.16 and a decrease in R_I by roughly 0.10. The results are in line with the expectation that the measures capture a distance to default.

Table 1: Determinants of R_I and R_{II} with NCI index, controlling for financial markets and macroeconomic factors

	R_I^t			R_{II}^t		
	(1)	(2)	(3)	(4)	(5)	(6)
NCI^t	-0.068***	-0.162***	-0.161***	-0.015***	-0.100***	-0.098***
	(0.006)	(0.018)	(0.021)	(0.004)	(0.014)	(0.017)
$Controls^t$	No	Yes	Yes	No	Yes	Yes
$Controls^{t-1}$	No	No	Yes	No	No	Yes
Intercept	0.722***	-0.723	-0.544	0.354***	-0.698	-0.592
	(0.014)	(0.674)	(0.819)	(0.011)	(0.523)	(0.636)
# of Observations	1226	868	678	1226	868	678
R-Squared	0.108	0.164	0.164	0.009	0.157	0.160
Adj. R-Squared	0.110	0.160	0.150	0.010	0.150	0.140

Notes : This table summarizes the OLS regressions results of the risk measures on the crypto-currencies index *NCI* (in thousands), controlling for financial markets price indexes and macro-economics parameters (contemporeneous and with 1 day of lag). The standard errors are reported in parentheses below the coefficients. *NCI* is a value-weighted price index for crypto currencies, obtained from the Nasdaq exchange. The asset constituents of the index are mainly Bitcoin (61.7%), Ethereum (35.09%). The other constituents are Litecoin, Chainlink, Uniswap, Bitcoin cash, Stellar Lumens, Filecoin. The set of control variables is comprised of the variables *VIX, CRSP, SCHP, GOLD, T-Bill Spread, Unemployment,* and *Inflation*. *VIX* is the Chicago Board Options Exchange daily volatility index. *CRSP* is the daily return of the Center for Research in Securities Prices value weighted equity market index for S&P500. *SCHP* is the daily price index of the Schwab inflation-indexed bond (SCHP TIPS ETF). *GOLD* is the daily price of gold. *T-Bill Spread* is the difference between the daily 10-Year and 3-Month Treasury Par Yield Curve rates. *Unemployment* is the monthly US unemployment rate. *Inflation* is the monthly US inflation rate (Consumer Price Index). t and t-1 denote respectively current day and previous day. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

We conclude this section by considering the link between liquidations and the risk measures. Given that risk measures are invariant to the size of the market, we similarly define liquidations as the ratio of dollar liquidations to lagged dollar borrowings. Risk measures and liquidations are computed separately for AAve and Compound from blockchain queries.[12] We winsorize the liquidations at the 1st and 99th percentile levels to reduce the effect of outliers. Figure 3 reveals that, overall, liquidations are increasing in the risk measure, consistent with our measures capturing risk at an aggregated level.

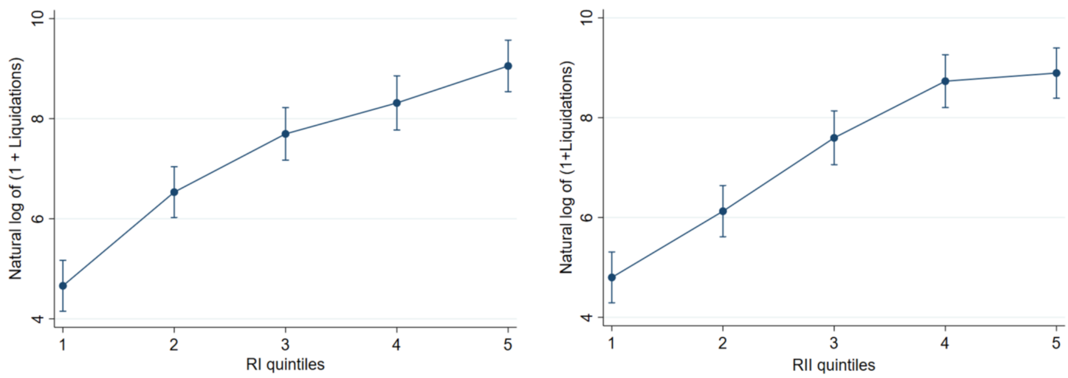

Figure 3: Liquidations as function of R_I (left) and R_{II} (right) quintiles

Conclusion

Decentralized finance offers new opportunities for direct matching of borrowers and lenders (Harvey, Ramachandran and Santoro 2021), but also introduces new types of risks that are no longer centrally maintained. In this study, we offer a practical measure of DeFi lending risk based on a decomposition of aggregate lending and borrowing into a synthetic borrower and a synthetic lender. The measure can be obtained without knowledge of individual net positions, and is interpretable in terms of maximal allowable changes in cryptocurrency prices held by borrowers. We use the measure to detect significant increases in risk identifying in real time potential fragilities in the system. The measure offers a first step to track risks at an aggregate level.

In the event of recurrent high risk level, the evolution of the industry may be reflecting a movement from guaranteed deposits to fiat banking, similar to a traditional bank and sensitive to bank runs á la Diamond and Dybvig (1983). On its own, this evolution, if matched with higher interest rates, may

[12] The query is available at https://dune.com/queries/463010.

reflect economic demands for higher yields but comes with new risks that are not yet fully understood nor monitored. Indeed, many of the safeguards currently in place to protect against under-collateralized lending, such as issuing the platform's governance coin (e.g., the Compound coin), are similar to those in place in the recent Terra USD coin collapse, which called for issuing the Luna coin to meet any excess withdrawal. The new banking system proposed in DeFi has become more sensitive to loss of trust in the protocol and its associated governance coin. While we have not explored these questions here, these challenges call for a complete economic theory of DeFi lending where the incentives of lenders, borrowers, liquidators and sponsors are better understood.

Bibliography

Aigner, Andreas A, and Gurvinder Dhaliwal (2021) 'Uniswap: Impermanent loss and risk profile of a liquidity provider.' *arXiv preprint arXiv:2106.14404*

Berberidis, Dimitris, Pierre J Liang, and Leman Akoglu (2022) 'Summarizing labeled multi-graphs.' *arXiv preprint arXiv:2206.07674*

Carter, Nic, and Linda Jeng (2021) 'Defi protocol risks: the paradox of defi.' *Regtech, Suptech and Beyond: Innovation and Technology in Financial Services RiskBooks–Forthcoming Q*

Catalini, Christian, Alonso de Gortari, and Nihar Shah (2021) 'Some simple economics of stablecoins'

Chohan, Usman W (2021) 'Decentralized finance (defi): an emergent alternative financial architecture.' *Critical Blockchain Research Initiative (CBRI) Working Papers*

Clark, Jeremy, Didem Demirag, and Mahsa Moosavi (2019) 'Sok: demystifying stablecoins.' *Communications of the ACM, Forthcoming*

Clements, Ryan (2021) 'Built to fail: The inherent fragility of algorithmic stablecoins.' *Wake Forest L. Rev. Online* 11, 131

Dai, Jun, and Miklos A Vasarhelyi (2017) 'Toward blockchain-based accounting and assurance.' *Journal of information systems* 31(3), 5–21

Dai, Jun, Yunsen Wang, and Miklos A Vasarhelyi (2017) 'Blockchain: an emerging solution for fraud prevention.' *The CPA Journal* 87(6), 12–14

Diamond, Douglas W, and Philip H Dybvig (1983) 'Bank runs, deposit insurance, and liquidity.' *Journal of political economy* 91(3), 401–419

Gervais, Arthur, Ghassan O Karame, Vedran Capkun, and Srdjan Capkun (2014) 'Is bitcoin a decentralized currency?' *IEEE security & privacy* 12(3), 54–60

Gudgeon, Lewis, Daniel Perez, Dominik Harz, Benjamin Livshits, and Arthur Gervais (2020) 'The decentralized financial crisis.' In '2020 Crypto Valley Conference on Blockchain Technology (CVCBT)' IEEE pp. 1–15

Harvey, Campbell R, Ashwin Ramachandran, and Joey Santoro (2021) *DeFi and the Future of Finance* (John Wiley & Sons)

Jensen, Johannes Rude, and Omri Ross (2020) 'Managing risk in defi.' In 'JR Jensen and O. Ross,"Managing Risk in DeFi" in CEUR Workshop Proceedings, Aachen'

Kao, Hsien-Tang, T. Chitra, Rei Chiang, and John Morrow (2020) 'An analysis of the market risk to participants in the compound protocol'

Meyer, Eva, Isabell M Welpe, and Philipp G Sandner (2021) 'Decentralized financea systematic literature review and research directions.' *Available at SSRN 4016497*

Nguyen, Hung T, Pierre J Liang, and Leman Akoglu (2020) 'Anomaly detection in large labeled multigraph databases.' *arXiv preprint arXiv:2010.03600*

Perez, Daniel, Sam M Werner, Jiahua Xu, and Benjamin Livshits (2021) 'Liquidations: Defi on a knife-edge.' In 'International Conference on Financial Cryptography and Data Security' Springer pp. 457–476

Saengchote, Kanis (2021) 'Decentralized lending and its users: Insights from compound.' *Available at SSRN 3925344*

Scharfman, Jason (2022) 'Decentralized finance (defi) compliance and operations.' In 'Cryptocurrency Compliance and Operations' (Springer) pp. 171–186

Sun, Xiaotong (2021) 'Centralized governance in decentralized finance (defi): A case study of makerdao.' *Available at SSRN 3971791*

Wang, Dabao, Siwei Wu, Ziling Lin, Lei Wu, Xingliang Yuan, Yajin Zhou, Haoyu Wang, and Kui Ren (2020) 'Towards understanding flash loan and its applications in defi ecosystem.' *arXiv preprint arXiv:2010.12252*

Zetzsche, Dirk Andreas, and Linn Anker-Sorensen (2021) 'From centralized to decentralized finance: The issue of fake-defi'