Liquidation cascades in decentralized finance

Abstract

Liquidation cascades are the self-reinforcing process by which waves of liquidations of assets pledged as collaterals for loans depreciate collaterals' prices that leads to further liquidations. These market dynamics jeopardize financial stability. This is even more so when the asset borrowed, and the asset pledged as collateral are of the same class and exhibit high level of volatility. Traditional finance (or TradFi) designed numerous mechanisms to mitigate risks of liquidation cascades over decades, such as intermediation, credit scoring and relationship lending. The core characteristics of decentralization and pseudonymity of blockchain-based credit transactions preclude reusing these efficient mitigation tools but compel designing new mechanisms and tools. The goal of the paper is to expose and discuss the limits of the main existing mechanisms to mitigate risks of liquidation cascades in decentralized finance (or DeFi).

Synopsis

A growing literature argues that decentralized finance (or DeFi) has the potential to dramatically improve the efficiency of financial mechanisms in terms of transaction costs, transparency, and speed of transactions. Indeed, blockchain-based transactions are borderless and open 24/7 and have no entry barrier or permission requirements (at least for permissionless public blockchains). These characteristics, it is argued, may foster market liquidity and improve the allocation of resources. For its part, the 50 years-old SWIFT messaging system (SWIFT-FIN) is secure, scalable (with an average of more than 48 million messages per day), with significant network externalities, but is not without defects in terms of speed of transaction (several days for basic international payments) and governance opacity (Scott & Zachariadis, 2012).

Apart from transactional concerns, proponents of decentralized finance (or DeFi) further argue that it can compete with traditional financial institutions and technologies for any type of financial services, including the large-scale provision of cheap credits to financial real-life economic activities, similar to what modern fractional reserve banking does to finance firms in the short term (cash flow management) and long term (investments). As a source of cheap external funding, fractional reserve banking reduces risks of debt rationing and business bankruptcy, and fosters investment, innovation, and growth. Can DeFi do that?

The goal of the paper is to expose and discuss the limits of the main existing mechanisms to mitigate risks of liquidation cascades in decentralized finance (or DeFi). It is argued that the current limits of DeFi can be mitigated by smoothing liquidation mechanisms and widening the classes of assets to be pledged as collateral in crypto-loans to break the crypto-loan-crypto-collateral chain.

1. Intermediation and collateralization in traditional finance

The provision of credit poses problems that other financial services, such as payment and swapping, do not pose, especially in terms of information asymmetry, agency costs, and contract incompleteness. To a large extent, financial intermediation and regulation have been designed to mitigate these risks in credit transaction (Rubinstein & Wolinsky, 1987).

The issue of information asymmetry in credit transactions gave birth to an extensive financial literature on financial intermediation, transaction and relationship lending, incentive mechanisms, and regulation (Diamond, 1984). It is usually argued that financial intermediaries have a net cost advantage relative to direct lending and borrowing and that delegating monitoring to an intermediary allows a superior Pareto allocation because it considers the *causes* of default. As Diamond (1996: p. 65) argued,

> ‘Liquidation is potentially inefficient. If the lender cannot monitor the borrower’s business, then the lender should liquidate whenever there is a default, no matter what the cause. If the lender can monitor the situation, then the ability to selectively remove the threat to liquidate in return for a concession from the borrower can provide power over the borrower without using inefficient liquidation’

Extensions of this literature argue that the banks’ cost advantage of monitoring increases in repeated lending because enduring relationships between banks and borrowers reduces direct monitoring costs and increases trust (Haubrich, 1989). Relationship lending is especially important for unsecured loans only supported by the borrower’s creditworthiness, rather than by a (usually tangible) collateral. Similarly, Boot (2000) argued that relationship lending contributes to alleviate adverse selection and moral hazard problems, with the basic insight that a close relation between borrower and lender should facilitate the *ex ante* screening and *ex post* monitoring and thus mitigate informational opaqueness (Steijvers & Voordeckers, 2009). Beck et al (2018) found that relationship lending is not associated with credit constraints during a credit boom and alleviates credit constraints during a downturn. However, other empirical studies suggest that a close bank-borrower relationship may increase the willingness to take more risk (Jimenez & Saurina, 2004).

Contrary to the previous literature, the theory of incomplete financial contracts initiated by Aghion & Bolton (1992) focuses more on transaction than on relationship lending and gives collateral a significant role in the mitigation of risks of adverse selection that arise when borrowers have *ex ante* private information (Berger et al., 2011, Bolton et al., 2016, Cerqueiro et al., 2016). According to Gambacorta et al (2023, p. 369),

> 'Collateral is used in debt contracts to mitigate agency problems arising from asymmetric information. Banks usually require their borrowers to pledge tangible assets, such as real estate, to lessen ex-ante adverse selection problems, or as a way to reduce ex-post frictions, such as moral hazard, costly state verification, and imperfect contract enforcement'.

Creditors' right to repossess collateral in case of credit default (either strategic default or bankruptcy) is seen as a credible threat without which credit transactions with asymmetric information could not take place, with the insight that the stronger the protection creditors obtain via collateral, the more abundant and cheap credit will be for entrepreneurs and households. As a consequence, collateral requirements are even more important for informationally opaque borrowers. In this respect, assuming that information asymmetry between lenders and borrowers leads to credit rationing, collateral is an informational asymmetry reducing instrument that remedies credit rationing and improves credit-market efficiency (Coco, 2000, Steijvers & Voordeckers, 2009).

A complementary view argues that banks' economic function is not only to provide cheap credit, but also to screen projects to reduce the number of project failures and mitigate their private and social costs (Manove et al, 2001). In line with Diamond (1996), it is argued that lenders' unrestricted reliance on collateral and automatic liquidation in case of credit default may have a negative impact on credit-market efficiency, with risks of undue credit rationing. Instead, the authors argue that banks are well placed to assess the expected profitability of a business project, while a high level of collateral requirement will disincentive banks to do so. Over-reliance on the protection of creditors makes bank "lazy" toward screening. In this regard, collateral and screening are substitutes from the point of view of banks but are very different from a social standpoint: 'Because of their superior expertise in project evaluation, the screening activity of banks is a value-enhancing activity for society, whereas the pledging of collateral is not, since it merely allows a transfer of wealth from the borrower to the bank when things go badly' (Manove et al., 2001, p. 728). Ruckes (2004) analyses the screening behaviour of banks and discovers that bank screening intensity displays an inverse U-shape as a function of economic prospects. In periods of positive economic perspectives, average default probabilities of borrowers decline, leading banks to conduct less screening activity and to extend loans to lower-quality borrowers. On the contrary, when business perspectives worsen, price competition diminishes, credit standards tighten, and credit provision becomes procyclical. This is consistent with the result of Jimenez & Saurina, (2004) that relationship lending incentivizes risky investment decisions and Dell'Ariccia & Marquez (2006: p. 2511) who argue that as banks obtain private information about borrowers and information asymmetries across banks decreases, banks loosen their lending standards, 'leading to an equilibrium with deteriorated bank portfolios, lower profits, and expanded aggregate credit', these lower standards being associated with 'greater aggregate surplus and greater risk of financial instability'.

Screening and relationship lending are not the sole mechanisms by which lenders can obtain information about a potential or actual borrower's creditworthiness. Credit scoring companies for consumer lending (Thomas, 2000) and rating agencies for bonds (White, 2013) are financial intermediaries that offer judgements about the credit quality of borrowers to lenders. As White points out (2010: p. 212), 'along with collecting their own information about borrowers, and imposing requirements like collateral, co-signers, and restrictive covenants in bond indentures or lending agreements, those who lend money may also seek outside advice about creditworthiness'. Determining whether rating agencies significantly improve investment decisions and risk management or escalate systemic risks, bank's laziness and biases is still an open debate (Frost, 2007, White, 2009).

Taken together, all these financial intermediaries and banking practices emerged to mitigate information asymmetry and contract incompleteness in credit transactions (Holmström & Tirole, 1997). Debates over their virtues and efficiency notwithstanding, they are all parts of the modern banking system that provides cheap and large-scale secured and unsecured financing to firms, consumers, and States (Benmelech et al., 2024).

2. Disintermediation and overcollateralization in decentralized finance

Credit risk mitigation in DeFi tremendously differs from risk mitigation in traditional finance. The very nature of the blockchain technology (especially decentralization of lending protocols and pseudonymity of lenders and borrowers) incentivizes lending platforms to use transactional risk mitigation tools based on in-built risk parameters, overcollateralization, automatic liquidation, and reserves, and to ignore relationship lending.

In decentralized finance, lending takes the form of an interaction with a transparent smart contract that specifies the amount and type of assets to be supplied, borrowed, and pledged as collateral. The smart contract may also specify other features, such as liquidation procedures, haircuts, and reserve factors that allocate a share of the protocol's interests to a collector contract to mitigate solvency risks. On the one hand, liquidity providers (i.e., suppliers) deposit the loan token into the smart contract. On the other hand, borrowers provide a collateral token to secure their loans (except in flash loans). The Loan-to-Value ratio determines the maximal amount that can be borrowed according to the value and characteristics (in terms of volatility and market liquidity for example) of the cryptocurrency pledged as collateral. If the value of the collateral decreases to the liquidation Loan-to-Value ratio (or liquidation threshold), the borrow position is eligible for automatic liquidation. Assets are priced with the market's oracle and borrowers pay lenders interest according to the protocol's interest rate model (a dynamic interest rate algorithm that automatically adjusts borrowing and savings rates as a function of utilization rate of the liquidity pool). All lending platforms use similar risk management procedures and tools.

a. Overcollateralization

Apart from the specific cases of flash loans and credit delegation that represent a marginal fringe of borrowing in decentralized finance, all other types of loans in DeFi are overcollateralized. To obtain a loan (usually in stablecoin), the borrower must pledge cryptocurrencies (a volatile asset) as collateral with a market value superior to the amount borrowed. In most cases, collateralized assets do not earn or pay interest. The maximum borrowing power of a specific collateral (or asset's borrow collateral factor) is the "Loan-to-Value" ratio. LTV ratios depend on the protocol's risk parameters. The amount of collateral and the collateral factor together determine the borrow position. The ratio depends on the volatility of the collateralized asset, without considering the risk profile of borrowers, with the basic insight that the more volatile the asset, the lower the LTV. For instance, at the time of writing, the LTV of Ethereum on the Aave platform is 80,5%, 77% for the USDC and Tether stablecoins, and much lower for more risky cryptocurrencies, such as 40% for the Lido DAO token. The collateral ratio is simply the ratio between the value of the collateral and the borrowed amount.

b. Liquidation

Depending on the risk assessment and platforms, assets differ with respect to liquidation factors and liquidation mechanisms (Saengchote, 2023). Sufficient margins and incentives are needed for the open position to remain collateralized in case of adverse event, at both the market (e.g., bear market) and asset (e.g., hack or depeg of a stablecoin) levels. If the value of the collateral falls below a predetermined liquidation threshold, a portion of it will be either sold with a discount or auctioned to repay a portion (often 50%) of the debt position and keep the ongoing borrow collateralized. Liquidation mechanisms are mainly twofold: an atomic fixed spread strategy and a non-atomic English auction (Qin et al, 2021). Given the incentives scheme of liquidation discount, undercollateralized loans are swiftly liquidated to preserve the platform's solvency.

The liquidation threshold is the maximum debt-to-collateral ratio of a borrow position before it is defined as undercollateralized and eligible to liquidation. For each wallet, the liquidation threshold is calculated as the weighted average of the liquidation thresholds of the collateralized assets i and their value:

$$Liquidation\ Threshold = \frac{\sum Collateral_i\ in\ ETH\ \times Liquidation\ Threshold_i}{Total\ collateral\ in\ ETH}$$

For instance, if the liquidation threshold is 0,8, the account is liquidable when the amount borrowed is worth at least 80% of the collateral pledged. The liquidation threshold differs from the loan-to-value to maximize capital efficiency:

> 'By providing a buffer, the protocol can balance between having an aggressive liquidation policy (e.g., liquidation threshold = LTV) for volatile assets and a capital efficient policy for more stable assets. For instance, if we have a stablecoin-stablecoin loan (e.g., USDT as collateral to borrow USDC) then providing a buffer (liquidation threshold > LTV) gives a borrower more time to recollateralize a loan. However, for assets where there are dramatic differences in liquidity, which would

strain liquidator profitability, the protocol should prefer an aggressive liquidation policy' (Gauntlet Research Report, 2021: p. 11).

For instance, on the Aave crypto-lending protocol, the LTV of USDC is 77%, while the liquidation threshold is 80%, with a liquidation penalty of 4,5%. The account becomes liquidable when the value of debt exceeds its borrowing capacity, that is, when the collateral's value falls below the collateral requirement. In this case, the "health factor" of the loan falls below 1, with the Health Factor defined as

$$H_f = \frac{\sum Collateral_i \ in \ ETH \ \times Liquidation \ Threshold_i}{Total \ Borrows \ in \ ETH}$$

Remark that "unhealthy" loans are still solvent, but eligible for liquidation. To avoid liquidation, borrowers must improve their health factor by pledging more collateral or repaying part of the loan. Users can monitor their health factor in real time with specific applications or auto-liquidate their loans. In case of liquidation, the protocol does not purchase the remaining collateral or employ trusted third parties (such as debt recovery agencies) to liquidate insolvent loans but incentivizes external liquidators to do so either through a "liquidation bonus", that is, a discount on the collateral purchased for the liquidator (fixed spread liquidation in atomic liquidation), or through auction (non-atomic liquidation). Along with transaction costs, market liquidity plays a major role in the risk and profitability of the liquidation process. Quite intuitively, liquidators engage in liquidation only if the collateral can be sold immediately to repay the flash loan or to make profitable arbitrage, unless the liquidator holds the depreciated collateral in expectation of future increase. Liquidity of second-hand markets for collateral is thus a central factor for actual market liquidation because a loan can be healthy and overcollateralized but effectively not liquidable because of second-hand market lack of liquidity.

Every user can become a liquidator (or "keeper" in the MakerDAO protocol). In the absence of entry barriers, the market for liquidation is highly contestable and liquidators developed specific tools (such as bots) to be the first to liquidate undercollateralized loans and get the liquidation bonus. Liquidators can obtain the capital to buy the asset pledged as collateral at a discount with a flash loan. The flash loan will often be repaid by swapping part of the collateral received in a decentralised exchange, which will incur additional costs such as swapping fees, slippage (the aggregated transaction fees a liquidator has to pay to sell an asset), and gas fess[1]. Only the remaining collateral after fees counts as profit. In this respect, fixed spread liquidation mechanisms financed by flash loans exhibit all the characteristics of pure profit arbitrage *à la* Kirzner according to which entrepreneurs exploit price discrepancies without engaging capital and endorsing risks of capital loss.

- *Fixed spread liquidation*

Atomic liquidation is settled in one blockchain transaction. Once the Health Factor is below 1, the borrowing position is liquidated with a pre-determined liquidation penalty (from the borrower point of view) or bonus (from the liquidator point of view). For example, with a liquidation penalty of 6%, liquidators pay up to 50% of the outstanding borrowed amount on behalf of the borrower. In return, they can buy the collateral at a 6% discount of the current market price and keep the difference (i.e., the liquidation penalty) as a bonus. The liquidation bonus is known upfront and is adjusted as a function of asset volatility and liquidity and updated via governance processes, so that riskier assets have a higher liquidation bonus than safer assets to facilitate liquidation of riskier undercollateralized loan positions.

- *Auction liquidation*

Auction mechanisms allow for a dynamic debt pricing. Contrary to the fixed spread liquidation mechanism, liquidators' profits are not known upfront, but depends on the competition between liquidators. They are more complex and flexible than fixed spread liquidation. Accordingly, they are mostly used by experienced traders and bot-trading[2]. For example, the Liquidation 1.2 system of liquidation of the Maker protocol utilized English auctions (ascending-price auctions) and worked as follows (Darlin et al., 2021)[3]:

(1) When the health factor drops below 1, a loan becomes eligible to liquidation. The system takes over the collateral and auctions it off to cover both the debt in the vault and a liquidation penalty. All aspects of the auction are specified in a liquidation contract.

[1] It is likely that massive waves of liquidation happen in times of high market volatility when gas fees are higher than usual, and liquidity of risky assets decrease. In this situation, liquidators are not incentivized to buy a volatile collateral with high transaction costs and low market liquidity. Furthermore, automatic liquidation mechanisms can amplify shocks and instability (Aramonte et al., 2021).

[2] For example, the auction mechanism of defichain.com imposes the initial bid to be 5% higher than the start value, while subsequent bids have to be at least 1% higher.

[3] For more details, see https://docs.makerdao.com/keepers/the-auctions-of-the-maker-protocol.

(2) For large loans (or, in this case, vaults), vaults are not liquidated at once, but by "lots", because partial liquidations make auctions more flexible and less likely to impact the base collateral price by creating a single large liquidation transaction. If the amount of the vault is inferior to a pre-specified lot size of the auction, a single auction for collateral in the vault is organized.

(3) A liquidator starts the auction. The first bidder can bid any amount of Dai (the native stablecoin of the Maker protocol) to acquire the collateral amount.

(4) Interested liquidators provide their bids. Bid amounts increase by a percentage with each new bid (the "beg" function). For example, when the beg is set at 3%, if the current bidder has placed a bid of 100 Dai, the next bid must be at least 103 Dai, and so forth. The purpose of the bid increment system is to incentivize early bidding and make the auction process move quickly.

(5) Depending on the risk parameters of the auction, the auction ends when the bid duration (that is, the time between two bids, usually 6 hours) or the auction duration (usually 24 hours) has been reached. The auction expiration and bid expiration parameters depends on the specific type of collateral, where more liquid collateral types have shorter expiration times.

(6) Once the auction is over, a swap happens whereby the winning bidder pays the bid in Dai to obtain the collateral.

The main limit of this type of auction is that the winning bidder's capital is locked until it is outbid or until the auction terminates. This lock-up period exposed bidders to risks of price volatility and opportunity costs. To mitigate these limitations, the Maker protocol liquidation mechanism adopted in 2021 a price-versus-time Dutch auction mechanism that settles instantly (Qin et al, 2021) [4]. Since bidder do not have to lock-up their funds during the auction period, instant settlement does not require capital for bidders (excepting gas fees) and can be financed by flash loans. The main drawback is that there is less incentive to quickly liquidate vaults than in the previous auction mechanism, especially for risky assets. To mitigate this risk and incentivize early bid, an incentive mechanism was added for liquidators, with a constant amount of Dai plus an amount of Dai that scales linearly with the amount of debt to be liquidated.

c. *Reserves*

[4] The proposal to redesign the liquidation system has been made in June 2020 (https://forum.makerdao.com/t/a-liquidation-system-redesign-a-pre-mip-discussion/2790/1).

Reserves are the last risk management tool of most DeFi lending platforms. The basic idea is that the borrow interest rates paid are distributed as yield for liquidity providers, minus a share of yields sent to a reserve account to promote the platform's growth and stability. The collector contract is freely auditable. Assets have different reserve factor, depending on their risk level. When the DeFi platform is a decentralized autonomous organization, the share of yield distributed is updated periodically by users' votes.

All the risk management tools implemented by DeFi lending platforms (maximum LTV, liquidation threshold, liquidation penalty, reserve factor, and optimal utilization rate) depend on the risk level of the borrowed asset. The table below illustrates the risk management parameters of Aave for five cryptocurrencies (ranked by total supply at the time of writing):

	Maximum LTV (%)	**Liquidation threshold (%)**	**Liquidation penalty (%)**	**Reserve factor (%)**	**Optimal utilization rate (%)**
Ethereum	80,50	83	5	15	90
Wrapped BTC	73	78	5	20	45
USDC & USDT	77	80	4,5	10	90
Chainlink	53	68	7	20	45
Balancer	57	62	8,3	20	80

3. Liquidation cascades and the limits of DeFi's risk management

DeFi lending is a self-referential crypto-to-crypto system, where loans of cryptocurrencies (mostly stablecoins) are collateralized by volatile cryptocurrencies. To align lenders and borrowers' incentives and manage risks of default, DeFi lending platform require lenders to pledge collateral in cryptocurrencies. However, even though overcollateralization mitigates information asymmetries, it fosters procyclicality. In boom periods and bull runs, appreciating prices increase the value of collateral and relax borrowing constraints. This expands loan volumes that, in turn, further feeds price appreciation and loan volumes. In other words, bull markets favor leverage. Even though similar dynamics between appreciating value of collateral (say, real estate, treasury bills or stocks) and global indebtment occur in traditional financial circuits, the interaction is not as tight as in DeFi but is mediated by transactions between different asset classes and financial intermediaries, such as banks. On the other hand, in bust periods and bear markets, the value of the cryptocurrencies pledged as collateral may sharply decline and automatically trigger massive waves of liquidation and price-liquidity feedback loops that further put downward pressure on the valuation of the liquidated cryptocurrencies. Furthermore, it is likely that massive waves of liquidation happen in times of market volatility and high transaction volumes when gas fees are higher than usual, and liquidity of risky assets decreases. In this situation, liquidators are not incentivized to buy a volatile collateral with high transaction costs and low market liquidity. Other works point out that rehypothecation magnifies risks of procyclicality (Cornelli et al., 2024). As Aramonte et al (2022: pp. 3-4) argue,

> ‘Procyclicality is further amplified when borrowed cryptoassets are used as collateral for additional loans (akin to rehypothecation), giving rise to “collateral chains”. For example, a borrower can post $100 in crypto collateral to borrow $80 of stablecoins, and then use the stablecoins to borrow $60 of another cryptoasset when a trading opportunity arises. For a given stock of collateral, the total amount of lending that can occur is inversely related to collateralization rates, so lower collateralization rates increase the “monetary multiplier”’.

Accordingly, because DeFi is a self-referential system, valuation/indebtment dynamics and toxic liquidation spirals are unavoidable. In the absence of financial intermediation and shock-absorbing capacity, it is argued, market risks and default risks are not disconnected, but interrelated and magnified.

a. Liquidation design and incentive schemes

Warmuz et al. (2022) specifically point to the inappropriate design of liquidation procedures to explain “toxic liquidation spirals” and liquidation cascade (see also Tovanich et al 2023). They argue that DeFi lending platforms suffer from a fundamental flaw in the liquidation logic that causes toxic liquidation spirals (see also Cohen et al, 2023). They propose to modify the incentives driving liquidation, with the introduction of dynamic liquidation incentives and closing factor policies, with the idea that progressively larger portions of a user’s portfolio should be allowed to be closed as the user’s portfolio comes progressively closer to becoming undercollateralized. This new incentive scheme would halt sudden massive liquidation processes and prevent toxic liquidation spirals when high risks of liquidation cascades appear. However, it introduces major complexities that may discourage the entry of inexperienced liquidators and give rise to an oligopolistic market of liquidation detrimental to price discovery.

Chiu et al (2023) also point to the inherent instability of DeFi lending in a complex model of dynamic price-liquidity feedback loop. Assuming asymmetric information about the collateralized asset's future payoff between lenders and borrowers (assuming that borrowers have more information about the future payoff of the pledged asset than all other market participants), the authors argue that the market outcome in any given period depends on agents' expectations about lending activities in future periods. Because of the deterministic aspect of smart contracts, higher future price expectation leads to more lending and higher price today, that in turn leads to multiple self-fulfilling equilibria. Accordingly, DeFi lending volumes and asset prices can co-move according to non-fundamental market sentiments. In line with the previous criticism of smart contracts' inflexibility and automaticity, they further argue that flexible updates of smart contracts can restore equilibrium uniqueness and ensure a liquidity backstop. However, if stability requires flexible and state-contingent smart contracts, the main issue is then about knowing whether smart contracts can be pre-programmed to replicate the flexible contract design:

> 'The rigid haircut rule imposed by the DeFi smart contract generates financial instability in the form of multiple equilibria, and potential sentiment driven equilibria, and lowers welfare. Can a DeFi smart contract be pre-programmed to replicate the flexible contract design? This can be challenging in practice. First, flexible contract cannot be implementing using simple linear haircut rules that are typically encoded in DeFi contracts. Second, the optimal debt threshold depends on information that may not be readily available on-chain. Alternatively, the lending protocol can replace the algorithm by a human risk manager who can adjust risk parameters in real time according to the latest information. Relying fully on a trusted third party, however, can be controversial for a DeFi protocol' (Chiu et al., 2023: p. 30).

In other words, smart contracts should be more complex and dynamically managed by a centralized third-party to be more flexible *ex post*. That is, smart contracts should not be simple, transparent, automatic, and decentralized. Stated differently, the major issue for financial services powered by smart contracts is smart contracts themselves.

b. *Real-World Assets*

Along with the issue of automaticity of liquidation mechanisms, other proposals to mitigate systemic risks in crypto-lending point to the volatility of the assets pledged as collateral. Both Chiu et al (2023) and Aramonte et al (2022) mention the tokenization of real-world assets (such as government-issued securities) to be pledged as collateral as a way out. Both argue that pledging a non-crypto class of asset (either financial or real) as collateral would mitigate the self-referential characteristics of DeFi lending and risks of liquidation spirals:

> ‘DeFi lending must engage in large-scale tokenization of real-world assets, unless it wants to remain a self-referential system fueled by speculation. Representing assets such as buildings or capital equipment on the blockchain, so that it can serve as collateral underpinning loans would be particularly beneficial for SMEs, which have more limited access to finance’.

Bibliography

Aghion Philippe & Bolton Patrick, 1992, An incomplete contracts approach to financial contracting, *The Review of Economic Studies*, Vol. 59, No. 3, pp. 473-494.

Aramonte Sirio, Huang Wenqian & Schrimpf Andreas, 2021, DeFi risks and the decentralisation illusion, *BIS Quarterly Review*, December.

Aramonte Sirio, Doerr Sebastien, Huang Wenqian & Schrimpf Andreas, 2022, DeFi lending: intermediation without information?, *BIS Bulletin*, No. 57.

Beck Thorsten, Degryse Hans, de Haas Ralph & von Horen Neeltje, 2018, When arm's length is too far: Relationship banking over the credit cycle, *Journal of Financial Economics*, Vol. 127, No. 1, pp. 174-196.

Benmelech Efraim, Kumar Nitish & Rajan Raghuram, 2024, The decline of secured debt, *The Journal of Finance*, Vol. 79, No. 1.

Berger Allen, Espinosa-Vega Marco, Frame Scott & Miller Nathan, 2011, Why do borrowers pledge collateral? New empirical evidence on the role of asymmetric information, *Journal of Financial Intermediation*, Vol. 20, No. 1, pp. 55-70.

Bolton Patrick, Freixas Xavier, Gambacorta Leonardo & Mistrulli Paolo Emilio, 2016, Relationship and transaction lending in a crisis, *The Review of Financial Studies*, Vol. 29, No. 10, pp. 2643-2676.

Boot Arnoud, 2000, Relationship banking: What do we know?, *Journal of Financial Intermediation*, Vol. 9, No. 1, pp. 7-25.

Cerqueiro Geraldo, Ongena Steven & Roszbach Kasper, 2016, Collateralization, bank loan rates, and monitoring, *The Journal of Finance*, Vol. 71, No. 3, pp. 1295-1322.

Chiu Jonathan, Ozdenoren Emre, Yuan Kathy & Zhang Shengxing, 2023, On the fragility of DeFi lending, https://personal.lse.ac.uk/yuan/papers/defi.pdf.

Coco Giuseppe, 2000, On the use of collateral, *Journal of Economic Surveys*, Vol. 14, No. 2, pp. 191-214.

Cohen Samuel, Sabate-Vidales Marc, Szpruch Lukasz & Delaunay Gontier Mathis, 2023, The paradox of adversarial liquidation in decentralised lending, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4540333.

Cornelli Giulio, Gambacorta Leonardo, Garratt Rodney & Reghezza Alessio, 2024, Why DeFi lending? Evidence from Aave v2, *BIS Working Paper*, No. 1183.

Darlin Michael, Papadis Nikolaos & Tassiulas Leandros, 2021, Optimal bidding strategy for Maker auctions, https://arxiv.org/pdf/2009.07086.pdf.

Dell'Arriccia Giovanni & Marquez Robert, 2006, Lending booms and lending standards, *The Journal of Finance*, Vol. 61, No. 5, pp. 2511-2546.

Diamond Douglas, 1984, Financial intermediation and delegated monitoring, *The Review of Economic Studies*, Vol. 51, No. 3, pp. 393-414.

Diamond Douglas, 1996, Financial intermediation as delegated monitoring: A simple example, *Federal Reserve Bank of Richmond Economic Quarterly*, Vol. 82, No. 3, pp. 51-66.

Frost Carol Ann, 2007, Credit rating agencies in capital markets: A review of research evidence on selected criticisms of the agencies, *Journal of Accounting, Auditing & Finance*, Vol. 22, No. 3, pp. 469-492.

Gambarcorta Leonardo, Huang Yiping, Li Zhenhua, Qiu Han & Chen Shu, 2023, Data versus collateral, *Review of Finance*, Vol. 27, No. 2, pp. 369-398.

Gauntlet Research Report, 2021, *Market Risk Assessment – An Analysis of the Financial Risk to Participants in the Aave Protocol*, https://www.gauntlet.xyz/resources/aave-market-risk-assessment.

Haubrich Joseph, 1989, Financial intermediation: Delegated monitoring and long-term relationships, *Journal of Banking & Finance*, Vol. 13, No. 1, pp. 9-20.

Holmström Bengt & Tirole Jean, 1997, Financial intermediation, loanable funds, and the real sector, *The Quarterly Journal of Economics*, Vol. 112, No. 3, pp. 663-691.

Jimenez Gabriel & Saurina Jesus, 2004, Collateral, type of lender and relationship banking as determinants of credit risk, *Journal of Banking & Finance*, Vol. 28, No. 9, pp. 2191-2212.

Manove Michael, Padilla Jorge & Pagano Marco, 2001, Collateral versus project screening: A model of lazy banks, *RAND Journal of Economics*, Vol. 32, No. 4, pp. 726-744.

Qin Kaihua, Zhou Liyi, Gamito Pablo, Jovanovic Philipp & Gervais Arthur, 2021, An empirical study of DeFi liquidations: incentives, risks, and instabilities, https://arxiv.org/pdf/2106.06389&ved=2ahUKEwiT4d_A-sjxAhW4wAIHHeb8D6UQFnoECCoQAQ&usg=AOvVaw35XC11xAX-0KX-SoTRlVf1.pdf.

Rubinstein Ariel & Wolinksy Asher, 1987, Middlemen, *The Quarterly Journal of Economics*, Vol. 102, No. 3, pp. 581-593.

Ruckes Martin, 2004, Bank competition and credit standards, *The Review of Financial Studies*, Vol. 17, No. 4, pp. 1073-1102.

Scott Susan & Zachariadis Markos, 2012, Origins and development of SWIFT, 1973-2009, *Business History*, Vol. 54, No. 3, pp. 462-482.

Saengchote Kanis, 2023, Decentralised lending and its users: Insights from Compound, *Journal of International Financial Markets, Institutions and Money*, Vol. 87, Article 101807.

Steijvers Tensie & Voordeckers Wim, 2009, Collateral and credit rationing: A review of recent empirical studies as a guide for future research, *Journal of Economic Surveys*, Vol. 23, No. 5, pp. 924-946.

Thomas Lyn, 2000, A survey of credit and behavioural scoring: Forecasting financial risk of lending to consumers, *International Journal of Forecasting*, Vol. 16, No. 2, pp. 149-172.

Tovanich Natkamon, Kassoul Myriam, Weidenholzer Simon & Prat Julien, 2023, Contagion in decentralized lending protocols: A case study of Compound, https://hal.science/hal-04221228/document.

Warmuz Jakub, Chaudhary Amit & Pinna Daniele, 2023, Toxic liquidation spirals, https://arxiv.org/abs/2212.07306.

White Lawrence, 2009, The credit-rating agencies and the subprime debacle, *Critical Review*, Vol. 21, Issue 2-3, pp. 389-399.

White Lawrence, 2010, The credit rating agencies, *Journal of Economic Perspectives*, Vol. 24, No. 2, pp. 211-226.

White Lawrence, 2013, Credit rating agencies: An overview, *Annual Review of Financial Economics*, Vol. 5, pp. 93-122.