On the Inherent Fragility of DeFi Lending

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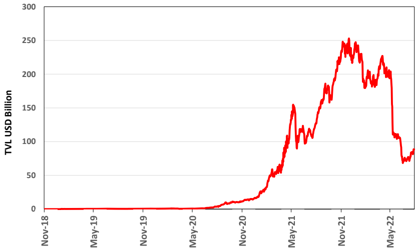
Motivation

- Tremendous growth in **De**centralized **Fi**nance
  - aims to use smart contracts to provide financial services without traditional intermediaries.



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- A major DeFi component is **Defi lending**
  - e.g., Aave, Compound, Venus
- Policy makers concern about their **financial stability implications** (BIS 2022; IOSCO 2022).
  - e.g., Aave loans 27 times more volatile than bank loans
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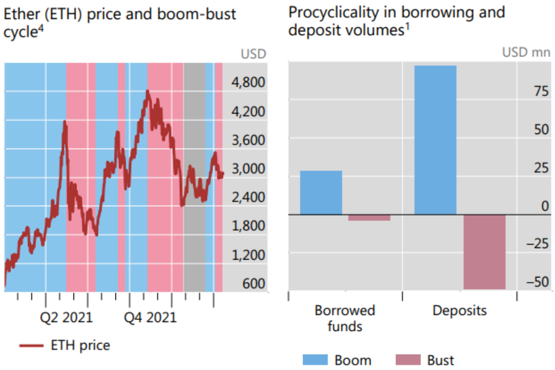
- BIS report (2022): DeFi lending is **procyclical**, amplifying boom-bust cycles.



Sources: CryptoCompare; Dune, @echolon166; @zkmark; authors' calculations.

Questions

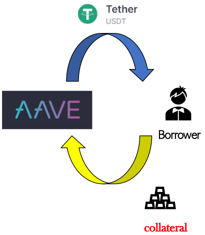
1. What is special about DeFi lending?
2. Are there inherent limitations to DeFi that leads to fragility?
3. What are the implications for crypto price dynamics?

Special Features of DeFi Lending

	TradFi	DeFi
Regulations	Reserve, liquidity, capital requirements, etc.	None
Borrower	Identified	Anonymous
Collateral	Standard assets	Crypto assets
Intermediary	Trusted human actors	Pre-programmed smart contracts

Special Features of DeFi Lending

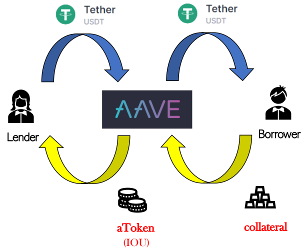
- Linear, non-recourse **debt contracts**
  - rely on over-collateralization (i.e., collateral haircuts)



Special Features of DeFi Lending

Rigid contract terms:

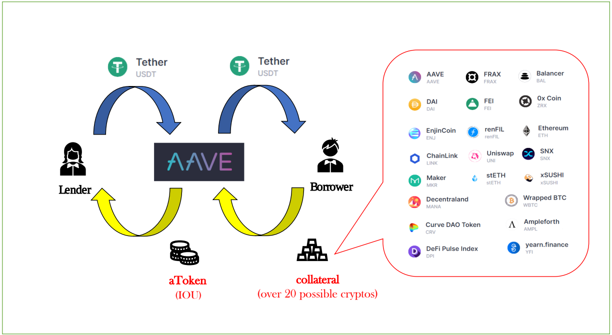
- pre-programmed contractual terms
- infrequent updates due to decentralized governance



Special Features of DeFi Lending

Information Frictions

- Lenders cannot control the underlying **collateral mix**.



Special Features of DeFi Lending

Information Frictions

- Lenders cannot control the underlying **collateral mix** with **opaque assets**.
- Borrowers have **unobservable private valuations**.
- Borrowers and lenders have **asymmetric incentives** to spend effort acquiring information about the collateral pledged (e.g., monitor new information, conduct data analytics)
- Smart lending contracts rely on **price feeds**
  - Contracts respond to the feed even when the price changes are non-fundamental/noise based

Literature

- **General Overview**
  - Schar (2021), Harvey et al. (2021) ...
- **Decentralized exchanges**
  - Aoyagi & Ito (2021), Barbon & Ranaldo (2022), Capponi & Jia (2021), Lehar & Parlour (2021), Park (2021) ...
- **Decentralized stablecoins**
  - Li & Mayer (2021), Kozhan & Viswanath-Natraj (2021), d'Avernas, Bourany & Vandeweyer (2021) ...
- **Decentralized lending protocols**
  - This paper: a dynamic model of Defi lending & crypto pricing

Agents

- Two types of agents
  - borrower owns one unit of a risky crypto asset
  - lender provides funding
- Gain from trading funding:
  - borrower's MV $= z > 1 =$ lender's MV
- ... but agents cannot commit to future repayment
- Smart contract (Chiu, Kahn & Koeppl, 2022)
  - Loan is collateralized on crypto asset
  - Collateral is locked until repayment
  - Contract is pre-programmed (no incentive problems)

Assets and Asymmetric Info

- Crypto assets
  - pays dividend δ
  - post-dividend price of crypto asset is ϕ at end of period
- Asymmetric info: Borrower privately observes asset quality before loan decision
  - **H**-quality (w.p. $1-\lambda$): $\delta_H = \delta$, survival prob is $s_H = 1$
  - **L**-quality (w.p. λ): $\delta_L = 0$, survival prob is $s_L \sim F$

Smart Contract

- Smart contract (R, D)
- Debt limit per unit of collateral given by $D \equiv (\phi + \delta)(1 - h)$ where h is the haircut.
    - haircut is pre-determined by the lending protocol and rigid
    - gross loan rate R: if the borrower borrows ℓ_t units of funding, the face value of debt is $R_t \ell_t$.

Borrowers

- Given (R_t, D_t), a type $i = H, L$ borrower chooses collateral a_t to pledge and loan ℓ_t to borrow from the DeFi pool.
    - Borrower either repays or loses the collateral
- Borrowers problem is:

$$\max_{a_t, \ell_t} z\ell_t - \mathbb{E}\min\{\ell_t R_t, a_t(\delta_i + s_i\phi_t)\}$$

subject to a collateral constraint

$$\ell_t R_t \leq a_t D_t.$$

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Borrowers

- Collateral constraint is binding so borrower chooses a_i to max:

$$a_i[zD_t/R_t - \mathbb{E}\min\{D_t, \delta_i + s_i\phi_t\}]$$

- Note $a_t \in \{0,1\}$and $a_L \geq a_H$ (since $\delta_H > \delta_L$ and $s_H > s_L$) and low-type borrows (weakly) more.
- When both types borrow pooling, when only low type borrows separating.

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Lenders

- Lenders break even $\Rightarrow$ funding size q_t satisfies:

$$\sum_i \frac{a_{i,t}\lambda_i}{\sum_i a_{i,t}\lambda_i}\mathbb{E}\min\{D_t, \delta_i + s_i\phi_t\} - q_t - fq_t = 0$$

  where f is fee charged by the protocol per unit of funding.
- In equilibrium funding supply and demand are equal: $\ell_t = q_t$.

Loan Rate and Asset Price

- Platform chooses R_t given ϕ_t and h to max $f[\lambda \ell_{Lt} + (1-\lambda)\ell_{Ht}]$ s.t.
  - borrowers choose loan size optimally
  - lenders make zero profit.
- Asset price is given by the discounted continuation value of the asset:

$$\phi_t = \beta \sum \lambda_i \left(\underbrace{zq_{t+1} - a_{i,t+1}\mathbb{E}_i \min\{D_{t+1}, \delta_i + s_i\phi_{t+1}\}}_{\text{Collateral Value}} \right) + \beta \sum \lambda_i a_{i,t+1} \underbrace{\mathbb{E}_i(\delta_i + s_i \phi_{t+1})}_{\text{Fundamental Value}}$$

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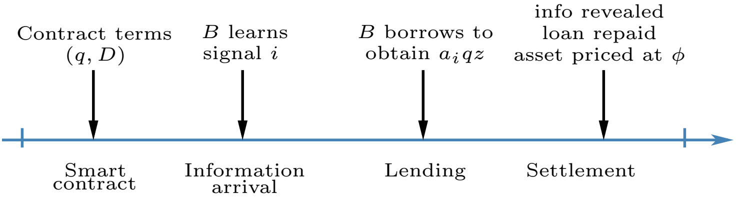
Equilibrium

Given haircut h and fee f, an equilibrium consists of asset prices $\{\phi_{t,}\}_{t=0}^{\infty}$, debt thresholds $\{D_t\}_{t=0}^{\infty}$, loan rates $\{R_t\}_{t=0}^{\infty}$, funding size $\{q_t\}_{t=0}^{\infty}$ and collateral quantities $\{a_{Lt}, a_{Ht}\}_{t=0}^{\infty}$ such that

1. debt thresholds are given by $D_t = (\phi_t + \delta)(1 - h)$
2. borrowers' loan decisions are optimal
3. lenders earn zero profits
4. R_t solves intermediary's problem
5. the asset pricing equation is satisfied

Timeline



Contract terms (q, D)
B learns signal i
B borrows to obtain $a_i qz$
info revealed
loan repaid
asset priced at ϕ
Smart contract
Information arrival
Lending
Settlement

Adverse Selection in Lending

- Under pooling funding size is:

$$q(1+f) = \lambda \mathbb{E}_L \min\{D, s_L \phi\} + (1-\lambda) D$$

- H borrows iff

$$z\lambda \mathbb{E}_L \min\{D, s_L \phi\} + z(1-\lambda) D \geq (1+f) D \Rightarrow$$

$$\zeta(h, \phi_t) \equiv \frac{\mathbb{E}_L \min\{D_t, \delta_L + s_L \phi\}}{\mathbb{E}_H \min\{D_t, \delta_H + s_H \phi\}} \geq 1 - \frac{z-1-f}{z\lambda} \equiv \bar{\zeta}$$

- Pooling can be supported when the debt contract is sufficiently info insensitive ($\zeta \uparrow$), which requires
  - high ϕ
  - high h (or low D)

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Adverse Selection in Lending

Prop.: Given ϕ and h there is a unique equilibrium in DeFi lending:

- Info sensitive: $\zeta(h,\phi) < \bar{\zeta} \equiv 1 - \frac{z-1-f}{z\lambda}$ $\Rightarrow$ **separating**
  - $a_L = 1$ and $a_H = 0$
  - $q^S = \mathbb{E}\min\{D_t, \delta_L + s_L\phi\}$
- Info insensitive: $\zeta(h,\phi) > \bar{\zeta}$ $\Rightarrow$ **pooling**
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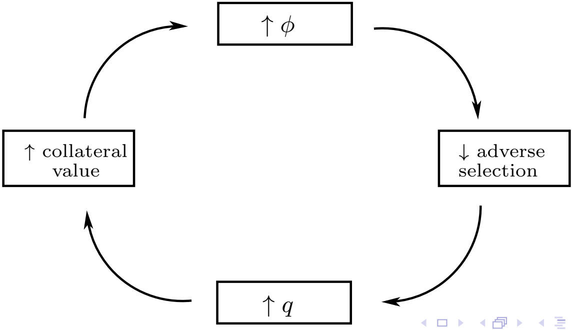
Implication 1: Multiple Equilibria under Rigidity

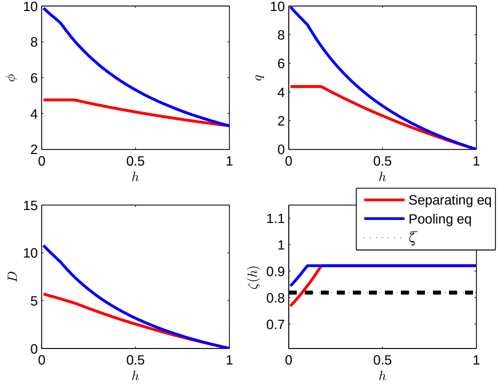
Prop. Fix h. Stationary pooling and separating equilibria can co-exist when h is not too high.

$$\phi = \beta \left[\underbrace{\mathbb{E}(\delta_i + s_i \phi)}_{\text{fundamental}} + \sum_i \underbrace{\lambda_i a_i [zq - D + \Delta_i(\phi)]}_{\text{collateral value}} \right]$$



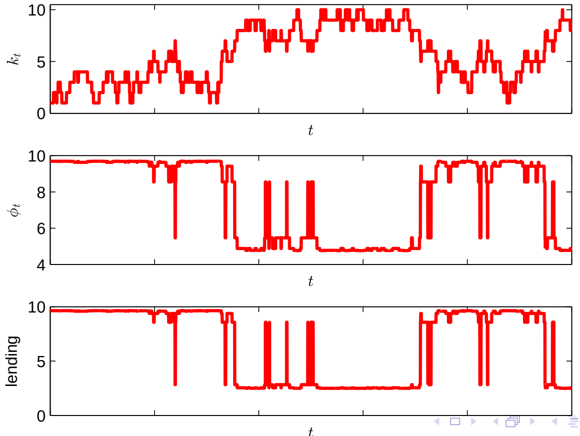
Multiple Equilibria: Example

- Suppose $s_L = 1$ with probability π, and $s_L = 0$ with probability $1 - \pi$.



Implication 2: Sentiment Equilibrium & Procyclicity

There exists **sentiment equilibria** where crypto prices and lending co-move according to a non-fundamental sunspot state variable $k_t \in \{1, 2, ..., K\}$.



Implication 3: Flexible Contract Terms

Instead of pre-setting the haircut h in the smart contract, suppose the lending platform can adjust D_t (or h_t) each period.

Prop. Optimal state-dependent debt limit increases surplus from lending and eliminates multiplicity & sentiment-driven cycles.

- Suppose there are multiple equilibria.
- Separating will not survive setting flexible haircut!

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Implication 3: Flexible Contract Terms

- Suppose equilibrium is separating and asset price is low.
- Platform sets low D_t to induce pooling $\Rightarrow$ higher price $\Rightarrow$ higher D_t $\Rightarrow$ more lending $\Rightarrow$ higher price so on...
- Leads to selecting pooling equilibrium uniquely.
- With sentiments:
  - bad sentiment: set low D_t to induce pooling
  - good sentiment: set high D_t to maximize the trade surplus
- Highlight the importance of flexible contract terms for efficiency and stability.

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Implication 3: Flexible Contract

- ... but optimal flexible haircuts maybe hard to implement with a smart contract
  - not a simple linear haircut rule
  - can depend on off-chain info
  - frequent updates are difficult under decentralized governance
  - difficult to enforce additional collateral requirements and costly to add collateral

Example: Optimal flexible haircut

In a two-point-distribution example (i.e., $s_L \in \{0, 1\}$), the optimal haircut

$$h_t^* = \begin{cases} 0 & , \text{ if } \pi < \bar{\zeta}, \\ \max\left\{1 - \frac{\pi \phi_t}{\bar{\zeta}(\delta + \phi_t)}, 0\right\} & , \text{ if } \pi \geq \bar{\zeta}, \end{cases}$$

where $\bar{\zeta} = 1 - \frac{z - 1 - f}{z\lambda}$, and $\pi = \Pr(s_L = 1)$.

Conclusion

- Developed a dynamic model of Defi lending:
  - Defi lending can increase both crypto price and its volatility
  - ... also lead to sentiment-driven fluctuations
- Highlighted the difficulty to achieve stability and efficiency in a decentralized environment:
  - high haircut: sacrifice efficiency
  - low haircut: introduce instability
- To improve stability & efficiency, it may be necessary to give up certain degree of decentralization in DeFi.