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Where do DeFi stablecoins go? A closer look at what DeFi composability really means

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ABSTRACT

One of the benefits of decentralized finance (DeFi) – an alternative financial system built on blockchain – is composability, which means the system's building blocks (tokens) can freely interact with one another to form new services. One example is stablecoin, a token with fixed exchange rate, which is backed by token collaterals. While stablecoins can be used to facilitate payments and exchanges, in DeFi they can be used to earn returns ("yield farming"), potentially multiplicatively. We use transaction-level blockchain data to analyze a stablecoin's flows between protocols and provide suggestive evidence of DeFi yield-chasing behavior. We shed light on what DeFi total value locked might really measure and highlight the complexity in DeFi analysis and market surveillance.

Key words: DeFi, stablecoin, total value locked, yield farming, systemic risk

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1. Introduction

Stablecoins are blockchain-based tokens whose values are pegged to low volatility assets such as US dollars. While cryptocurrencies have experienced explosive growth in late 2010s (Bouri et al., 2019), their prices have been highly volatile, with Bitcoin volatility as high as 10 times those of national currencies (Yermack, 2015). The popularity of stablecoins is said to be related to cryptocurrency growth, as Lyons and Viswanath-Natraj (2020) argue that they (1) reduce trading costs for cryptocurrencies relative to using dollar, and (2) provide on-ramp (access) to venues that restrict acceptance of national currencies such as Binance.

There are many ways of issuing a stablecoin. Generally, users who want stablecoins would send the issuer specific assets which would then be exchanged for the pre-determined amount of stablecoins. The issuer then stands ready to redeem ("burn") the stablecoins for the assets. In its simplest form, the assets could be US dollars of equivalent value, making it backed one-for-one with "safe assets", which is the definition in Gorton and Zhang (2021). The two largest stablecoins are minted in this way, with Tether (USDT) – one of the first stablecoins – commanding market capitalization of $62 billion as of July 2021 is, followed by USD Coin (USDC) with market capitalization of $26.8 billion.[1] The assets could be specific cryptocurrencies (such as Ether – ETH) and minted as interest-bearing fixed-value debt instead (hence the pledged assets become collateral to be reclaimed when the stablecoins are redeemed). Dai (DAI) is one such example, with market capitalization of $5.5 billion. Or the assets could be a basket of cryptocurrencies, some of which could be issued by the stablecoin issuer themselves without any explicit collateral. Such stablecoins are often referred to as algorithmic stablecoins. Saengchote (2021) provides details of how Iron Finance – an algorithmic stablecoin protocol on the Polygon blockchain – works and its "bank run" experience.

While they are supposed to make cryptocurrencies more stable and facilitate payments and exchanges, stablecoins have experienced mixed receptions from regulators. For example, Facebook's initial attempt to launch Libra – its global stablecoin – had been met with resistances. Current regulatory concerns generally evince in two forms: first, stablecoins are private money and their issuers are banks, thus they are vulnerable to runs (Gorton and Zhang, 2021; Li and

[1] There are other stablecoins created in the same way, such as TrueUSD (TUSD) and Paxos Standard (PAX), but they pale in comparison to USDT and USDC, with market capitalization of $1.3 billion and $0.9 billion respectively (Source: CoinMarketCap, as of July 21, 2021).

Mayer, 2021); and second, they could be used to conduct shadow banking activities (e.g. to pump Bitcoin price, as suspected by Griffin and Shams, 2020).[2] Both concerns rest on the premise that stablecoin issuers are unregulated bank and could pose systemic risk to the financial system. In this study, our objective is to demonstrate another potential source of systematic risk which is related to what is now commonly known as decentralized finance (DeFi) through the journeys of a stablecoin.

From 2020, DeFi carries a very a specific meaning: it refers to an alternative financial system built on a public blockchain-based infrastructure that promises openness, efficiency, transparency, interoperability, and decentralization (for example, Harvey et al., 2021; Schär, 2021).[3] In smart contract-enabled blockchains, cryptocurrencies (we refer to them generally as tokens) can become "programmable money" embedded with algorithms that are connected together as a "protocol" that can replicate traditional financial services such as lending, exchange, and asset management.[4] In this world, tokens are smart contracts, and the system is built on a collection of tokens which can interact with one another to form a network across multiple protocols without the need to ask for each other's permission. This interoperability is often referred to as "composability", and DeFi tokens as "Lego money" for this reason. To operate these smart contracts, users are required to deposit tokens, whose values are referred to as total value locked (TVL), a metric often used to measure size. DeFi TVL has grown from $1 billion in early June 2020 to almost $90 billion in mid-May 2021.[5]

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[2] The shadow banking activity concern rests mainly with USDT, not only because of its size, but how because how USDT is minted. While other stablecoins tend to be minted on demand, USDT tends to be minted in lumps of round numbers. We analyze Ethereum blockchain data (USDT is present on multiple blockchains, and USDT minted on Ethereum is approximately $30.5 billion, representing around 50% of its market capitalization) and find that USDT has only been issued 144 times, with median issuance size of $120 million and max of $3 billion, all of which are issued to Bitfinex, an exchange that have common owners as Tether. USDC's median mint size is $80,000, and microtransaction with fractions of dollars exist. Griffin and Shams (2020) find "one large player on Bitfinex uses Tether to purchase large amounts of Bitcoin when prices are falling and following the printing of Tether. Such price supporting activities are successful as Bitcoin prices rise following the periods of intervention." Other authors, e.g. Ante et al. (2021), find mixed evidence that stablecoin issuances are related to cryptocurrency prices.

[3] Recent research (Gryglewicz et al., 2021; Cong et al., 2021b) has shed light on the attractiveness of tokens for means of payments and fundraising for platform businesses arising from the flexible nature of the tokens, but the key attribute that we want to focus on in this study is composability.

[4] There are many smart contract-enabled blockchains, such as Ethereum, Binance, Polygon and Cardano. Ethereum was launched in 2015 and is one of the earliest, making it still the most popular blockchain for DeFi applications.

[5] Source: https://defipulse.com/, accessed on July 24, 2021. TVL is calculated as the market value of tokens deposited/locked in the system, so it is highly dependent on token prices.

In this article, we use high-frequency, transaction-level blockchain data of DAI (stablecoin of the MakerDAO protocol) transactions and network analysis to illustrate the its with other protocols.[6] We show how stablecoins are used in DeFi other than for payments and exchanges, and document tokens flow patterns consistent with a "DeFi yield-chasing" behavior. We also provide another perspective on what DeFi TVL might really measure when the system is built on interoperability – and potential risks it may carry. We caution the readers that this study is an early attempt at understanding the workings of the DeFi system using detailed, transaction-level level data, and further studies are required to draw a conclusion on this issue.

2. Data and Empirical Methodology

The Ethereum blockchain data used in this article is obtained from Google BigQuery, which is hosted and listed Google Cloud Marketplace. We retrieve DAI transactions between June 2020 and June 2021, covering over 8 million transactions between 982,042 unique addresses. Owners of smart contracts typically identify themselves and provide their source codes for community audit on websites such as Etherscan.io, but this is not mandatory, and many smart contracts are intelligible to a human reader. While the content of blockchain is transparent for all to see, to an observer, all she sees is binary data that cannot be reverse engineered to any specific programming language. By manually inspecting the content of each address, one can classify whether it is part of a DeFi protocol, a generic smart contract, or a wallet. For example, the address '0x2a1530c4c41db0b0b2bb646cb5eb1a67b7158667' is the swap pool for DAI/ETH token pair of Uniswap (a decentralized token exchange protocol).[7]

We manually inspect the top 100 sources and targets in terms of both token amount and frequency of transactions and classify them by type into 9 categories: (1) DAI mint/burn address, (2) Compound protocol, (3) Aave protocol, (4) yield aggregator protocols, (5) asset management protocols, (6) decentralized exchange (DEX) protocols, (7) other smart contracts, (8) on-ramp

[6] DAI is a stablecoin of MakerDAO, an Ethereum-based protocol identified by most as a lending protocol as it involves depositing accepted tokens whose value act as collateral for DAI stablecoins, which are minted via a borrowing transaction. Kozhan and Viswanath-Natraj (2021) provide a detailed analysis of how the protocol works. Readers may wonder why users would be willing to pay interest to have access to stablecoins. There are three main reasons: first, the user may not want to sell the token collateral (e.g. they would rather hold indefinitely or they do not want to incur taxable income); second, other stablecoins up to this point require users to trust the issuing entity who hold off-chain assets as collateral, making this non-DeFi (e.g. USDC, USDT); and third, minted DAI could be used to earn "income" that can exceed the cost of borrowing, making the transaction profitable. The third reason is "yield farming", which is the focus of this paper.

[7] While token transfers are easily identifiable in the blockchain data, the reasons behind the transfers are much more difficult to discern without technical knowledge. This is an important limitation of our study.

service providers, (9) wallets. Details of how we define these protocols are provided in the Appendix. We explicitly identify Compound and Aave because (like MakerDAO) they are the early pioneers of DeFi that launched in 2017-2018 and have consistently been the top protocols in terms of TVL and therefore are more likely to be connected to other protocols. We exclude other smart contracts (which comprise less popular protocols such as derivatives, and smart contracts that do not identify themselves or provide legible codes), on-ramp service providers and wallets as the objective is to investigate protocol-level interactions.[8]

The analyses are conducted at daily frequency. For each day beginning at midnight of Coordinated Universal Time (UTC), we aggregate token flows to and from address types and analyze the relationship between token flows and their determinants. Popular destinations are identified by the relationship between minted DAI and token flows to a protocol represented by β_k for each protocol type k – the higher the coefficient, the more popular. Because DAI is collateralized by other token, we include price levels and one-day return (measured in percentage points) of ETH as control variables in all regressions.[9]

$$\log\left(Flow_{k,t}\right) = \alpha_k + \beta_k \log(Mint_t) + \gamma_k X_k + \varepsilon_{k,t}$$

Generally, protocols require users to deposit their tokens into a contract as a starting point. For example, when DAI is deposited into Compound's cDAI contract, it could be lent out to borrowers and the depositor would receive a "wrapped" cDAI in return as "depository receipts" that effectively allows Compound to pay interest on DAI deposits; when sent to Aave, depositor would receive a aDAI as receipt.[10] Panel A of Exhibit 1 presents the summary statistics of token

[8] Blockchain data shows that DAI is also used widely for transfers and payments. The average daily value of inter-wallets transfers during the sample is 121.2 million (5,551 transactions), reaching as high as 1,039 million on May 19, 2021 (on that day, cryptocurrencies prices collapsed, with ETH dropping over 40% in 24 hours).

[9] As of July 2021, DAI is mostly collateralized by ETH (around 30%), USDC (around 60%) and wrapped Bitcoin (WBTC) (around 4%) (source: daistats.com). The ratios change overtime, but ETH has always been the most popular collateral. Also, ETH and BTC are highly correlated: the correlation coefficients between ETH and DAI prices are 0.86 and returns 0.74, so we only include ETH to avoid multicollinearity. The correlation between ETH price and ETH one-day return is -0.04.

[10] Wrapping is a term used to describe conversion of token issued by one blockchain to be usable on another. For example, owners of BTC on the Bitcoin blockchain would need to wrap their tokens into an equivalent WBTC to use on the Ethereum blockchain. In terms of blockchain reporting, there would be both BTC on the Bitcoin blockchain and WBTC on the Ethereum blockchain because the liability held by the protocol sponsor who facilitated the wrapping is not visible on blockchains. Originally, wrapping had been used to refer to cross-chain conversion, but it is also now used to refer to cross-protocol conversion. DAI is issued by MakerDAO, but by wrapping DAI into Compound's cDAI, Compound has authority over what do with cDAI, such as minting/burning or setting exchange rate between cDAI and DAI to effectively pay interest.

inflows and outflows from protocols, and the similar magnitudes corroborates the in-out nature of DeFi protocols. We also analyze the *net* flows into protocols, which present a different perspective and insights. The Figures in Exhibit 2 plot the time series flows of tokens. For Compound and Aave (which are collateralized lending protocols) the net flows were relatively flat until December 25, 2020 (marked as red vertical line), where flows became more volatile.[11]

A DeFi system is an interconnected network of smart contracts across multiple protocols (see Exhibit 3), so one can employ network statistics such as indegree and outdegree (numbers of incoming and outgoing links to a node) to identify connectedness. The sum of indegree and outdegree is called degree. Caballero (2015) and Bhattacharya et al. (2020) use this approach to analyze borrowing connections between global banks and finds that the level of integration is positively associated with a higher incidence of crises and higher credit risk. However, our application is closer to Caballero et al. (2018), who relate bank interconnectedness to trade flows. We calculate degrees and indegrees for each smart contract in each month, average them by protocol type, and them include them as additional regressors in both models.[12] The network statistics are reported in Exhibit 1 Panel B.

[11] That day is not associated with any announcement, but over $260 million worth of DAI was minted, $250 million of which went to the cDAI contract. While the 2020-2021 appreciation began in November, its pace picked up in mid- to late-December, particularly for ETH. Beginning January 2021, ETH price began to rise faster relative to BTC, likely driven by increased interest in DeFi.

[12] Because of the in-out nature of smart contracts, indegree and outdegree (and thus degree) are highly correlated. We report the correlation coefficients between degree and indegree in Exhibit 1 Panel B. Because of this high correlation, regression analyses are conducted separate for degree and indegree to avoid multicollinearity.

Exhibit 1: Summary statistics

Panel A reports the summary statistics of DAI token flows between June 1, 2020, and June 30, 2021, to and from Ethereum addresses classified by DeFi protocol type. Only flows to and from protocols are included; smart contracts which do not identify themselves, on-ramp service providers and private wallets are excluded. The frequency of data is daily, and units in millions of DAI tokens, which are pegged to $1. Panel B reports the summary statistics for how connected a smart contract (a node) is relative to those in the DAI network. Indegree (in) counts the number of smart contracts that send DAI *into* this node, while degree counts *both* the incoming and outgoing connections. Correlation coefficients between indegree and degree are also reported.

Panel A: Token flow statistics

	1. Mint/burn			2. Compound			3. Aave		
	Mint	Burn	Net	To	From	Net	To	From	Net
Mean	83.8	71.1	12.7	131.0	128.9	2.1	25.2	23.9	1.2
Std. Dev	107.1	113.9	45.7	226.9	228.0	37.9	45.2	41.3	10.0
Median	53.1	35.2	5.5	55.9	55.1	0.0	12.1	12.0	0.0
Max	1,106.4	1,108.9	243.3	1,981.7	1,941.3	236.6	497.3	435.9	65.4
Min	0.6	0.6	-436.3	0.1	0.1	-234.4	0.0	0.0	-44.5

	4. Yield Aggregator			5. Asset Management			6. Decentralized Exchange		
	To	From	Net	To	From	Net	To	From	Net
Mean	152.2	151.3	0.9	6.0	5.9	0.0	169.4	167.9	1.5
Std. Dev	1,676.8	1,676.8	17.7	13.8	13.3	10.4	320.1	323.0	33.9
Median	22.7	23.4	0.0	2.8	2.7	0.0	126.4	122.5	0.3
Max	33,325.3	33,324.1	253.7	207.9	187.8	101.0	5,859.8	5,846.6	270.8
Min	0.0	0.0	-95.1	0.0	0.0	-141.2	0.8	0.7	-354.5

Panel B: Protocol connectivity statistics

	2. Compound		3. Aave		4. Yield Agg		5. Asset Mgmt		6. DEX	
	Degree	In	Degree	In	Degree	In	Degree	In	Degree	In
Mean	25.5	17.6	9.7	4.7	3.2	1.5	3.3	1.5	9.5	4.7
Median	22.0	19.0	10.0	4.5	3.0	1.5	3.2	1.3	8.1	4.1
Max	42.0	22.0	11.0	5.4	4.3	2.2	5.3	2.8	17.7	8.8
Min	15.0	11.0	6.5	4.0	2.3	1.1	1.3	0.3	4.2	2.0
Std. Dev	8.4	3.6	1.2	0.4	0.6	0.3	1.4	0.9	4.6	2.3
Corr.		0.043		0.366		0.967		0.987		0.999

Exhibit 2: Flow-to-protocol time series graphs.

Figure A plots the daily number of DAI tokens minted and token flows to smart contracts identified as part of (2) Compound protocol, (3) Aave protocol, (4) yield aggregator protocols, (5) asset management protocols, and (6) decentralized exchange (DEX) protocols. Unidentifiable smart contracts, on-ramp service providers, generic wallets are excluded. Figure B plots *net* DAI tokens minted and *net* token flows into smart contracts. The vertical redline is drawn for December 26, 2020, a day when over $260 million worth of DAI was minted, $250 million of which went to the cDAI contract. From January 2021, Ether (ETH) price began rising faster than Bitcoin (BTC) price. The data period is June 2020 to June 2021 and unit of measurement is millions of DAI.

Figure A: Flow to protocols. For mint/burn, this represents DAI minting.

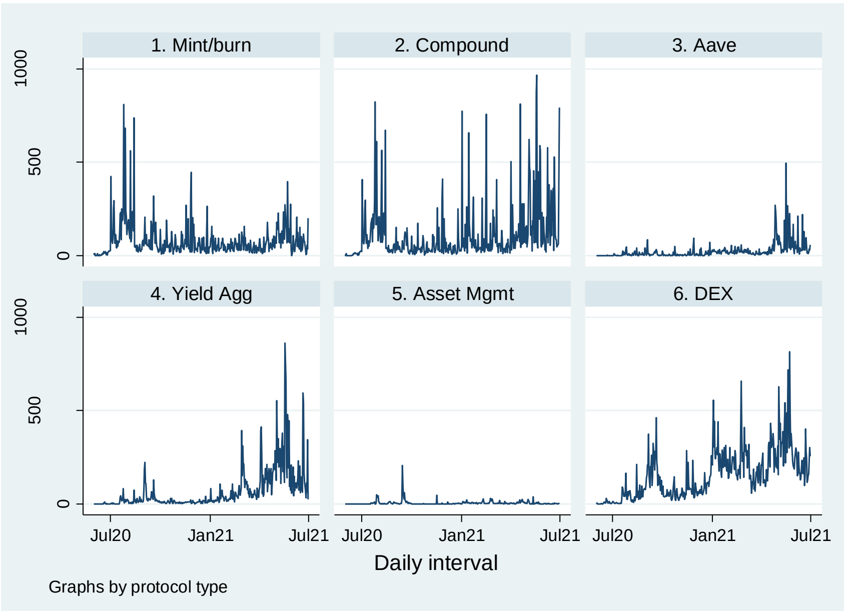


Figure B: Net flow from protocols. For mint/burn, this represents net DAI minting.

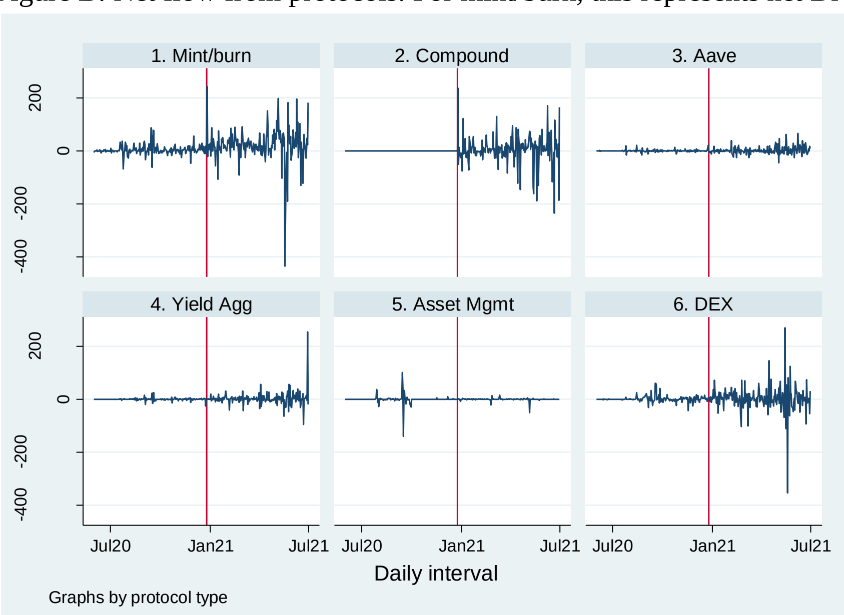


Exhibit 3: DAI network diagrams.

Figure A plots DAI flows between smart contracts identified as part of Compound protocol, Aave protocol, yield aggregator protocols, asset management protocols, decentralized exchange (DEX) protocols, and other smart contracts that exist in June 2020 Arrowheads indicate direction of flows and weights of lines indicate volume of flows. Figure B plots a simplified view (without named labels) of smart contracts in June 2020 and June 2021. The number of connected nodes rise from 51 in June 2020 to 117 in June 2021.

Figure A: DAI flows in June 2020

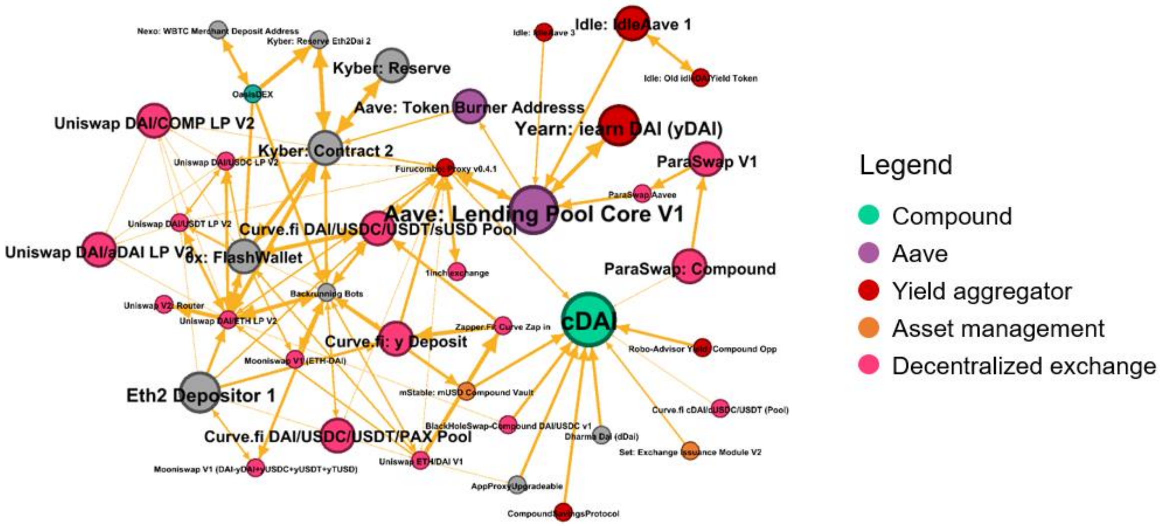
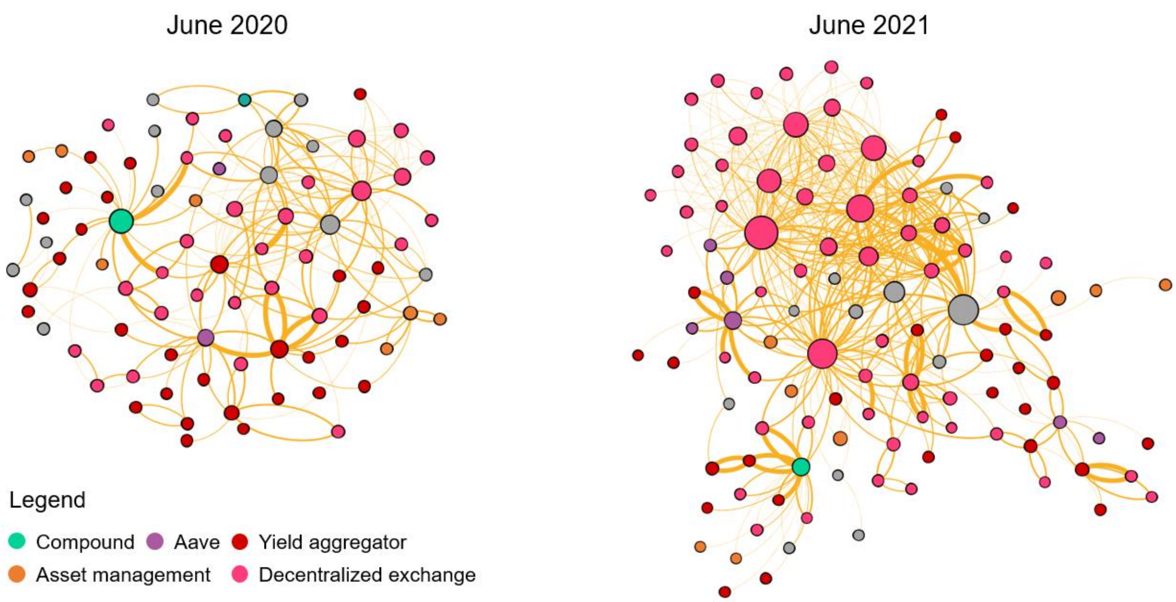


Figure B: Simplified DAI flows in June 2020 and June 2021



3. Yield Farming

Let us visualize the network of smart contracts that interact with DAI. Exhibit 3 Figure A shows the network diagram for June 2020, the period referred to by the crypto community as the beginning of the "DeFi summer". While DeFi protocols have existed prior to this point, on June 16, Compound began distributing COMP, a token minted by the protocol that allow holders to propose and vote on upgrades to the protocol, but do not have any other rights beyond that. This type of token became known as "governance token", a subset of "native token" issued by protocol sponsors that may or may not have any rights attached. COMP is earned by depositing tokens to the protocol in exchange for cTokens (DAI is deposited for cDAI), and for borrowing tokens from the protocol (DAI is borrowed from cDAI contract).[13] COMP, like any other tokens in DeFi, are tradeable and can be employed by other smart contracts willing to accept them as deposits. In fact, Compound also accepts COMP as collateral, issuing interest-bearing cCOMP and further earning COMP as reward. This practice came to be known as "liquidity mining" (liquidity for the market-making activity that participants must provide in a decentralized system and mining as analogue for how cryptocurrencies such as BTC and ETH are minted) and "yield farming" (yield for the return earned from participating in the protocol and farming as analogue for growing tokens on fertile soil). Yield farming kickstarted the DeFi Summer.[14] Prior to this, the strategies of yield aggregator protocols involved searching for best deposit rates across other protocols; now they had access to yield farming returns as well.

The distributed native tokens were well-received by the community: COMP price doubled within 24 hours of launch.[15] Other protocols took notice and followed suit: for example, Curve (a yield aggregator protocol) began distributing CRV as reward in August, while Uniswap (a DEX protocol) started distributing UNI in September. CRV and UNI can also be deposited in reward-eligible contracts elsewhere, and the reward will be distributed in the protocol's native token. In this article, we focus only on DAI, but the DeFi ecosystem is abundantly populated by such

[13] Other terms are used for depositing in DeFi, for example, staking or locking. Locking typically implies that the deposit is subject to a lockup period and cannot be called at-will.

[14] While yields are distributed in native tokens, they are often reported in dollar-equivalent annual percentage rate (APR) or annual percentage yield (APY), which are based on number of tokens earned and their prices. Protocols may provide disproportionately high rewards (but temporary) to attract early depositors, as most protocols rely on liquidity pools and their performance, in turn, depend on the thickness of the pool. Rewards are often adjusted at a block interval (approximately 13 seconds for Ethereum), but are quoted on an annual basis and expressed as nominal (dollar) rate, making a comparison to typical investment opportunities with longer duration potentially misleading.

[15] Source: https://www.coindesk.com/compounds-comp-token-price-doubles-amid-defi-mania, accessed on July 24, 2021.

protocols. In June 2020, the DAI network involved 51 smart contracts, 21 of which belong to decentralized exchange protocols; by June 2021, the number had grown to 117 and the number of decentralized exchange smart contracts had risen to 58. While Compound's protocol in this network only consists of the cDAI contract, the indegree and outdegree have changed from to 20 and 0 to 12 and 17 during this period, much higher compared to other protocols, pointing to its centrality in this network throughout due to its first-mover advantage.

4. Results

Having seen the visual connections between protocols, now we turn to the magnitudes of token flows. Exhibit 4 Panel A reports the sensitivity of DAI flows. First, we begin with the baseline regression (column 1) to show the determinants of DAI minting. Higher ETH price is positively related to DAI minting, reflecting one of the use cases of collateralized stablecoins: users may want to spend their appreciated token wealth without disposing of tokens and incur transaction fees or trigger taxable event, so a collateralized provides them with a lower-cost alternative. However, there relationship is weak economically (a 1% rise in ETH price leads to 0.147% increase in minted DAI) and statistically, also reflected in low adjusted R-squared. On average, new DAI is being minted daily and, as reflected in Exhibit 2 Figure A, more so during the DeFi Summer of June – September 2020.

Now, let us turn to the relationship between minted DAI and flows to protocols. In all types of protocols, the relationship is positive and statistically significant at 1% level. The adjusted R-squared values for flow-to-protocol regressions are also significantly higher than minting regression, underscoring the strength of this relationship. The sensitivity for Compound is the highest of all protocols at 0.948, consistent with its connectivity in the network. The relationship between flows to protocols and ETH price is also much stronger compared to DAI minting, both economically and statistically. One view consistent with this result is that DeFi popularity that began in late-December 2020 led to higher demand for ETH. This is evident in the relative price between ETH and BTC the began increasing in January 2021 amidst market-wide appreciation.

In Exhibit 4 Panel B, network statistics are added to the regressions. In sociology, indegree is often used as measure of popularity, and our DeFi interpretation is similar. For asset management and DEX protocols, both degree and indegree provide additional explanatory power for token flows. The similarity between degree and indegree can be seen in the high correlation between the two variables, as reported in Exhibit 2 Panel B. For Compound and Aave, the results are slightly different, as evident in their lower correlation coefficients, and caused by idiosyncratic reasons. For Compound, with only cDAI contract but highly connected, the negative correlation between indegree and token flow is a result of a sharp reduction in indegree that is offset by an increase in outdegree as described earlier. Compound flows remain closely tethered to DAI minting. For Aave, the negative relationship is caused by a structural change in the protocol that occurred around December 2020 that introduced new contracts, leading to a reduction in average degree during that time while token inflows increased. For yield aggregator protocols, smart contracts tend to be less connected, consistent with their intention of aggregating tokens to provide concentrated liquidity, making the less reliant on connectivity.

Overall, our results highlight the challenge of using network analysis for DeFi, as information in blockchain is reported at address level and protocols may restructure themselves overtime, requiring a DeFi analyst to proactively keep abreast of the changes. This is a sharp contrast to analyses of traditional financial services, where entities are more well-defined.

Exhibit 4: Flow-to-protocol analysis.
This table reports the result from the regressions of log DAI flows. In Panel A, column 1 sets the baseline analysis for DAI minted, while column 2 to 6 analyzes the flow to protocol by type on log DAI minted, log ETH price and one-day ETH return (measured in percentage point). In Panel B, network statistics included as additional regressors are reported. The statistics used are average indegree (number of smart contracts that send DAI in) and degree (number of smart contracts interacted in both directions) by protocol type, assessed at monthly interval. For brevity, control variables (same as Panel A) are not reported. Standard errors are computed using the Newey-West procedure with one-day lag and reported in parenthesis. Stars correspond to statistical significance level, with *, ** and *** representing 10%, 5% and 1% respectively.

Panel A

	(1) Mint/burn	(2) Compound	(3) Aave	(4) Yield Agg	(5) Asst Mgmt	(6) DEX
Log(Mint)		0.948***	0.670***	0.536***	0.698***	0.409***
		(0.062)	(0.068)	(0.071)	(0.106)	(0.064)
Log(ETH)	0.147*	0.501***	1.24***	1.53***	0.982***	1.09***
	(0.087)	(0.055)	(0.065)	(0.078)	(0.137)	(0.069)
r_ETH	-0.002	0.011	0.001	0.006	0.017	0.008
	(0.009)	(0.008)	(0.008)	(0.009)	(0.015)	(0.007)
Intercept	2.96***	-3.04***	-8.73***	-9.27***	-8.84***	-4.43***
	(0.623)	(0.379)	(0.516)	(0.588)	(1.01)	(0.536)
Adj. R-Sq	0.011	0.680	0.688	0.682	0.347	0.630

Panel B					
	(2) Compound	(3) Aave	(4) Yield Agg	(5) Asst Mgmt	(6) DEX
Log(Mint)	0.944***	0.676***	0.541***	0.721***	0.439***
	(0.066)	(0.067)	(0.072)	(0.102)	(0.064)
Degree	-0.003	-0.082***	0.066	0.414***	0.091***
	(0.006)	(0.031)	(0.124)	(0.131)	(0.017)
Adj. R-Sq	0.679	0.695	0.682	0.368	0.649
Log(Mint)	0.941***	0.676***	0.536***	0.722***	0.439***
	(0.062)	(0.069)	(0.072)	(0.104)	(0.063)
Indegree	-0.021**	-0.096	-0.008	0.539**	0.200***
	(0.009)	(0.058)	(0.249)	(0.266)	(0.033)
Adj. R-Sq	0.686	0.689	0.682	0.355	0.653

The net flow analysis in Exhibit 5 can be viewed as demand-supply imbalance, where net inflows indicate excess supply. In this analysis, the unit of measurement is millions of tokens rather than log, as net flows can be negative. The baseline regression on net minting activity in Exhibit 5 Panel A shows similar relationship, and now both ETH price level and one-day return are positively related to the dependent variable, with much higher adjusted R-square. On days that ETH appreciated more, there was likely to be excess demand for DAI, leading to net minting activity (rather than being acquired in the open market, as DAI price might exceed $1 when there is excess demand). The excess demand for DAI, in turn, is positively related to net inflow into Compound, DEX and then Aave. This relationship is reflected in Exhibit 2 Figure B. The relative magnitudes of the relationship could be related to yield farming demand explained in Section 3, as Compound and DEX yields are relatively easier to obtain and hence more popular.[16]

Further investigations by including network statistics reported in Exhibit 5 Panel B do not yield any additional insights, as the coefficients and adjusted R-squared remain unchanged. Unlike the earlier flow analysis, net flow analysis represents incremental demand from ETH appreciation, so the effect of protocol connectivity should manifest in *average* inflows rather than net (incremental) inflows. Popular destinations of net inflows are consistent with DeFi yield-chasing behavior.

[16] Aave's incentive mechanism is less attractive compared to other protocols, so this could explain its lower sensitivity. For yield aggregators, many protocols ask users to lock their tokens, so the time lock likely makes flows less responsive. Further explanations can be found in the Appendix.

One important limitation of our study is that flows are undifferentiated: we cannot distinguish whether an inflow to the cDAI contract is a DAI deposit or a DAI loan repayment. Ideally, such distinction is important and should be made across different types of protocols, but without further technical expertise, it is difficult to do so. Consequently, a full-visibility DeFi analysis requires technical blockchain knowledge as well as complete knowledge of all outstanding tokens, smart contracts, and their roles in the ecosystem, pointing to a challenge that a DeFi analyst would face despite its purported transparency.

Exhibit 5: Net-flow-to-protocol analysis.

This table reports the result from the regressions of net DAI flows. In Panel A, column 1 sets the baseline analysis for net DAI minted (minted minus burned), while column 2 to 6 analyzes the net flow to protocol (flow to minus flow from) by type on net DAI minted, log ETH price and one-day ETH return (measured in percentage point). In Panel B, additional explanatory variables that represent average indegree (number of smart contracts that send DAI in) and outdegree (number of smart contracts that DAI is sent out to) by protocol type, assessed at monthly interval. Standard errors are computed using the Newey-West procedure with one-day lag and reported in parenthesis. Stars correspond to statistical significance level, with *, ** and *** representing 10%, 5% and 1% respectively.

Panel B:

	1. Mint/burn	2. Compound	3. Aave	4. Yield Agg	5. Asst Mgmt	6. DEX
Net mint		0.445***	0.028**	0.041*	0.023	0.309***
		(0.116)	(0.014)	(0.025)	(0.027)	(0.083)
Log(ETH)	11.4***	-2.81	1.47**	0.519	-0.425	-3.53
	(3.067)	(2.877)	(0.584)	(1.15)	(0.587)	(2.29)
r_ETH	3.06***	-1.04*	-0.370***	-0.075	0.013	1.95***
	(1.05)	(0.545)	(0.140)	(0.180)	(0.087)	(0.449)
Intercept	-65.2***	15.8	-8.72**	-3.08	2.54	20.0
	(18.537)	(16.963)	(3.560)	(6.81)	(4.23)	(13.8)
Adj. R-Sq	0.170	0.236	0.056	0.004	0.003	0.350

Panel B

	(2) Compound	(3) Aave	(4) Yield Agg	(5) Asst Mgmt	(6) DEX
Net mint	0.446***	0.028*	0.041	0.023	0.310***
	(0.130)	(0.015)	(0.025)	(0.027)	(0.082)
Degree	0.065	-0.019	-1.22	0.036	0.628
	(0.206)	(0.186)	(1.67)	(0.633)	(0.887)
Adj. R-Sq	0.235	0.054	0.003	0.000	0.350
Net mint	0.445***	0.027*	0.041	0.023	0.309***
	(0.129)	(0.015)	(0.025)	(0.027)	(0.082)

Indegree	0.086	-0.350	-2.19	0.253	1.41
	(0.318)	(0.534)	(3.22)	(1.03)	(1.77)
Adj. R-Sq	0.235	0.055	0.003	0.000	0.351

5. Conclusion

In this article, we document the flows of DAI, a DeFi stablecoin of the MakerDAO protocol that are connected to a variety of protocols in the ecosystem. We show that DAI minting is related to ETH price, and minted DAI tends to flow into protocols that are more popular (first-mover advantage in the case of Compound; connectedness in the case of other protocols), and the popularity may be related to yield farming returns. While yield-chasing behavior is common in traditional finance, it is important to note that DeFi yield is denominated in native tokens with unclear benefits, unlike traditional securities such as common equity or fixed income securities that bundle many economic rights and legal protections. If the rapid growth in DeFi activity is driven by yield farming demand, which is dependent on native token prices, then the momentum could lose steam if interests in incentive tokens wane.[17] We also show how complicated DeFi analysis is, as there is no reporting entity and a DeFi analyst needs to have both technical expertise and detailed knowledge of protocols' smart contracts to make a meaningful analysis.

In our early attempt to understand the DeFi ecosystem, our impression is that the token-based and in-out nature of DeFi protocol makes accounting exercises very intricate. When DAI is deposited in the cDAI contract, cDAI is minted (as protocol's token asset and liability), then transferred out to the depositor in exchange for DAI, so it is the deposited DAI that gives cDAI value, otherwise it is simply an empty token. Now the cDAI contract holds DAI assets (visible on blockchain) and cDAI liability (invisible). As DAI is lent out, a DAI loan asset is created (invisible) and DAI is transferred to the borrower, who now holds DAI asset (visible) and DAI loan liability (invisible). In other words, not all money-equivalent entries in traditional accounting are directly visible on the blockchain. cDAI is Compound's liability, a concept that is not facilitated in blockchain reporting as liabilities are not tokenized. In fact, the cDAI token could even be considered a derivative DAI given their close ties.

[17] Cong et al. (2021a) present conditions where transactional demand for tokens can give rise to its value, but for many DeFi protocols, the purposes of their native tokens are unclear. For those that do have purposes, their ultimate purposes maybe to staking rewards. Iron Finance is an example of DeFi protocol that uses its native token as collateral for minting stablecoins, which could be considered a purpose, and the native token (and the stablecoin) could be farmed to earn more native token. Saengchote (2021) documents how the Iron Finance's mechanism design that incentivized yield farming could be a factor that eventually led to its eventual downfall.

From a simple flow analysis, the cDAI contract may have a net zero inflow, but the deposited DAI will be counted as TVL by Compound despite being already lent out. Moreover, the minted cDAI will also be counted as TVL by another protocol that accepts it (say, Curve), which in turn can mint another token against the accepted cDAI (crvCOMP, when cDAI and cUSDC are deposited) and earn reward (CRV). Both the depository receipt and reward can be further deposited into another smart contract (for example, crvCOMP can be deposited in yearn.finance to earn tokens in other protocols, while CRV can be locked with Curve to earn a share of trading fees), and the deposited tokens are once again counted as TVL. This is the story behind the protocol connections in Exhibit 3 (which only shows DAI, not its dependencies or other companion tokens) and what TVL really measures, and the picture gets more complicated each day as more DeFi protocols proliferate.

This cascade of connection may be reminiscent of securitization and structured product creation (e.g. the network of credit default swaps and synthetic collateralized debt obligations prior to the 2008 financial crisis), but their traditional finance counterparts do not generate continuous participatory incentives that are easily and cheaply minted by sponsors. This incentive unique to DeFi encourages repeated protocol stacking. Thus, the comparison of DeFi to Lego money may not be entirely accurate. In DeFi, tokens can be derivatives of one another: a single starting token could be used to mint new tokens endlessly if no one is carefully keeping records.

While blockchain is transparent and open for all to see, the information we readily see is only tokens outstanding, akin to total assets of the system. The web of inter-protocol liabilities that allows the DeFi system to rapidly leverages its initial capital and a lack of consolidated reporting makes it difficult to understand how much leverage there really is. With the open and permissionless nature of blockchain, new protocols and new connections can always appear, making the task of network surveillance very complex and haphazard. While stablecoins may have their potentials to facilitate payments and exchanges, they are the key foundations of the DeFi stack, and further research into this issue is required to fully understand their role in the ecosystem and any additional risks they may pose. [18]

[18] In addition to ETH, other non-DeFi stablecoins (e.g. USDC, USDT) are other popular entry points into DeFi, as explained in an earlier footnote. In fact, stablecoins are more popular as basis tokens due their “stability” in value.

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APPENDIX

Smart contract and DeFi protocol classification

In this appendix, we briefly explain the nature of DeFi protocols and how their incentives are distributed so readers can understand the distinctions and the reason behind the classification scheme. We divide Ethereum addresses into 9 categories.

1. MakerDAO

One of the first DeFi protocol known for its stablecoin, Dai (DAI). MakerDAO started in 2014, before the launch of Ethereum blockchain. DAO stands for decentralized autonomous organization, encapsulating the desire behind those involved to create an alternative financial system independent of intervention from centralized authority. Among many reasons, DAI is named as an homage to Wei Dai, the computer engineer who pioneered the concept of cryptocurrency.[19]

In their whitepaper, MakerDAO state that they "believe that stable digital assets like Dai Stablecoin are essential to realizing the full potential of blockchain technology", pointing to volatility of cryptocurrencies such as Bitcoin and Ether as motivation.[20] DAI is minted via collateralized debt position smart contracts with overcollateralization to protect the value of DAI. The interest rate (called "stability fee") is the charge for borrowing the stablecoin. The accrued fee is used to pay interest (called "Dai savings rate") to those who choose to lock (deposit) DAI in Oasis Save smart contract, which in turn creates demand for DAI. We cannot find the address of the smart contract, so it is omitted from our analysis. Useful real-time statistics about the protocol can be found on https://daistats.com/. Most DAI transfers occur between wallets, with average value (and frequency in parentheses) daily inter-wallet transfers of 121.2 million (5,551 transactions), reaching as high as 1,039 million on May 19, 2021

MakerDAO has a governance token called MKR which had been auctioned off as emergency funds to recapitalize DAI when it lost its peg in March 2020, but there is no explicit minting algorithm and protocol users cannot earn MKR as reward. There are 991,328.38 MKR in circulation, 8,671.62 of which have been burned and 84,000 held in treasury.[21]

2. Compound

Founded in 2017, Compound launched its "money market protocol" in September 2018. The protocol's mission is to generate an efficient system for earning interest, which is achieved by a dynamic interest rate algorithm that automatically adjusts borrowing and saving rate as a function of available liquidity. Users must deposit accepted tokens into Compound's cToken smart contracts, which return the wrapped cToken (i.e. DAI for cDAI) as depository receipts. The cToken smart contracts set the exchanger rates between the tokens according to accrued saving rates, giving users more of the deposited tokens when redeemed, effectively paying interest upon

[19] Source: https://blog.makerdao.com/little-known-facts-about-makerdao/, accessed on July 25, 2021.
[20] Source: https://makerdao.com/whitepaper/Dai-Whitepaper-Dec17-en.pdf, accessed on July 25, 2021.
[21] Source: https://makerburn.com/#/, accessed on July 26, 2021.

redemption. The deposited tokens become part of the liquidity pool that can be lent out to users. In other words, it is a peer-to-contract (or peer-to-pool) interaction. Users who want to borrow must first deposit accepted tokens as collateral and maintain sufficient overcollateralization, or face being liquidated. Consequently, it is often classified as a lending protocol rather than money market protocol because it needs lending income to generate returns for its money market products.

Compound initially accepted 4 tokens: wrapped Ether (WETH), 0x Protocol (ZRX), Basic Attention Token (BAT), and Augur (REP). As of July 2021, the list stands at 12 tokens, including stablecoins such as DAI, USD Coin (USDC) and Tether (USDT), and its governance token, COMP. The most popular deposited tokens in Compound are USDC ($5 billion), followed by DAI ($4.3 billion) and ETH ($3.3 billion).[22] The utilization rates for stablecoins are typically higher than other tokens, making their borrow APYs typically higher than other tokens (but not always, as interest functions contain both intercept and slope terms) and thus supply APYs high as a result.

It is backed by several high-profile venture capital funds, such as Andreessen Horowitz, Polychain Capital and Bain Capital Ventures, who are majority holders of their governance tokens, COMP. As of July 26, 2021, the three VC firms own a combined voting power of 32.85%.[23] Compound is the pioneer of rewarding protocol participants with its governance token. Within one week of its launch on June 15, 2020, the price of COMP doubled. The event is said to have kickstarted the yield farming phenomenon and the brief DeFi Summer of 2020 that ended in September 2020.[24] A governance token is a special case of a native token (token issued by the protocol's smart contract) that contains voting rights. A native token may or may not contain any rights at all. As of July 26, 2021, COMP had circulating supply of 5,373,538.37 and had already distributed 973,535 with current rate of 2,312 per day.[25]

3. Aave

A collateralized lending protocol also founded in 2017, Aave began as ETHLend, offering a decentralized peer-to-peer lending platform. It pivoted to peer-to-pool strategy like Compound and rebranded as Aave in September 2020 and employ a similar but slightly different design. While Compound's cTokens use algorithmically determined exchange rates to pay interests on deposits, Aave's aTokens are pegged one-to-one to the original token and pay interest in aTokens instead. In other words, aTokens are derivative stablecoins of the deposited tokens.

In their first iteration (V1), Aave use a common pool and internal accounting to manage token loans, but Aave V2 (launched in December 2020) use explicit aToken smart contracts for each underlying token, much like Compound's cTokens. This structural shift led to a change in the network diagram discussed in the article. aDAI now existed in two versions: aDAI V1 and aDAI V2, highlighting the challenge in DeFi network analysis when the underlying structure of protocols can change as they are upgraded.

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[22] Source: https://compound.finance/markets, accessed on July 26, 2021.
[23] Source: https://compound.finance/governance, accessed on July 26, 2021.
[24] Source: https://www.coindesk.com/comp-below-100-defi-summer-over, accessed on July 26, 2021.
[25] Source: https://coinmarketcap.com/currencies/compound/, https://compound.finance/governance/comp, accessed on July 26, 2021.

Unlike Compound whose main purpose is money market investment, Aave's purpose is to offer token loans, so it also offers both variable and fixed interest rate (variable APY and stable APY) loans. It also offers flash loans, which are uncollateralized loans that must be repaid within the same transaction block (so effectively, it is as if the user had never borrowed the tokens at all) for a small fee. This type of transaction lowers the cost of arbitrage in DeFi, helping restore price parity across trading venues. As price parity is an important goal for decentralized exchanges, Uniswap incorporate the idea as flash swap in their V2 upgrade.

Aave currently accept 27 tokens as collaterals, including 7 stablecoins and MKR, CRV and UNI (but not COMP). Aave's governance token is AAVE and can be earned by staking the token in its Safety Module smart contract which acts as buffer for shortfall events in the ecosystem, and AAVE is distributed as Safety Incentive. As of July 26, 2021, AAVE had circulating supply of 12,912,411.49 and distribution (emission) rate of 1,100 per day.[26] When AAVE is staked, users receive stkAAVE as depository receipt. Beginning April 2021, Aave began distributing 2,200 stkAAVE per day as incentives for providing liquidity in selected pools.[27]

4. Yield aggregator

Yield aggregator protocols are similar to mutual funds. Claiming reward tokens is a blockchain transaction which costs gas, and gas cost depends on computation complexity, not the monetary value of the transaction, so users with small transactions will not find it economical to claim rewards often, missing out on the compounding effect. With larger pool of tokens, yield aggregators can claim more frequently, and thus earn more yield overtime. In addition, yield aggregators can deploy complex strategies such as using explicit leverage or staking wrapped tokens across multiple protocols, earning multiple token yields. In return, the protocol will take a cut of the yield (like hedge fund carry). Some strategies are illiquid, so mechanisms such as load fees are often designed into protocol to encourage users to lock their tokens for longer. Examples of such protocols are Akropolis, Alpha Homora, Harvest, Idle and Yearn.finance.

Users deposit their tokens into the protocol's vault (creating a wrapped token in the process), which would then be deployed according to the strategies set forth by the protocol. When the tokens are redeemed, users would get back a pro-rata share of pool. Like Compound's cToken and Aave's aTokens, these depository receipts are tradeable and can be deposited into protocols that accept them. For the case of Yearn.finance, their wrapped tokens are yTokens.

Yield aggregators may also team up with other protocols. For example, Yearn.finance created its governance token YFI in July 2020, but it was only available by staking yTokens (all wrapped stablecoins) in Curve's liquidity pool. This type of interoperability is possible if smart contracts grant permissions to interact with one another.

5. Asset management

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[26] Source: https://coinmarketcap.com/currencies/compound/, https://app.aave.com/staking, accessed on July 26, 2021.
[27] Source: https://aave.github.io/aip/AIP-16/, accessed on July 26, 2021.

Asset management protocols are like indexed funds: they allow users to maintain a balanced exposure to a basket of tokens or a specific strategy. Examples of such protocols are Set Protocol and Balancer. There are few protocols under this category because liquidity pools in decentralized exchanges (to be described later) can also be considered asset management protocols, but the permissible baskets are much more limited (e.g. only two tokens, or stablecoins only). Under this definition, stablecoin protocols (e.g. mStable) can also be considered an asset management protocol, as it is indexed to the value of US dollar.

This highlights another facet of DeFi: underneath various product classifications, many protocols' smart contracts work in the same way. Typical processes are (1) deposit a token into a smart contract and mint a derivative token as depository receipt, or (2) deposit multiple tokens into a smart contract and receive different tokens of equivalent value when redeemed. The principle of equivalent (or sufficiently collateralized) exchange is at the heart of DeFi transactions. The same protocol structure can be marketed as different products, depending on the desire of the protocol's sponsor: MakerDAO could be a stablecoin (hence asset management) or a collateralized lending protocol; Compound could be a collateralized lending or a money market protocol. This is simply semantics, since underneath, the workings are the same.

6. Decentralized exchange (DEX)

Decentralized exchange protocols are sometimes referred to as automated market makers (AMM) protocols as they facilitate token exchanges without the need for a centralized institution (that typically use order book matching system). The inherent reason why order book matching in DeFi does not work is because order flows generate data trails that are extremely costly to record on the blockchain (any information updating on blockchain requires users to pay gas, whether that transaction has any monetary value or not) and can lead to network congestion. Consequently, an alternative method is required.

Just as the name suggests, participants are, in fact, market makers who must then face inventory risk. Users who provide liquidity in a pool (by depositing or staking tokens) are willing counterparties for users who wish to exchange their tokens (again, a peer-to-pool transaction). In the order book matching system, users send in the desired orders, which are then matched to counterparties with the same terms of trade, providing price certainty at the expense of execution uncertainty. In AMM, users send one type of token she wishes to exchange, and the pool will send the other type of token in return. A bonding curve (pricing function) will determine how many tokens of the other type she will receive. In other words, the user will have execution certainty (provided that she pays enough gas and the pool has sufficient liquidity) but faces price uncertainty since price is a mathematical output of the bonding function.

The bonding curve is a function of quantities of tokens available in the pool, so large transactions *will* result in price slippage, and an illiquid pool can have wild swings in prices that are out-of-sync with other trading venues. Bonding curves (e.g. the constant product function $xy = k$) generate relative token prices that make the token type in low supply prohibitively expensive to acquire (and vice versa). With DeFi openness, arbitrageurs would restore price equilibrium relative to other trading venues (which is likely why Uniswap introduced flash swap in its V2 upgrade). The constant product function earlier (the most popular, used by many protocols such as

Uniswap and SushiSwap) permits only a pair of tokens, but generalized bonding curves can allow for more tokens (such as Curve and Balancer). As market prices change, the ratios of tokens in liquidity pools will change to keep up with market prices. Consequently, DEX protocols can also be viewed as asset management (automatic portfolio rebalancing) protocol that allows users to change their portfolio composition without paying gas.

As protocol performance directly depends on liquidity, protocol sponsors often provide generous staking incentives for users willing to provide liquidity, especially when the market is thin (liquidity mining). In fact, some of the most generous rewards are often found in the nascent days of a DEX protocol as it tries to attract liquidity.[28] Rewards could be provided in the protocol's native tokens, or other protocol's native tokens if a partnership between protocols can be formed. For example, the Aave liquidity pool on Curve (which accepts aDAI, aUSDC, and aUSDT) provides CRV (Curve's governance token) and stkAAVE (staked version of AAVE) as reward.

When tokens are deposited, users receive a depository receipt (often referred to as an LP token) which represents a pro-rata share of the pool. Most DEX pools accrue transaction fees, so users will also get their share of fees upon redemption. However, if one compares the ratio of tokens deposited to the ratio of tokens redeemed, there may be a discrepancy in value referred to as "impermanent loss" or "divergent loss". This results from movements along the bonding curve and is more likely for token pairs with divergent prices, which is an unavoidable feature of DEX. Consequently, stablecoin pools tend to be more popular among users (but because of their popularity, they also tend to provide little or no reward for liquidity mining).

The reliance on deep liquidity is not limited to DEX but a general feature of peer-to-pool transactions. Lending protocols also require liquidity (measured as utilization ratio), otherwise interest rates will skyrocket. This highlights the nature of DeFi that smart contracts are simply intermediaries; it is users who are the participants, but rules of engagement must be explicitly written into smart contracts, and no discretion is allowed. This is what it means to be a decentralized autonomous organization. In any case, it is in a protocol's interest to build up liquidity, but with DeFi openness akin to perfect token mobility, offering staking rewards (expressed as nominal dollar-like yield) using tokens that can be minted by protocols becomes a popular strategy to attract yield-chasing "hot money" into protocols.

7. Other smart contracts

Ethereum addresses that have codes written inside are identified as smart contracts rather than wallets. This information is visible on blockchain explorer websites such as Etherscan.io. However, not all smart contracts disclose their source codes and their affiliations, and all we can see is binary data. One example is address '0x0000006daea1723962647b7e189d311d757Fb793' which, as of July 26, 2021, holds records of over 546,400 transactions and 124 types of tokens worth over $104 million. However, nothing else about the address is known. Nevertheless, not all contracts are as active and valuable as this example. We exclude such contracts from our network diagram and analysis.

[28] For example, Uniswap only provided liquidity mining reward for two months in 2020. Source: https://www.theblockcrypto.com/linked/84762/dex-uniswap-liquidity-mining-over, accessed on July 26, 2021.

8. On-ramp service providers

On-ramp service providers are addresses that identify themselves as belonging to centralized exchanges such as Binance and Coinbase. They aggregate orders and transact on behalf of clients. For our study, we treat them like private wallets and thus exclude them from our network diagram and analysis.

9. Wallets

Ethereum addresses that are neither smart contracts nor wallets belonging to some protocols are treated as private wallets. The purpose of our study is to analyze protocol-to-protocol interactions, so we exclude them from our network diagram and analysis.