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Composable Finance

Michael Junho Lee

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Abstract

Composability – open interactions between assets and protocols – facilitates a modular financial architecture. I document the emergence of composed asset transformation, where tokenized assets are re-bundled to alter access, liquidity, and risk characteristics to broaden and enhance the set of tokenized U.S. dollar instruments. Yet, I argue that "naive" composability fundamentally conflicts with the provision of pooled arrangements needed for liquidity provision, risk-sharing, and capital backstops. I demonstrate this in an economy consisting of a vertical chain of protocols. Upper-layer protocols expand access to users, but bootstrap contingent liquidity from lower-layer protocols, resulting in a waterfall of externalities. In equilibrium, the base protocol rations liquid reserves, resulting in systemic illiquidity across the economy. Under severe circumstances, total utilization shrinks with composability. I offer principles and direction for building a sustainable, composable system.

JEL classification: E41, E42, G10, G20, D47
Key words: composability, tokenization, composed asset transformation, decentralized finance, protocol economy

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Lee: Federal Reserve Bank of New York (email: michaeljunholee@gmail.com). The author gives special thanks to Janice Wang for exceptional research assistance.

1 Introduction

Composability is a design principle where systems consist of components that can be selected, assembled, and reassembled in various combinations to satisfy specific user requirements. It reflects a deep philosophy of modular technical architecture (Baldwin and Clark 2000), and is rooted in a long tradition of economic thought on combinatorial innovation as an engine for economic growth (Schumpeter 1911).

Permissionless blockchains offer compelling infrastructure for a composable financial system. Decentralized protocols facilitate a market of "financial primitives," basic functions such as custody, exchange, and lending, and allow for the output of one protocol to serve as the input for another without restrictions. These could evolve into a competitive market of ideas, whereby builders compete on tailored solutions, ensuring market contestability.[1] A modular system could shift financial systems toward a Coaseian environment, facilitated by a nexus of programmable contracts, rather than through financial intermediaries and centralized markets (Meckling and Jensen 1976).

I first document an emerging practice I refer to as *composed asset transformation*, in which tokenized assets are restructured to alter the liquidity, access, and risk characteristics of financial claims. Composability facilitates traditional asset transformations achieved through securitization, including asset restructuring to improve liquidity or risk-sharing, but also allows for *access* transformation, through which a broader set of users gain indirect access to financial claims.

Notwithstanding these virtues, I argue that "naive" implementation of composability conflicts with the provision of pooling mechanisms, a cornerstone of finance. Pooling mechanisms allow for the aggregation of resources (money) or liabilities (risk) to achieve outcomes that individuals cannot easily achieve alone, and serves as the basis for liquidity provision, risk-sharing, and capital backstops.

I demonstrate this specifically in the context of liquidity provision. I consider an economy consisting of a vertical chain of protocols, each building on top of another. Protocols take capital as input, and provide services that generate long-term value to users. Each protocol addresses a unique market of users, and thus inherently broadens access to finance. All protocols, however, offer liquidity to users that seek early withdrawal – a feature commonly sought out by users and

[1] This idea is also referred to as "money lego" (Harvey, Ramachandran and Santoro 2021).

offered by protocols.

I show that upper-layer protocols bootstrap contingent liquidity from lower-layer protocols, resulting in a waterfall of liquidity externalities flowing all the way down to the base protocol. Up to a certain tolerance, the base protocol internalizes costs and sustains full liquidity provision, enabling protocols to expand reach. However, when the economy grows beyond a critical mass, the base protocol holds insufficient liquid reserves, leaving the entire chain of protocols systemically illiquid. Composability expands access at the expense of stability. Troublingly, I show that composability can even reduce the overall user base when externalities are too severe.

Liquidity provision and more generally, pooled mechanisms work by facilitating cross-subsidization between users faced with idiosyncratic shocks. A protocol recoups costs associated with liquidity provision from profits generated through its long-term users. An upper-layer protocol integrates a lower-layer protocol *exclusively* for its liquidity provision, without contributing to longer-term capital. This shortens the effective duration of capital held in the lower-layer protocol. At a breaking point, the base protocol rations liquidity at the expense of its users and the entire ecosystem built on top of it.

The composability problem with liquidity provision is not only instructive, but critical, in light of a burgeoning tokenized U.S. dollar ecosystem (Lee 2025). To date, there is over $300 bln in tokenized US dollar assets, consisting of stablecoins, tokenized treasuries, and other tokenized money market instruments.

Explicitly, I provide a map detailing how stablecoins and tokenized treasuries are used by a web of protocols to create composed stablecoins augmented with different access and financial characteristics. Composed stablecoins bundle liquid, safe assets with illiquid, risky claims, which could lead to cross-contagion through operational and financial dependencies. Moreover, the network of protocols reveals hidden liquidity dependencies borne by "base" providers, issuers of stablecoins and tokenized funds that provide redemption at par. Practically, composed stablecoins compress the effective liquidity ratio of fiat-backed stablecoins. Failures or losses from risky operations could lead to fire sales and a domino effect across composed tokens and protocols, with these shocks ultimately being transmitted back to the banking system and Treasury market and disrupting the traditional financial system.

The composability problem is exacerbated with rival protocols. In the case of nonrival protocols, differentiated services allow gains to accrue through composability by enabling access to a broader set of users. However, when upper-layer protocols offer rival services, they not only impose externalities on the base protocol, but also steal their core users that are needed to cross-subsidize. A negative feedback loop erodes the entire protocol economy, further constraining liquidity provision in equilibrium.

A notable example on the rival composability problem is that of Morpho Optimizer, a lending protocol built on top of existing lending protocols, Aave and Compound. Morpho offered an innovative on-chain lending and borrowing service that quickly grew its total value locked to over $2 bln within 18 months after launch. However, its design inherently posed an externality on lower-layer protocols in two ways. First, it provided rate guarantees to its customers by diverting excess demand to the lower-layer protocol only when it could not deliver more attractive rates, thereby ensuring that it could always offer rates that were at least as good as the lower-layer protocol.[2] But by doing so, Morpho attracted borrower-lender matches with high surplus, adversely selecting lower-layer protocols. Second, it posed greater stress on lower-layer protocols' liquidity reserves, which were designed to "equilibrate" demand, by subjecting them to external dependencies. This meant that lower-layer protocols would need to recalibrate their provisions, or be subject to liquidity fragility.

Although mainly motivated in the context of liquidity provision, the model can readily be modified to show similar externalities emerge for other pooled arrangements, involving risk-sharing, such as insurance, and contingent capital, such as backstops. This is because the externalities surfaced through composability are core issues that are operative, more generally, for efficient pooling mechanisms in finance.

Composability amplifies potential externalities because it implicitly requires assets and protocols are readily available to all, and importantly, *without discriminatory access or prices*. This stands in contrast to traditional financial systems. In the case of partnerships, contracts are negotiated so that surplus generated is distributed. In the case of insurance, insurers conduct risk evaluations to appropriately price insurees, taking into account heterogeneity. In the case of collateralized lending markets, borrowers are screened and eligible collateral is designated to minimize market frictions. A common thread in all these cases is the appropriate

[2]An analogy to this is price-matching by platforms.

use of discriminatory pricing (infinite, in the case of restricting access) so that market participants implicitly compensate the pool when externalities on others are expected to be large. Aave landed at a similar solution. Among many strategies employed, Aave launched its "Merit" reward system, which excluded users who engaged with Aave through Morpho Optimizer, essentially discouraging users from engaging with Morpho's protocol.[3]

Existing studies view composability primarily through the lens of operational risk, which mechanically result in operational linkages between protocols that could lead to contagion and financial instability (Tolmach, Li, Lin and Liu 2021, Kitzler, Victor, Saggese and Haslhofer 2023, Auer, Haslhofer, Kitzler, Saggese and Victor 2024). I point out foundational issues that composability poses on the nature of the economic arrangements themselves. In particular, inter-agent and intertemporal pooling mechanisms are ingrained in the design of financial arrangements but require screening and pricing schemes that counteract externalities. Importantly, the problem highlighted in this paper does not apply to many core financial functions – to name a few: escrow, atomic swaps, programmatic transfers. The problem does highlight, however, the need for a thoughtful approach to developing modules that can serve as resilient, public goods.

The findings with regards to composed asset transformation share a conceptual lineage with the literature on non-bank financial intermediation. Non-bank financial intermediation is fundamentally characterized by liquidity transformation – the funding of illiquid assets with money-like liabilities – performed through long chains of specialized intermediaries rather than a single bank (Pozsar, Adrian, Ashcraft and Boesky 2010, Adrian and Ashcraft 2012). Similar to rehypothecation of collateral in traditional repo markets, I show that the protocol economy effectively expands liquidity creation from a limited base of collateral (Singh and Aitken 2010). Just as excessive rehypothecation can lead to "churn" that masks the true leverage of the system and exacerbates fragility during deleveraging events, I show that composability allows protocols to bootstrap liquidity from base layers without internalizing the associated risks. I demonstrate a clear mechanism through which systemic risks could build up in decentralized finance (DeFi) architectures, in which leverage and rigidity are amplified by the absence of elastic public backstops (Allen 2023).

The breakdown in liquidity provision contributes to a growing body of work

[3] Morpho also pivoted in following iterations of its protocol.

on stablecoin fragility. Recent contributions have formalized the run risks inherent in stablecoins due to the similarity in structure to money market funds, and demonstrate that stablecoins are prone to flight-to-safety dynamics (Gorton and Zhang 2021, Ma, Yao and Zhang 2023, Anadu, Azar, Cipriani, Eisenbach, Huang, Landoni, La Spada, Macchiavelli, Malfroy-Camine and Wang 2025, d'Avernas, Maurin and Vandeweyer 2022). My paper offers a distinct and novel source of financial fragility arising from composability. In the context of composed asset transformation, I identify a new amplification channel through which composed stablecoins can transmit risks down to the base layer and to the braoder financial system.

Before going into a formal treatment, I provide an illustrative example. Section 2 describes the baseline model, which is analyzed in Section 3. The case with rival protocols is explored in Section 4. I outline the emergence of composed asset transformation in Section 5. In Section 6, I offer discussion on building a sustainable, composable system. All proofs can be found in the Appendix.

Illustrative Example. I provide an example that illustrates the main tension. There are two protocols, a lower protocol and an upper protocol. Each protocol has an addressable market of users with $100, among which 10% are hit by liquidity shocks in the interim period. Thus, each protocol must provision $10 to fully service liquidity needs.

The lower protocol takes as input $1, and outputs a protocol token T1. T1 is used to redeem at demand for cash. To service $10, the lower protocol holds $10 in reserves, at a management cost of 10%. The upper protocol takes as input $1, and outputs protocol token T2. However, instead of redeeming T2 for a $1, it redeems it with T1, which then converts to $1. To service $10 dollars, the upper protocol holds 10 units of T1.

The total demand for T1 is $110 dollars: $100 from its native users and $10 from the upper protocol. The protocol's overall market cap rises from the upper protocol's utilization, but the entire $10 is expected to be withdrawn early. Hence, the upper protocol's entire deposit of $10 must be held in reserves, costing an additional $1 in management costs without commensurate contribution to support the lower protocol.

2 Model

There are three periods, $t = 0, 1, 2$. There are $i = 1, 2, ..., N$ islands, each consisting of one protocol and a unit mass of users. Users on island i are home-biased toward protocol i on island i. In this way, protocols are nonrival, either due to differentiation in the nature of their services or user reach.[4] Islands are linked in a chain, with protocol i accessing protocol $i-1$ on the preceding island. Only the protocol on island 1 can hold cash.

A protocol i takes a unit of capital from users, and transfers a token. The token generates long-term value $u > 1$ to users. Users also value contingent liquidity, and the protocol chooses the level $\mu_i \in [0, 1]$ to hold liquid for those transferring tokens back in return for capital. The protocol distributes capital pro-rata if there is excessive demand, i.e. $\frac{\mu_i}{D_i}$ when $D_i > \mu_i$, for total demand D_i, so that the payout is $R_i = \min\{1, \frac{\mu_i}{D_i}\}$.

The protocol obtains payoff V for the remaining $1 - \mu_i$ share of capital deployed long-term. Liquidity management is assumed to cost k_i. For X_i units of capital from users, the expected payoff of the protocol is

$$\max\{0, X_i\mu_i - D_i\} + X_i(1 - \mu_i)V - X_i\mu_i k_i. \tag{1}$$

I assume $k_1 = aV > k_i = 0$ for $i \neq 1$, reflecting that only protocol 1 actively offers cash redemption.[5] Given the uniqueness of protocol 1, I refer to it as the *base* protocol.

Users have a private type $\theta \sim U[0, 1]$. A user $i\theta$ (type θ on island i) owns a unit of capital and decides whether to use protocol i, i.e. $x_{i\theta} \in \{0, 1\}$. All users have an outside option 1. Each user is hit with a liquidity shock with probability $\gamma \in (0, 1/3)$; failing to exit at par result in penalty θ. Each user choose whether to exit $w_{i\theta} \in \{0, 1\}$. A type θ user's payoff is summarizes below:

$$\begin{cases} c_1 - \theta \cdot \mathbb{1}_{c_1 < 1} & \text{with probability } \gamma \\ c_1 + c_2 & \text{with probability } 1 - \gamma. \end{cases} \tag{2}$$

Whenever there is under-provision of liquidity, users face a discontinuous drop of θ, reflecting a liquidity premium associated with expediency.

[4] I revisit the implications of rival protocols in Section 4.

[5] As long as $c_1 > c_i$ for $i \neq 1$ all results hold.

Timeline.

$t = 0$ Protocols sequentially select μ_i. Users deposit capital in protocols.

$t = 1$ Liquidity shocks hit. Users withdraw from protocols.

$t = 2$ Final payoffs are realized.

Equilibrium Concept. A subgame-perfect Nash equilibrium is $(\{\mu_i^*\}, \{x_{i\theta}^*\}, \{w_{i\theta}^*\})$, where $\{x_{i\theta}^*\}$ represents protocols' optimal strategies, and $\{x_{i\theta}^*\}$ and $\{w_{i\theta}^*\}$ represent users' optimal use and exit strategies, respectively.

3 The Composability Problem

3.1 Benchmark

I use the single-island environment as a benchmark for understanding how composability impacts the equilibrium provision of protocols. The principle interest is pinning down the conditions under which full liquidity provision is sustained in equilibrium. Given X capital, a user's expected payoff from depositing into the base protocol is:

$$\gamma \min\left\{1, \frac{\mu X}{D}\right\} - \theta \mathbb{1}_{\frac{\mu X}{D} < 1} + (1-\gamma)u. \tag{3}$$

The total demand at $t = 1$ is $D = \gamma X$. A user's payoff is

$$\begin{cases} \gamma + (1-\gamma)u & \text{if } \mu \geq \gamma \\ \gamma\left(\frac{\mu}{\gamma} - \theta\right) + (1-\gamma)u & \text{if } \mu < \gamma \end{cases} \tag{4}$$

I restrict attention to the parameter space where the utility u derived from the protocol is not so high as to always satisfy users' participation condition, and a is not prohibitively high so as to make full provision of liquidity $\mu = \gamma$ unprofitable. The first ensures that liquidity provision matters for user participation; the second ensures that full liquidity provision satisfies individual rationality for the base protocol.

Assumption 1 (Participation conditions)**.** $1 > (1-\gamma)u$ *and* $1 - \gamma(1+a) > 0$.

Given $\mu < \gamma$, a user of type $\bar{\theta}$ is indifferent between depositing and not:

$$1 = \gamma \left(\frac{\mu}{\gamma} - \bar{\theta} \right) + (1 - \gamma) u, \tag{5}$$

implying $\bar{\theta} = \frac{1}{\gamma}((1-\gamma)u - (1-\mu))$, and in which case total deposits is $X = \bar{\theta}$. Consider the protocol's optimal μ given $\mu < \gamma$. The protocol choose μ to maximize:

$$\frac{1}{\gamma}\left((1-\gamma)u - (1-\mu)\right)(1 - \mu - a\mu)V. \tag{6}$$

Lemma 1. *Given $\mu < \gamma$, the base protocol's optimal μ' and market share $\bar{\theta}'$ is:*

$$\mu' = \frac{2+a}{2(1+a)} - \frac{u(1-\gamma)}{2} \tag{7}$$

and

$$\bar{\theta}' = \frac{1}{\gamma}\left(\frac{(1-\gamma)(1+a)u - a}{2(1+a)} \right) \tag{8}$$

For $\mu = \gamma$, the base protocol reaps $(1 - (1+a)\gamma)V$. I establish that the optimal protocol strategy is $\mu^* = \gamma$ for a not too large:

Proposition 1 (Breakdown in liquidity provision)**.** *There exists cutoff $\bar{a}_1$ such that for $a < \bar{a}_1$, the protocol chooses full liquidity provision $\mu^* = \gamma$ in a single island and all users on the island use the protocol.*

As long as the cost associated with managing and providing liquidity is not too large, the protocol is willing to satiate aggregate demand for liquidity.

The first-best allocation is:

$$\underbrace{(1-\gamma)(u-1)}_{\text{user value}} + \underbrace{(1-\gamma-a\gamma)V}_{\text{protocol value}} \tag{9}$$

which is attained whenever $\mu = \gamma$. For $\mu < \gamma$, total payoff relative to the first-best is:

$$\underbrace{-\gamma\int_0^{\bar{\theta}}\theta d\theta}_{\text{loss from under-provision}} + \underbrace{(\bar{\theta}-1)\left[(1-\gamma)(u-1)+(1-(1+a)\gamma)V\right]}_{\text{loss from lower total utilization}} + \underbrace{\bar{\theta}(1+a)(\gamma-\mu^*)V}_{\text{gain from cost reduction}} \tag{10}$$

Whenever the base protocol choose $\mu < \gamma$, the base protocol under-provides liquidity insurance, effectively rationing liquidity across those in demand. Two forms of inefficiency arise. On the extensive margin, the protocol forgoes the provision of its service to users with large θ. On the intensive margin, users hit with liquidity shocks incur costs due to liquidity rationing.

3.2 Vertical Economy

Now, consider the economy with $N = 2$. The general case with $N > 2$ will follow. Protocol 2 chooses the share μ_2 of capital to be held in protocol 1's tokens, taking μ_1 as given. Protocol 2 token holders seeking capital must first return P2 tokens in exchange for protocol 1 tokens, and then exchange protocol 1 tokens in exchange for capital. An island 2 user's expected payoff is:

$$\gamma\left(\underbrace{\min\left\{1,\frac{\mu_1 X_1}{D_1}\right\}}_{R_1}\underbrace{\min\left\{1,\frac{\mu_2 X_2}{D_2}\right\}}_{R_2} - \theta\mathbb{1}_{R_1R_2<1}\right) + (1-\gamma)u. \tag{11}$$

An island 2 user gets disutility when withdrawals are insufficient either from protocol 2 or protocol 1. Suppose $R_2 < 1$. An island 2 user of type $\bar{\theta}_2$ where:

$$\bar{\theta}_2 = \frac{1}{\gamma}\left((1-\gamma)u - (1-\mu_2 R_1)\right), \tag{12}$$

Protocol 2's payoff given $R_2 < 1$ is

$$\frac{1}{\gamma}\left((1-\gamma)u - (1-\mu_2 R_1)\right)(1-\mu_2)V. \tag{13}$$

It is straightforward to show that this is strictly dominated by payoff realized with $\mu_2^* = \gamma$:

Lemma 2. *Protocol 2's optimal choice is* $\mu_2^* = \gamma$. *Island 2 adoption is* $\frac{1}{\gamma}((1-\gamma)u - 1 + \gamma R_1)$.

Even when protocol 2 sets $\mu_2^* = \gamma$, protocol 2's users are exposed to protocol 1's liquidity choice. Total capital in protocol 2, X_2, is

$$\begin{cases} \frac{1}{\gamma}((1-\gamma)u - (1-\gamma R_1)) & \text{if } R_1 < 1 \\ 1 & \text{otherwise.} \end{cases} \tag{14}$$

Now consider protocol 1's choice given demand X_2 from protocol 2. In contrast to the benchmark case, note that all γX_2 tokens held in protocol 2 will be paid to users seeking withdrawal at $t = 1$. Hence, given X_1 users from island 1, the total capital is $X_1 + \gamma X_2$ and total expected withdrawal at $t = 1$ is $\gamma(X_1 + X_2)$.

If protocol 1 chooses $\mu_1 = \frac{\gamma(X_1+X_2)}{X_1+\gamma X_2}$, which fully satiates liquidity demand, it obtains a payoff:

$$(1+\gamma)(1-(1+a)\mu_1)V. \tag{15}$$

The base protocol's payoff strictly diminishes with protocol 2's holdings X_2, which impose an additional cost $a\gamma V$ by requiring the base protocol to increase its liquid holdings. Island 1 users face:

$$\gamma \min\left\{1, \frac{\mu_1(X_1+\gamma X_2)}{\gamma(X_1+X_2)}\right\} - \theta \mathbb{1}_{R_1<1} + (1-\gamma)u \tag{16}$$

Conditional on $\mu_1 < \frac{\gamma(X_1+X_2)}{X_1+\gamma X_2}$, an island 1 user $\bar{\theta}_1$ is indifferent between depositing and not:

$$\bar{\theta}_1 = \frac{1}{\gamma}\left((1-\gamma)u - (1-\gamma R_1)\right) \tag{17}$$

Note that the cutoff for island 1 users is identical to that of island 2 users, since the liquidity characteristics between the two protocols are identical. R_1 reduces to:

$$R_1 = \frac{1+\gamma}{2\gamma}\mu_1, \tag{18}$$

which implies that

$$\bar{\theta}_1 = \frac{1}{\gamma}\left((1-\gamma)u - \left(1 - \frac{1+\gamma}{2}\mu_1\right)\right). \tag{19}$$

Protocol 1's payoff conditional on $\mu_1 < \frac{2\gamma}{1+\gamma}$ is:

$$\left(\bar{\theta}_1 + \gamma\bar{\theta}_2\right)(1-(1+a)\mu_1)V \tag{20}$$

$$\propto \left((1-\gamma)u - \left(1 - \frac{1+\gamma}{2}\mu_1\right)\right)(1-(1+a)\mu_1) \tag{21}$$

The base protocol's optimal stratey given $\mu_1 < \frac{2\gamma}{1+\gamma}$ is characterized below:

Lemma 3. *Given $\mu_1 < \frac{2\gamma}{1+\gamma}$, the base protocol's optimal μ_1' and market share $\bar{\theta}'$ are*

$$\mu_1' = \frac{1}{2(1+a)} - \frac{(1-\gamma)u - 1}{1+\gamma} \tag{22}$$

and

$$\bar{\theta}_1' = \frac{1}{\gamma}\left(\frac{1+\gamma}{4(1+a)} - \frac{1-(1-\gamma)u}{2}\right). \tag{23}$$

I show that there exists a cutoff value for a such that the base protocol underprovides liquidity, and moreover, this cutoff is tighter than in the benchmark economy:

Proposition 2 (Systemic illiquidity)**.** *There exists $\bar{a}_2 \in (0, \bar{a}_1)$ such that for $a > \bar{a}_2$, protocol 1's equilibrium liquidity provision is $\mu_1^* < \frac{2\gamma}{1+\gamma}$.*

In a vertical economy, the base protocol must fully internalize the entire economy's liquidity needs without commensurate gains from a broadening userbase. The cross-subsidization between long-term users, i.e. those who do not experience liquidity needs, and short-term users, i.e. those hit by the γ shock, is what allows the base protocol to internalize the unit cost a associated with managing liquidity. Protocol 2 is able to hold just enough liquidity to allow its users to access liquidity held by the base protocol while retaining the entire surplus arising its long-term users. In effect, by bootstrapping liquidity, protocol 2 transfers the cost $\gamma a X_2$ to the base protocol.

The core insight is that composability allows upper-layer protocols to replicate the liquidity features for their respective users without contributing to the lower-layer protocol's pooling mechanism.

In the model, composability mechanically expand its reach to potential users by allowing upper-layer protocols to extend contingent liquidity, which is highly valued by users. For $a < \bar{a}_2$, the base protocol internalizes costs and holds sufficient liquidity for its users and protocol 2's users. In equilibrium, both protocols run in full capacity, with the entire mass of users on each island depositing capital.

However, when a rises above $\bar{a}_2$, the base protocol rations liquidity in equilibrium. Relative to the benchmark with one protocol, there are two key distributional consequences. First, users with higher liquidity-sensitivity no longer use the protocol. The base protocol calibrates its liquidity provision that effectively excludes users with $\theta > \bar{\theta}$. Second, composability shifts access from island 1's users to island 2's users. In aggregate, the protocol economy renders service to less liquidity-sensitive.

The total user base is $2\bar{\theta}$. Composability net expands access if $2\bar{\theta} > 1$, i.e.

$$\frac{1}{\gamma}\left((1-\gamma)u - \left(1 - \gamma\frac{1+\gamma}{2\gamma}\mu_1'\right)\right) > \frac{1}{2} \tag{24}$$

which reduces to:

$$(1-\gamma)u - 1 + \frac{1+\gamma}{2(1+a)} > \gamma, \tag{25}$$

which requires $a < \frac{(\gamma-1)(-2\gamma+2u-3)}{2(\gamma-1)u-2(\gamma^2+\gamma-1)}$. For $u < \frac{1+3(1+\gamma)}{4(1+\gamma)(1-\gamma)}$, this condition always hold. This implies that in equilibrium, rationing strictly diminishes the total user base if u is not too large:

Proposition 3. *Suppose that $a \in (\bar{a}_2, \bar{a}_1)$ and $u < \frac{1+3(1+\gamma)}{4(1+\gamma)(1-\gamma)}$. Then, the total users in the protocol economy is lower relative to the benchmark economy.*

Intuitively, liquidity rationing occurs when externalities are too large. Furthermore, rationing intensifies with lower u, as users gain lower value relative to liquidity risk. The discontinuous drop in user adoption dominates the net benefit of expanding service.

The extension to multiple islands is straightforward. Consider $n+1$-layer protocol economy. I establish that the cutoff $\bar{a}_n = \bar{a}(n)$, and furthermore that $\bar{a}(n)$ is decreasing in n:

Proposition 4. $\bar{a}_{i+1} < \bar{a}_i$ *for* $i > 1$.

This result formalizes the main insight: composability results in a waterfall of externalities that flows down to the base protocol, and ultimately results in chronic illiquidity across the entire protocol economy.

4 Rival protocols

So far, I assumed that protocols are non-rival, i.e. they do not compete with each other for users. Nonrivalry isolates the negative externality that higher-layer protocols impose on lower-layer protocols when an arrangement depends on pooling. For liquidity provision, the protocol allocates funds to liquid assets on behalf of its user base, and offers liquidity to users in need of funds early. As the ratio of short-to-long term users rises as a result of liquidity bootstrapping, the base protocol no longer finds it too costly to provide its service to all users.

Even though the base protocol "rations" its service from users with high liquidity value (large θ) when upper-layer protocols extractive behavior is too strong, the total mass of users can net increase with non-rivalry, because they cater to a different segment of users. In this section, I show that this may no longer be the case with rival protocols.

Consider the baseline model with 2 protocols and with the following modifications. First, both protocols offer perfectly substitutable goods for a mass $b < 1$ of users from each island. Second, both protocols can offer per-user transfer τ_i to its protocol users at $t = 2$, where τ_i is bounded by protocol revenue. Transfers represent levers through which protocols compete, where protocols are subject to non-negative payoff.

First, note that for any strategy employed by the base protocol, protocol 2 can match and replicate the service and retain greater profits. This implies that protocol 2 can also choose a greater τ_2, and effectively transfer its payoff to users.

In contrast to the baseline model, there are $2b$ mass of users who decide which protocol to use. Observe that the liquidity characteristics between the two protocols are identical, and determined by μ_1. If the liquidity characteristics are identical between the two protocols, then users strictly prefer the protocol that offers greater transfers.

There are two candidate strategies for protocol 2: either retreat to its local market, $1 - b$, or compete for $2b$ users by matching protocol 1's transfer τ_1. Throughout this section, I fix protocol 2's asset strategy to $\mu_2 = \gamma$ following Lemma 2. Protocol 2 payoff from focusing on $1 - b$ is:

$$(1-b)\bar{\theta}(1-\mu_2)V. \tag{26}$$

Protocol 2's payoff from competing is

$$(1+b)\bar{\theta}\left[(1-\mu_2)V - (1-\gamma)\tau_1\right]. \tag{27}$$

Protocol 2's best response is competing if

$$2b\bar{\theta}(1-\mu_2)V - (1+b)\bar{\theta}(1-\gamma)\tau_1 > 0, \tag{28}$$

which requires $\tau_1 < \frac{2b}{1+b}V$. Protocol 1 faces a choice between deter ($\tau \geq \frac{2bV}{(1+b)}$) or retreat ($\tau = 0$) and maximizing its payoff from its local non-contested market. The case where protocol 1 retreats to its local market is outcome equivalent to the non-rival protocol economy with $(1-b), (1+b)$ users on protocols 1 and 2. It follows directly rivalry shifts the cutoff on a closer to 0.

To deter protocol 2, protocol 1 can now offer transfers to users, which benefits protocol 1's service by diluting the liquidity impact that protocol 2 has over its service. Second, when μ_1 drops below full liquidity provision, transfers are subsidized by protocol 2, which offers funds in exchange for negative NPV $t = 1$ claim. Offering $\tau = \frac{2bV}{(1+b)}$ obtains $1 + b$ native users and yields:

$$\bar{\theta}\left[(1+b+(1-b)\gamma)(1-(1+a)\mu_1)V - (1+b)(1-\gamma)\tau\right] \tag{29}$$

$$= \bar{\theta}\left[(1+\gamma-b(1-\gamma))(1-(1+a)\mu_1)V - 2b(1-\gamma)(1+a)\mu_1 V\right] \tag{30}$$

In contrast, the base protocol's payoff from retreat is:

$$(1-b+(1+b)\gamma)\bar{\theta}(\mu_{retreat})(1-(1+a)\mu_{retreat})V \tag{31}$$

Although in principle, deterrence is possible, this implies that deterrence cost is generally too high, and in equilibrium, the base protocol retreats:

Proposition 5. *With rival protocols, the base protocol rations liquidity if $a > \bar{a}_{rival}$ for some cutoff $\bar{a}_{rival}$. Furthermore, liquidity provision is strictly more constrained with rival protocols, i.e. $\bar{a}_{rival} < \bar{a}_2$.*

5 Composable Asset Transformation

I highlighted the composability problem in the context of liquidity provision. This choice is motivated by an emerging tokenized US dollar ecosystem (Lee 2025). In this section, I outline how composability is enables a novel form of asset transformation, and provide a mapping of the composed US dollar market at large.

Tokenization refers to the token representation of traditional financial assets, which imbues traditional assets with blockchain functionalities. Many applications for tokenized assets replicate existing services. For example, decentralized exchanges enable (whitelisted) investors to swap stablecoins and tokenized treasury funds. This represents a basic tool for investors to manage liquidity across different instruments directly on blockchains, without the assistance of traditional intermediaries or the issuer.

I document a novel application of composability of tokenized assets to alter the liquidity, access, return, and risk characteristics of financial claims. I refer to this practice as *composed asset transformation*. Each form of alteration is defined below:

- **Access**. a process through which the set of potential users who can access a type of asset is broadened.
- **Liquidity.** a process through which the liquidity of an asset is enhanced.
- **Return.** a process through which an asset's expected returns are increased.
- **Risk.** a process through which an asset is restructured to alter the risk profile.

Liquidity, return, and risk transformation are forms of asset transformation commonly observed in the traditional financial system. Access transformation is, however, a unique form that emerges in the context of permissionless blockchains. Classifying tokenization activity through the lens of asset transformation can be instructive in understanding how certain arrangements could improve the utility and demand of payment stablecoins.

Composed transformation results in three tiers of tokenized US dollars that become progressively more distant from the traditional financial assets, as illustrated in Figure 1. Payment stablecoins and other tokenized assets represent the

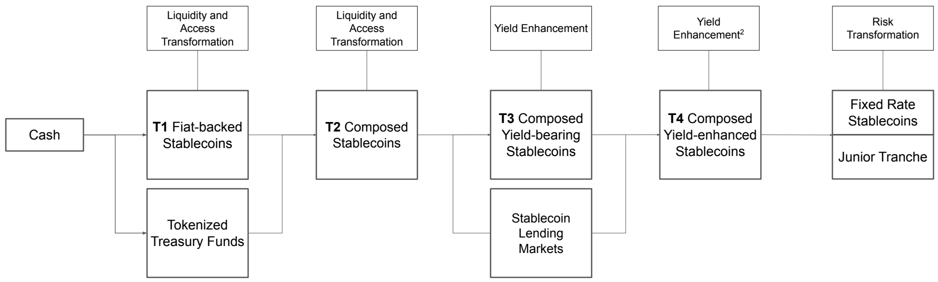

Figure 1: Composed Asset Transformation

first tier (T1). In this tier, cash is allocated across various traditional financial arrangements and assets as reserves, and tokens are issued to be circulated on-chain. These tokens offer redemption at-par, and since underlying assets are longer-term, constitutes a form of liquidity transformation. In the case of payment stablecoins, they can be held by anyone without verification. This aspect permits a broader set of holders than those who can access bank deposits or treasury securities, and thus involves access transformation.

The second tier (T2) is comprised of assets that use T1 assets as backing. A key example is composed stablecoins, which are tokens backed by T1 assets (tokenized money market funds and payment stablecoins). Like T1 stablecoins, T2 stablecoins are intended to provide greater liquidity to its holders than from directly holding its underlying assets, and to broaden (indirect) access to tokenized US dollars, and thus undergo liquidity and access transformation. T2 also includes on-chain Treasury funds, which are backed by T1 treasury funds and represent re-issuance treasury funds made accessible to a broader class of investors.

The third tier (T3) is comprised of tokens that are augmented. For example, a yield-bearing stablecoin is created by holding T1 or T2 stablecoins, (partially) deploying stablecoins to a lending protocol or market, and issuing tokens that pay holders the yield generated from lending activity. This form of yield enhancement changes the return characteristics of the original stablecoin and is achieved by composing non-interest-bearing stablecoins with various smart contracts. Yield-bearing stablecoins can be re-deployed to further enhance yield or be deposited in a smart contract that issues classes of tokens representing different risk-return characteristics, effectively securitizing different types of claims

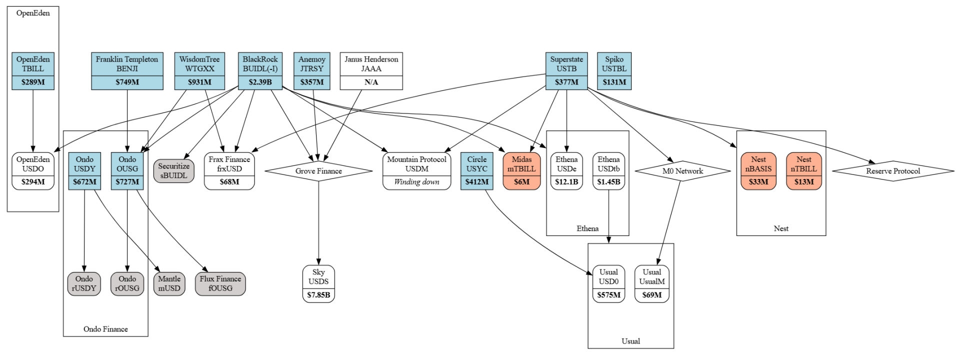

Figure 2: Composed US Dollar System.

through programmability.

I build a hand-collected data on the holdings of tokenized Treasuries using publicly disclosed smart contract addresses either directly by providers, or aggregated on Dune. The dataset examines holdings as of August 2025 across 10 blockchains.[6] This provides a comprehensive view on the state of composed asset transformation with tokenized US dollar assets.

Although nascent, composed asset transformation is not a theoretical possibility but are already being implemented on blockchain systems today. Figure 2 provides a breakdown of the layers through which cash is transformed and enhanced through layers of composed protocols, focusing on the tokenized fund industry as the starting point. Colors represent different stages of transformation: blue represents tokenized treasury funds; grey represents wrapped or rebasing tokens; and red represent yield-bearing tokens. Diamond shaped are entities rather than products.

Although composability enables innovative products to emerge, it is a novel source of financial stability risks. Composability allows tokens to be seamlessly used to support various arrangements, which can result in complex interdependencies between tokens. As shown in Figure 2, multiple different tokens can be held by an entity as reserves to back a newly issued token. This arrangement creates channels of cross-contagion: it exposes the backing tokens to the financial and operational risks of the issued token, and also links backing tokens to each other through co-mingling, reminiscent of complex counterparty risk issues in the

[6] The list is Avalanche, Ethereum, Polygon, Aptos, Arbitrum, Optimism, Solana, Mantle, Base, and Plume.

global financial crisis.

Each layer of composed asset transformation adds utility to the original claim but may amplify risks through leverage and rehypothecation. For example, composed stablecoins hold T1 stablecoins in place of cash to serve as their liquid asset, increasing the effective ratio of cash to Treasury securities. In the event of a run, composed stablecoins being unwound could put sudden, unexpected redemption pressures on the backing T1 stablecoin, which may not hold sufficient liquid claims. Ultimately, composed tokens may bundle safe assets with risky claims, which could expose safe assets to excess volatility arising from their risky counterparts. Failures or losses from risky operations could lead to fire sales and a domino effect across composed tokens and protocols, with these shocks ultimately being transmitted back to the banking system and Treasury market and disrupting the traditional financial system.

6 Conclusion

This paper sheds light on inherent challenges with achieving financial arrangements that depend on pooling mechanisms in a composable financial system. I demonstrate this in the context of liquidity provision, but the insights apply broadly. In hindsight, the issues surfaced here are obvious. In a composable system, resources, whether in the form of assets or protocols, are freely utilized by a wide array of users. A tragedy of the commons arises whenever there does not exist a mechanism through which users internalize the costs associated with maintaining such resources.

This raises the bar on how we should think about the systemic value of composability. As a start, it reveals that unlocking gains through composability requires more careful consideration on how it impacts the feasibility of certain markets or systems. From an implementation standpoint, the most straightforward solution is through price discrimination. Protocols that depend on pooling mechanisms could programmatically classify users and dependent protocols based on public signals regarding their type or utilization; in other words, a mechanism design problem. At the same time, discriminatory access or pricing could deteriorate the very values that make a modular, composable system appealing in the first place. Building a more comprehensive perspective on the efficient set of financial primitives to balance is a natural question of future research.

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A Proofs

Proof of Lemma 1. The protocol maximizes

$$\Pi(\mu) = \frac{1}{\gamma}\left((1-\gamma)u - (1-\mu)\right)(1-\mu-a\mu)V \tag{32}$$

Reorganizing the FOC:

$$\mu' = \frac{2+a}{2(1+a)} - \frac{u(1-\gamma)}{2} \tag{33}$$

and implies:

$$\bar{\theta}' = \frac{1}{\gamma}\frac{(1-\gamma)(1+a)u-a}{2(1+a)}. \tag{34}$$

Substituting μ' back into the objective function yields:

$$\Pi(\mu') = \frac{V}{\gamma}\frac{\left[a-u(1-\gamma)(1+a)\right]^2}{4(1+a)}, \tag{35}$$

which is positive since $\gamma(1+a) < 1$.

□

Proof of Proposition 1. Full liquidity provision occurs only if:

$$\Pi(\mu') < \left(1-(1+a)\gamma\right)V. \tag{36}$$

Expanding and rearranging terms with respect to $(1+a)$:

$$(1+a)^2\left[(1-u(1-\gamma))^2+4\gamma^2\right] - (1+a)\left[2(1-u(1-\gamma))+4\gamma\right]+1<0 \tag{37}$$

The condition is satisfied when $a < \bar{a}$, where:

$$\bar{a} = \frac{(1-u(1-\gamma))+2\gamma+2\sqrt{\gamma(1-u(1-\gamma))}}{(1-u(1-\gamma))^2+4\gamma^2} - 1 < \frac{1}{\gamma} - 1. \tag{38}$$

□

Proof of Lemma 3. We consider the optimization problem with respect to μ_1. Protocol 1 maximizes

$$\Pi(\mu_1) = (1+\gamma)\frac{1}{\gamma}\left[(1-\gamma)u - \left(1 - \frac{1+\gamma}{2}\mu_1\right)\right](1-(1+a)\mu_1)V \tag{39}$$

The FOC respect to μ_1:

$$\mu_1' = \frac{1}{2(1+a)} + \frac{1-u(1-\gamma)}{1+\gamma} \tag{40}$$

and implies:

$$\bar{\theta}_1' = \frac{1}{\gamma}\left(\frac{1+\gamma}{4(1+a)} - \frac{1-(1-\gamma)u}{2}\right). \tag{41}$$

□

Proof of Proposition 2. Protocol 1 provides full liquidity provision if:

$$\Pi(\mu_1') < (1-\gamma-2a\gamma)V \tag{42}$$

Substituting μ_1' and solving for the roots of this quadratic inequality gives bound $\bar{a}_2$:

$$\bar{a}_2 = \frac{1+\gamma}{2}\left(\frac{(1-X)+2\gamma+2\sqrt{\gamma(1-X)}}{(1-X)^2+4\gamma^2}\right) - 1 \tag{43}$$

which holds since $\gamma < 1$.

□

Proof of Proposition 4. Observe that the base protocol's problem with $n+1$ protocols is identical that with $N = 2$ with mass n users on island 2. We have:

$$R_1 = \frac{1+n\gamma}{(1+n)\gamma}\mu_1, \tag{44}$$

and

$$\bar{\theta}_1 = \frac{1}{\gamma}\left((1-\gamma)u - \left(1 - \frac{1+n\gamma}{1+n}\mu_1\right)\right) \tag{45}$$

Generalizing protocol 1's problem to such is:

$$\left((1-\gamma)u - \left(1 - \frac{1+n\gamma}{1+n}\mu_1\right)\right)(1-(1+a)\mu_1) \tag{46}$$

The first order condition yields:

$$\mu_1(n) = \frac{1}{2(1+a)} - \frac{((1-\gamma)u-1)(1+n)}{2(1+n\gamma)} \tag{47}$$

Note that since $\frac{1+n}{1+n\gamma}$ increases in n, $\mu_1'(n)$ decreases in n. Protocol 1 payoff with full liquidity provision is:

$$(1+n\gamma)\left(1-(1+a)\frac{\gamma(1+n)}{1+n\gamma}\right)V = (1+n\gamma-(1+a)\gamma(1+n))V \tag{48}$$

$$= (1+n\gamma-\gamma(1+n)-a\gamma(1+n))V \tag{49}$$

$$= (1-\gamma-(1+n)\gamma a)V \tag{50}$$

Protocol 1 payoff is greater with full liquidity provision if:

$$(1-\gamma-(1+n)\gamma a) > \frac{1+\gamma}{\gamma}\left((1-\gamma)u - \left(1-\frac{1+n\gamma}{1+n}\mu_1(n)\right)\right)(1-(1+a)\mu_1(n)) \tag{51}$$

which holds if a is sufficiently small:

$$a < \bar{a}(n) = \frac{1+n\gamma}{1+n}(\bar{a}_1+1)-1 \tag{52}$$

where $\bar{a}_n$ strictly decreases in n.

□