Temporal: Continuous Yield Curves for Real-World DeFi

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November 2023

Abstract

Temporal is a novel liquidity protocol introducing market-determined, continuous yield and forward curves for digital assets. Addressing the inefficiencies prevalent in the current DeFi landscape, Temporal offers a solution that enables credit markets to reflect underlying economic conditions, brings economic efficiency of markets to their theoretical limit, and introduces customized maturities. The protocol's AMM mechanism allows for fixed-rate credit markets at custom durations, creating real-time continuous yield curves. This paper presents the technical underpinnings of Temporal's AMM, including its interest rate determination mechanism, liquidity provision strategies, and the practical applications in yield trading and on-chain bond dealing. Temporal bridges a significant gap in DeFi's infrastructure.

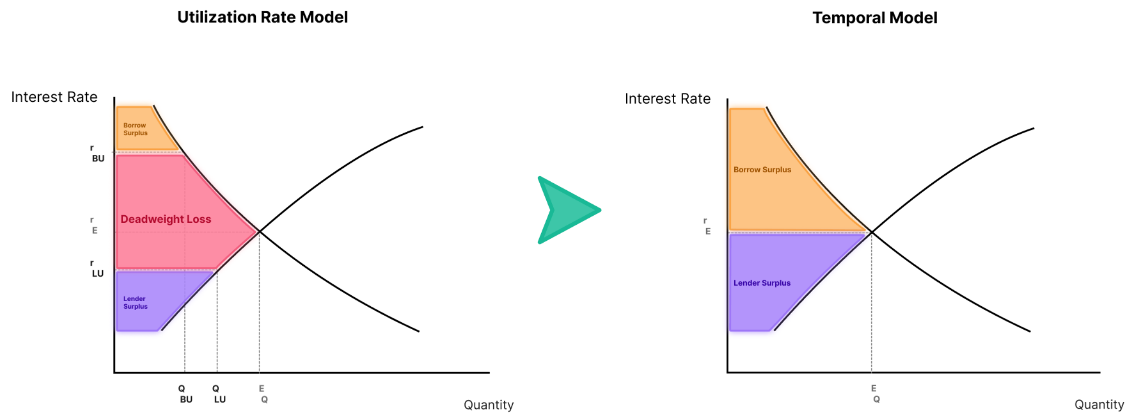
Introduction

Market-Determined Yield Curves are essential infrastructure for financial ecosystems. This is particularly evident at the short-end where instruments like the Repo trade to the tune of $5 trillion in daily volume, and are vital for well-run capital markets. Fundamentally, Yield Curves are requisite for pricing all financial instruments, enhancing liquidity, and enabling efficient resource allocation.

Despite their importance, a notable absence of market-determined yield curves is evident within DeFi. Incumbent solutions here rely heavily on the "Utilization Rate Model" instead of a market-determined yield curve, and consequently impose large scale inefficiencies on the system. This model's limitations are threefold:

1. **Interest rates do not reflect market conditions**. Rates under incumbent models are mechanically derived and updated manually, typically driven by governance. Implying that interest rates set by these models do not reflect the underlying economic reality.

2. **Economic inefficiency, i.e misallocation of resources**. Borrowing and lending markets in DeFi operate far from their equilibrium quantities, able to provide only 50% of the surplus actually owed to borrowers and lenders. Leading to substantial deadweight loss. This is the case for stablecoins like USDT where utilization rates tend to be 80%+. Utilization drops to ~50% for grade A assets like ETH, down to 25% for wstETH, and even lower for long-tailed assets[1]. Thus, the deadweight loss is much greater than 50% for most digital assets under the utilization rate regime.



3. **Crippling choices in maturity**. One of the biggest advances TradFi made was the introduction of the Repo. Facilitating borrowing and lending across various short-term maturities for 1-day, 2-days, etc. up to a year. The advantages are simple - matching maturities for your own borrow / lend needs reduces funding rates to long positions, and allows for a cheaper method to cover short positions. Such versatility greatly enhances liquidity. DeFi lacks this capability, unable to support both custom maturities and fixed rates, in the absence of a Yield Curve.

Temporal addresses these issues by introducing novel AMM-based, real-time, continuous yield curves to DeFi. The innovation enables fixed rates, custom maturities and market-determined yield curves. Key benefits include:

1. No Liquidity Fragmentation
2. Capital Efficiency
3. And Low Slippage

The mechanism we outline in the following sections is generalizable to creating forward curves as well. Bringing unprecedented functionality to on-chain credit and derivatives markets.

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[1] Estimated from popular protocols like Aave and Radiant

Section 1: AMM Mechanism

Temporal's novel AMM (Automated Market Maker) enables fixed-rate credit markets at custom durations by creating a real-time, continuous, and market-determined yield and forward curves

A. Interest Rate Determination Mechanism: Zero Coupon

1. This describes single asset Temporal AMM pool for asset 'X'
2. Let L_d be the number of asset units in the pool which unlock upon completion of the specific period 'd' (for **d**uration). Duration is specified in days.
3. Let A_d be the number of assets in the pool which unlock on or after completion of the specific period 'd' (L_d)
    a. $A_d = \sum_{d}^{d_{max}} L_d$ (from d through to d_{max})
4. Let iX be the 'notional interest units'; these are not real assets, but just book-keeping units created at pool bootstrapping to initialize a desired yield curve.
5. Let iX_d be the number of units of iX at d.
6. Let Y_d (**Y**ield) be the interest rate at d
    a. $Y_d = [(\frac{A_d + iX_d}{A_d})^{(\frac{365}{d})}] - 1$
7. For any transaction of 'u' units at 'd', the following occurs
    a. $L_d \pm u$; implying $\circlearrowleft_{z=d_{min}}^{d} (A_z \pm u)$. where, $\circlearrowright$ represents the function iterates itself from min to max value (here, d_{min} $through\ d$).
    b. $\circlearrowleft_{z=d_{min}}^{d} (iX_z \pm i)$; where $i = u \times \{(1 + Y_d)^{(\frac{d}{365})} - 1\}$
    c. $\pm$ are determined by the table below in section 'Transaction Impact'
8. In a borrowing / lending transaction (from pool's perspective), 'u' units are transferred to / from the pool at the time of the transaction, and $[u \times \{(1 + Y_d)^{(\frac{d}{365})}\}]$ are to be repaid by / to the pool at 'd'

B. Liquidity Provision

The AMM liquidity pool is bootstrapped with equity from LPs and notional interest units (iX) are created as desired to set up an initial yield curve in line with the reference market.

The LP position is an equity position designed to manage the AMM's balance sheet. The below formulas ensure an optimal amount of pool equity with capital adequacy and efficiency:

1. Let the income gap G be defined as follows:

$$G_d = Interest\ Income_d + Transaction\ Fees_d - Interest\ Expense_d$$

   - $where\ these\ income/expense\ items\ are\ attributable\ to\ lends/borrows\ with\ duration \geq d.$

2. $IF(Equity_d \leq G_d) \rightarrow pause\ further\ lending$ for durations ≥ d
   - $Equity_d\ represents\ total\ pool\ equity\ for\ durations \geq d$

The following points describe the structure of an LP position:

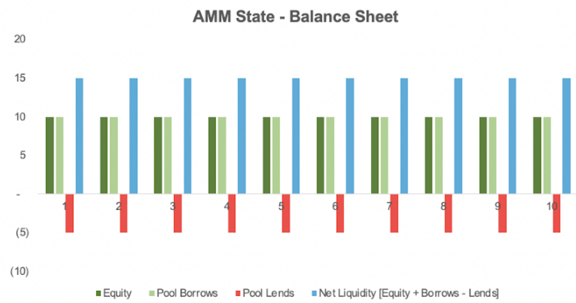
1. NAV (Net Asset Value)
   a. Cumulative since pool inception [i. LP funds provided to pool – ii. LP funds exited from pool + iii. Pool transaction fees earned + iv. Pool interest earned – v. Pool interest paid – vi. Other losses / expenses]

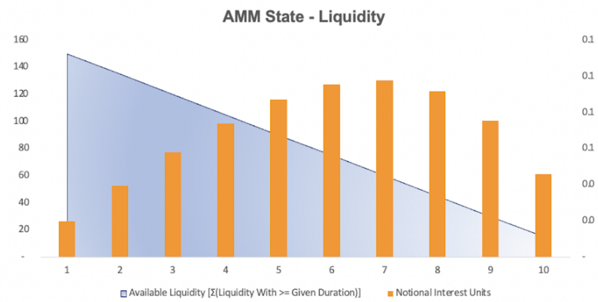
2. Pool Entry
   a. Percentage of pool owned by entering LP = $\frac{LP\ Amount}{[NAV \times (1-Discount)] + LP\ Amount}$
   b. Discount = $(\frac{Y_{min}}{Y_{max}}) \times (\frac{D}{D_{max}})$
      i. where D is LP duration
      ii. D_{min} and D_{max} are the minimum and maximum durations of the yield curve
      iii. Y_{min} and Y_{max} are corresponding yields
   c. Updation of all other LP stakes whenever an LP enters => Percentage of pool owned by any other LP × (1 – Percentage of pool owned by entering LP)

3. Pool Exit
   a. $\$LP_{exit} = \%\ owned\ by\ LP_{exit} \times Pool\ NAV$
   b. Updation of all other LP stakes whenever an LP exits => Percentage of pool owned by any other LP × (1 + Percentage of pool owned by exiting LP)

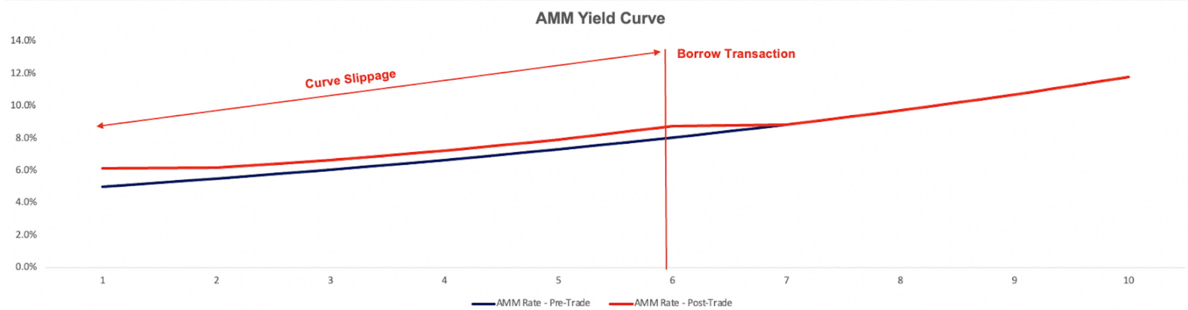
C. Simulation

AMM State - Pre Trade

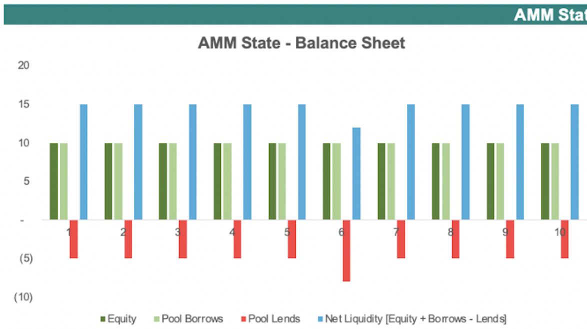


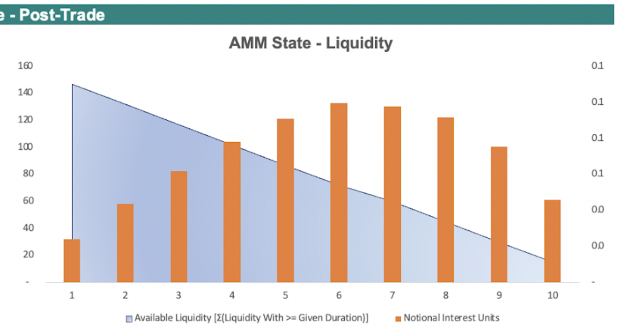


AMM State Change - Borrow Transaction



AMM State - Post-Trade





AMM Computation	Duration >>									
Pool State Pre-Transaction	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Equity	10	10	10	10	10	10	10	10	10	10
Pool Borrows	10	10	10	10	10	10	10	10	10	10
Pool Lends	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)
Net Liquidity [Equity + Borrows - Lends]	15	15	15	15	15	15	15	15	15	15
Available Liquidity [Σ(Liquidity With >= Given Duration)]	150	135	120	105	90	75	60	45	30	15
Notional Interest Units	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
Total Notional Interest %	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.2%	0.2%	0.3%	0.3%
AMM Rate - Pre-Trade	5.0%	5.5%	6.1%	6.7%	7.3%	8.1%	8.9%	9.7%	10.7%	11.8%
Transaction	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Available Liquidity	150	135	120	105	90	75	60	45	30	15
Notional Interest	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
Borrow - Funds Out						(3.0)				
Notional Interest In	-	-	-	-	-	0.0	-	-	-	-
Available Liquidity	147	132	117	102	87	72	60	45	30	15
Notional Interest	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
Pool State Post-Transaction	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Equity	10	10	10	10	10	10	10	10	10	10
Pool Borrows	10	10	10	10	10	10	10	10	10	10
Pool Lends	(5)	(5)	(5)	(5)	(5)	(8)	(5)	(5)	(5)	(5)
Net Liquidity [Equity + Borrows - Lends]	15	15	15	15	15	12	15	15	15	15
Available Liquidity [Σ(Liquidity With >= Given Duration)]	147	132	117	102	87	72	60	45	30	15
Notional Interest Units	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
Total Notional Interest %	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.2%	0.2%	0.3%	0.3%
AMM Rate - Post-Trade	6.1%	6.2%	6.6%	7.2%	7.9%	8.8%	8.9%	9.7%	10.7%	11.8%

D. Technical Implementation Note

The Temporal AMM produces a forward curve by adding a duration parameter. Consequently, time and space complexity exponentially increase for forward curve AMMs as opposed to incumbent AMMs. Thus, the traditional brute force approach is not efficient for such a construction, instead a tree like structure is proposed. We're using a self-balancing Red-Black (RB) Tree to achieve:

1. **Efficient Lookups**: O(logN) time complexity for Lookups, Insertion and deletion; where N is max LP duration.

2. **Concurrency**: The RB Tree is structured to allow concurrent Read and Write. Powers the system for a higher transaction throughput, where multiple users lend, borrow, and LP simultaneously.

Section 2: Trades & Applications

A. Trades

I. Borrow Short Lend Long

Banks primarily derive income through their net interest margin, a strategy encapsulated by the phrase "borrow short, lend long." This approach entails borrowing an asset for a brief period, typically at a low interest rate—for instance, over a span of 20 days—and subsequently lending out the same asset at a higher interest rate for an extended duration, such as 100 days. The borrowing process is rolled over into the next 20-day period. Short duration fixed rates are crucial here. This straightforward yet effective method of generating profit is notably absent from DeFi.

II. Yield Curve Trade

A simple way for a trader to express whether the curve according to them should be steeper or flatter. Say the 2 month ETH bond yields 3.5%; the 3mo yields 3.8%; 5mo yields 4.3%; and the 10mo yields 5.2%. Implying that the 2's - 10's curve is trading at 5.2% - 3.5% = 170 bps.

The trader might feel based on analysis that this is too flat and expect the curve to steepen. They can express this view by buying the 2mo ETH bond and shorting the corresponding 10mo bond. To remain at the current risk level, this will be done in PV01-equal amounts. For completeness let's say the PV01 of 10mo ETH bond is 7.15 and the PV01 of 2mo ETH bond is 1.49 – the trader would buy 4.79 units of 2mo ETH for each unit of 10mo ETH that is shorted.

These are popular and cost efficient ways for market participants to express their views on the yield curve and actually drive yield behavior. These trades/activities make sure that the curve is reflective of on-ground market reality, and consequently DeFi markets are representative of the underlying asset economics—corrections that are not possible under current DeFi credit market structures.

B. Applications

I. Yield Trading

Yield-bearing assets such as ETH can be liquid staked and separated into a yield component (YT) and a principal component (PT).

Existing AMMs for trading YT vs. PT work on the formula: Price(YT) + Price(PT) = Price(Underlying). Each AMM pool facilitates the exchange of YT vs. PT for a specific asset (e.g. ETH), with a specific maturity date (e.g. 31/12/23).

With Temporal's version, a single pool facilitates the exchange of YT vs. PT for a specific asset for any maturity with given frequency (e.g. daily maturities) and max-min maturities (e.g. 'today's date + 1 day' to 'today's date + 365 days').

II. On-Chain Bond Dealer AMM

Enhancing institutional bond market efficiency through Temporal's unified market for on-chain bonds.

In conventional bond markets, individual bonds are bought and sold by several OTC bond dealers quoting their prices for each bond. These bonds are quoted individually by dealers, and current TradFi market structure needs active participation from dealers. This characteristic results in concentration of trading activity predominantly at the inception and near maturity of the bonds. Consequently, leads to challenges in achieving accurate pricing or accessing a liquid market for bonds during the intermediary years of their lifespan.

Temporal's AMM vastly improves market efficiency by enabling automated pricing and dealing bonds across any duration or interest rate. Dealers simply initiate and maintain issuer-specific yield curves for single-asset bond AMMs. Only tactically adjusting the spread without altering the state of the underlying AMM.

Central to Temporal's system is its utilization of shared liquidity across the entire yield curve. In contrast to traditional OTC systems where there are separate 'fragmented' markets for each bond (having its own duration and interest rate).

The framework is versatile and generalizable to Treasuries, Investment Grade Bonds, and even the less frequently traded private credit. Dealers are enabled to allocate funds across various single-asset bond AMMs with ease, significantly reducing operational complexities.

The mechanism is outlined in Annexure B.

Section 3: Go-To Market Overview

Temporal is a liquidity protocol / layer designed to make it easier for other DeFi protocols, as well as centralized exchanges (CEX), to seamlessly integrate market-determined yield and forward curves into their dApps. Supporting a host of applications ranging from general purpose borrowing and lending to custom maturity yield trading; or on-chain bond dealing.

Additionally, Temporal provides an array of pre-built modules like under-collateralization with upto 10x leverage, fixed rate facilities, and a customizable front-end module, to facilitate this process.

Users of dApps or protocols integrated with Temporal do not need to possess TEMP tokens to transact. They can use the native tokens of the dApp they are interacting with. However, to access Temporal's features, the foundation behind the dApp / protocol will need to hold a certain amount of TEMP tokens, proportional to their transaction volume on Temporal[2].

This approach helps maintain a balanced ecosystem and adds value to the TEMP token.

Conclusion

Temporal represents a significant step forward in the evolution of DeFi: market-determined yield and forward curves through a novel AMM structure. Delivering unparalleled levels of sophistication and functionality via an elegantly simple design.

Temporal not only solves existing inefficiencies in DeFi borrowing and lending markets but also introduces new opportunities for yield trading and on-chain bond dealing. Its innovative approach to liquidity cumulation, interest rate determination, and customized maturities enhances capital efficiency and market liquidity. The Temporal protocol is poised to serve as a vital infrastructure for DeFi ecosystems, facilitating seamless integration with other protocols and centralized exchanges. Empowering users with more effective financial tools.

[2] Token economics and incentive programs are under development as of this writing.

Annexure

A. Yield Trading Generalization

Making the following changes to (1)(A), we can generalize the mechanism for yield trading:

1. Replace X with PTx; PTx is the principal component of a given yield-bearing asset X
2. Retain steps (2) through (6)
3. Bootstrap by setting $iX_d = R_x$ x A_d; where R_x is the staking APR; and then update by creating (+) / deleting (-) iX as APR changes: $\pm\ \Delta iX_d = \pm\ \Delta R_x$ x A_d
4. Point 7 is reframed as follows:
   a. For any transaction of 'u' PTx maturing at 'd', the following occurs:
   b. $L_d \pm u$; implying $\circlearrowleft_{z=d_{min}}^{d} (A_z \pm u)$. where, $\circlearrowright$ represents function iterates itself from min to max value (here, d_{min} $through\ d$).
   c. Define $C_t = yield\ payment\ due\ at\ t\ on\ principal\ u$
   d. $\circlearrowleft_{t=d_{min}}^{d} \circlearrowleft_{z=d_{min}}^{t} (iX_z \pm C_t)$
   e. $\pm$ are determined by table (1)(B) titled 'Transaction Impact'
5. Pricing occurs as follows:
   a. $P_{PTx/X,d} = \frac{1}{(1+Y_d)^{(d/365)}}$
   b. $P_{YTx/X,d} = 1 - P_{YTx/X,d}$
6. Yields are defined as follows
   a. $Y_{PTx,d} = Y_d$
   b. $Y_{YTx,d}$: Solve $\sum_{t=d_{min}}^{d} [\frac{C}{(1+Y_{YTx})^{(t/365)}}] - P_{YTx/X,d} = 0$ for Y_{YTx}; where C is the daily yield on a unit of X; and 'd' is denominated in days.

B. Bond Dealer Generalization

In section 1.A we showed the way Temporal works with zero-coupon borrowing and lending, here we generalize it to work with any bonds. With coupon bonds there is a stream of interest payments before the principal is repaid at maturity, rather than all interest + principal being paid at maturity.

Additionally, in the bond dealer context, we treat a bond sale as a borrow and bond purchase as a lend transaction. There would be a separate AMM pool dealing bonds of a given issuer, e.g. 'US Treasury'. We take the example of one such pool below:

Making the following changes to (1)(A), we can generalize the mechanism to deal in bonds:

1. Retain points 1 through 6

2. Point 7 is reframed as follows:
    a. For any transaction of 'u' face value / principal maturing at 'd', the following occurs:
    b. $L_d \pm u$; implying $\circlearrowleft_{z=d_{min}}^{d} (A_z \pm u)$. where, $\circlearrowright$ represents function iterates itself from min to max value (here, d_{min} $through\ d$).
    c. Define $C_t = coupon\ payment\ due\ at\ t\ on\ principal\ u$
    d. $\circlearrowleft_{t=d_{min}}^{d} \circlearrowleft_{z=d_{min}}^{t} (iX_z \pm C_t)$
    e. $\pm$ are determined by table (1)(B) titled 'Transaction Impact'
3. Point (8) will be adapted as follows:
When a bond is bought / sold by the AMM, each of the bond's payments (*principal 'u' and interest 'c'*) at 't' are discounted at 'Yt' and the whole bond is valued as sum of all discounted payments
    a. Value of bond as per AMM = $\sum_{t=d_{min}}^{d} [\frac{C_t}{(1+Y_t)^{(\frac{t}{365})}}] + [\frac{u}{(1+Y_d)^{(\frac{d}{365})}}]$ where 't' and 'd' are denominated in days

C. Futures Generalization

Making the following changes to (1)(A), we can generalize the mechanism to serve futures markets:

1. Replace X by nX (**n**otional)
2. Similarly to nX introduce nY
3. Rename L_d to $L_{nX,d}$ and similarly $L_{nY,d}$
4. Perform (3) for A_d
5. From (1)(A) omit points 4 through 7
6. Pricing occurs as follows:
    a. $P_{X/Y,d} = \frac{A_{nY,d}}{A_{nX,d}}$
    b. $P_{Y/X,d} = \frac{1}{P_{X/Y,d}}$
7. For any transaction of 'u' units of nX at 'd', the following occurs:
    a. $L_{nX,d} \pm u$; implying $\circlearrowleft_{z=d_{min}}^{d} [A_{nX,z} \pm u]$
    b. $L_{nY,d} \pm \{u \times P_{X/Y,d}\}$; implying $\circlearrowleft_{z=d_{min}}^{d} [A_{nY,z} \pm \{u \times P_{X/Y,d}\}]$
    c. opposing signs as above are used to update 'nX' and 'nY'