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| RESEARCH ARTICLE

Mitigating Impermanent Loss in DeFi: The Concentration-Asymmetric Liquidity Model

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| ABSTRACT

The Concentration-Asymmetric Liquidity Model (CALM) offers a novel solution to address the pervasive issue of impermanent loss (IL) in decentralized finance (DeFi) liquidity provision. Empirical data demonstrates that CALM significantly outperforms traditional liquidity models, such as Uniswap v2, even during extreme market fluctuations. CALM yields higher returns for liquidity providers while mitigating IL risk by allowing single-sided liquidity provision and effectively managing toxic order flow. This article argues for a paradigm shift in DeFi from focusing solely on high annual percentage yields (APY) to prioritizing sustainable, long-term profitability. The Radix platform, built to enhance user experience and developer engagement, provides the infrastructure necessary to support CALM's innovative features and foster broader adoption of DeFi solutions.

| KEYWORDS

Innovation, Liquidity, Impermanent-loss, DeFi, CALM-model

| ARTICLE INFORMATION

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1. Introduction

In Decentralized Finance, the search for high returns inevitably goes hand in hand with soaring risks. A fundamental obstacle is the strong appeal of towering Annual Percentage Yields (APY), a measure that all too often disregards the imminent threats associated with imminent loss (IL). Dissecting historic returns provides a sobering realization: Impermanent Loss often eclipses the appealing APY, resulting in considerable losses for most liquidity providers. Some protocols offer incentives to provide liquidity despite the risks, further complicating net loss-making liquidity schemes.

Losses by Liquidity Providers (LPs) are not limited to 'degen' protocols in the community. Even some of the most established and well-respected protocols leave room for improvement regarding impermanent loss. A quant trader going by the name of Alex on X (then Twitter) observed that IL, due to toxic order flow (ie arbitrage) experienced by liquidity providers on a major decentralized exchange, had outweighed their fee income at the largest liquidity pair on this exchange's v3 implementation (ETH/USDC) by just over 100 M$ [1], [2]. That is one hundred million dollars lost to the arbitrageurs at just one liquidity pair! Shockingly, the concentrated liquidity feature caused these exchange LPs to be, on average, worse off after fees than the same exchange's v2 features would have been before fees. A study published by a decentralized liquidity protocol investigated 17 large pools in just the first half of this major exchange's V3 lost a collective 60.8 M$ [10]. Why would any rational actor supply concentrated liquidity under those conditions?

The low-interest environment of the early 2020s has caused capital to chase yield in irresponsible ways. DeFi was one of the routes where yields were outperforming those in the traditional financial system. For a short while, the meteoric rise of decentralized exchanges seemed obvious and inevitable. Still, the cold, hard truth revealed by Alex's analysis is that the basic constant product AMM with concentrated liquidity (i.e., a v3 implementation) simply does not provide a sustainable operating model. The dream of passively providing liquidity and generating a net income remained over the horizon.

Any DeFi ecosystem can only be viable long-term if the products benefit all participants. The ever-present threat of impermanent loss, especially for concentrated liquidity positions, has proven to be a significant barrier to long-term viability. This article proposes a novel algorithm that aims to mitigate the risk of impermanent loss. It is key to understand that impermanent loss can never be prevented completely, as the only way to prevent it is to not trade away from equilibrium, which is the same as saying that trading would never occur. Thus, if the goal is to provide tokens with a liquidity protocol to create an opportunity to earn fees, one must expose oneself to the risk of impermanent loss to a certain degree. However, applying the CALM model introduced in this article, the risk of long-term impermanent loss may be greatly reduced compared to traditional liquidity protocols.

1.1. Context and Prior Art

One of the first proposals for a liquidity protocol was a pioneering liquidity network [3], [4], entering the space in 2017 and continuously innovating. During DeFi summer (2020 until early 2021), many innovative DeFi products were released. Decentralized exchanges were truly popularized with the rise of a leading exchange platform [5], [6], [7], with their V2 constant product liquidity pools being the first to reach into the billions of dollars in total value locked (TVL). A specialized exchange revolutionized capital efficiency for liquidity pools holding tokens of correlated value, such as stablecoins [12], [13]. A multi-asset protocol introduced imbalanced pools [11], and a predictive market maker platform introduced the predictive market maker (PMM) [15], which will be revisited in section 1.2.

The flurry of innovation combined with the high availability of capital lead to extreme growth, to the point that the Ethereum network became so congested that transaction fees reached levels that simply made in impossible to use for day-to-day applications. During this time, a low-cost exchange service was born, creating a DEX with high capital efficiency and the lowest possible gas costs per transaction. This platform uses a multi-token variant of the constant product market maker that the leading exchange popularized for token pairs. It works well and remains the cheapest way to execute token swaps on Ethereum.

The multi-asset protocol inspired this low-cost exchange on Ethereum [8], [9]. For this exchange's implementation on the Radix network, the objective became to develop an IL mitigating algorithm. Research suggested that the predictive market platform provided a better starting point. Thus, it is necessary to introduce this platform before introducing the CALM model.

1.2. Dodo – A Different Way of Looking at Liquidity

A Different Way of Looking at Liquidity

The predictive market platform stands out in crypto thanks to its innovative Predictive Market Maker (PMM). Unlike other decentralized exchanges (DEXes), this platform separates liquidity provided by its liquidity providers (LPs) into separate pools: Base Liquidity and Quote Liquidity. In addition, it employs a meticulous record-keeping process for each liquidity pool type, continuously monitoring which token is in short supply relative to its target. Furthermore, this platform leverages a flexible parameter, "k," which fine-tunes the concentration level of the liquidity. A k value of 1 mirrors the constant product autonomous market maker (AMM), mathematically equivalent to the leading exchange's V2. In contrast, a k value of 0 signifies maximum liquidity concentration, yielding a constant sum AMM with no price impact. Note that although the predictive platform's smart contracts don't allow for it, there is no fundamental barrier to using values of k larger than one, implying sparser liquidity than the default constant product AMM. This article will consider k values larger than zero, including those larger than one.

Without loss of generality, from here on out, the assumption will be that the base token is in short supply when discussing calculation examples. In the case of base shortage, the predictive platform's liquidity protocol is governed by the following equations:

$$p_{\text{margin}} = \left((1-k) + k\left(\frac{B_0}{B}\right)^2\right) p_0 \tag{1}$$

$$\Delta Q = (B_0 - B)\left((1-k) + k\frac{B_0}{B}\right) p_0 \tag{2}$$

Equation 1 gives the spot price at any given time, which depends solely on the reference price p0 and the ratio between the target for the base tokens B0 and the actual amount of base tokens B. This ratio is always greater than one since the base tokens are in short supply. Equation 2 is the result of integrating the price curve from equilibrium to a given base token shortage to give the number of quote tokens ΔQ held more than the quote token target Q0. This is the amount of quote tokens the pair has taken in while moving the base token amount from B0 to B.

The key insight that enabled the CALM model described in the next chapter is that due to separating the liquidity pools for base and quote and managing shortage concerning the target token amount, the predictive platform's implementation allows for the identification of which trades increase IL (ie, those that increase an existing shortage) versus those that reduce IL (i.e., those that move towards equilibrium). Nothing is stopping the application of different bonding curves, as long as care is taken not to create or destroy value at the interface. Treating trades increasing/reducing IL differently is exactly the core idea behind CALM.

As a side note, the reference price p0 in the predictive platform is supplied by an external price oracle, where the 'predictive' part in the PMM name comes from. The external oracle part of this protocol is explicitly not followed in the CALM protocol. In CALM, the reference price is tracked by an internal price oracle for which the oracle inspiration was the internal oracle mechanism of a specialized liquidity platform v2. However, the mechanism for reference price update in CALM is vastly different from that in the specialized platform.

2. Concentration-Asymmetric Liquidity Model (CALM)

The CALM model used at a decentralized exchange service applies different levels of liquidity concentration when increasing IL (kout) versus when reducing IL (kin). Specifically, the liquidity concentration is always sparser when increasing IL than when a trade reduces IL (i.e., kout > kin). Intuitively, trading along a sparser bonding curve means that one needs to supply more quote tokens than if the liquidity concentration is higher to get to a certain shortage of base tokens. Thus, if this mechanism is applied, a trade away from equilibrium creates a higher ΔQ than was expected at the same shortage point along the curve, trading back towards equilibrium. When mapping back to the IL reducing curve, these 'additional' tokens can either increase the reference price p0 or increase the base target amount B0.

2.1 Increasing IL – Trading Away from Equilibrium

When trading away from equilibrium, we use kout as the concentration parameter and solve equation 2 for B. Rearranging and using the helper variables of shortage (ΔB = B0−B) and scaled surplus (ΔQ′ = ΔQ/p0), we get an equation that is quadratic in ΔB, hence solving it gives two solutions. Only one has a physical meaning, so the other is discarded. The solution is given here by equation 3 below:

$$\Delta B = \frac{B_0 + \Delta Q' - \sqrt{B_0^2 + (4k_{out} - 2)\, B_0 \Delta Q' + \Delta Q'^2}}{2\,(1 - k_{out})} \tag{3}$$

The ΔB gives the total base token shortage to the equilibrium. To compute the number of output tokens for any trade, we can use equation 3 to fill in the new surplus value and simply subtract the original shortage. Note that equation 3 suffers from division by zero when kout equals one, as both the numerator and the denominator tend to zero. When kout is exactly equal to one, equation 2 may be simplified before solving for ΔB. For this special case, we can use the simplified equation 4 to calculate the shortage before and after the trade.

$$\Delta B = \frac{B_0 \Delta Q'}{B_0 + \Delta Q'} \tag{4}$$

2.2. Reducing IL – Trading Towards Equilibrium

Still assuming a base shortage in the pair, we use kin as a concentration parameter for trades towards equilibrium, i.e., trades that give base tokens as input and quote tokens as output. Using the helper variable ΔB = B0−B, and setting k = kin in equation 2 yields equation 5 after some rearranging.

$$\Delta Q = \frac{\Delta B\,(B + k_{in} \Delta B)}{B} p_0 \tag{5}$$

This equation describes the curve over which the trades are executed. The amount of output quote tokens for an input amount of base tokens is calculated by solving equation 5 for the corresponding values of B and ΔB.

2.3 Emerging Bid-ask Spread and Reference Filter

When trading away from equilibrium along the sparser curve, the shortage doesn't increase as much as it would have for the denser curve to reach the same spot price. This means that if no other values are changed, such as the reference price and/or the target values, the inward and outward bonding curves will have a different spot price. The spot price of the inward curve is the bid price, while the spot price for the outward curve is the asking price for the base token. Thus, a bid-ask spread spontaneously arises when trading far away from equilibrium. When there is sufficient volatility in the market, this bid-ask spread may be crossed, generating additional income for the liquidity providers. The size of the spread depends on the ratio between kout and kin, with a greater ratio causing a larger spread.

The bid-ask spread is closed from both sides in the decentralized exchange service. The bid and ask prices are moved towards each other by manipulating their respective reference prices. The reference price for the inward curve can be increased due to the excess quote tokens earned by trading outward on a sparser liquidity curve. Whatever gap remains is closed by reducing the reference price on the outward trading curve.

The bid-ask spread is closed gradually over time (using an exponential filter). In times of high market volatility, the LP providers profit from the additional income generated as the market crosses the bid-ask spread. As far as is known, this feature is unique to this decentralized exchange service. During times of high market volatility, LPs at other DEXes only pocket the fees of the trades flowing back and forth. With the CALM model, the LPs benefit from the different pricing on the inward/outward curves, which is the main driver of the improved performance demonstrated in section 3.

2.4. Moving Back and Forth Between the Trading Curves
Starting from equilibrium, if one or several trades increasing IL have occurred, trading in the other direction requires using the other bonding curve. This needs to be done carefully to ensure that the curves are respected without creating opportunities for exploitation.

Specifically, moving from trading with kout to trading with kin there is an excess of ΔQ to fit equation 2 with the same p0 and B0 values. To make the reserves fit the trading curve, one can either increase p0, increase B0, or combine both. In CALM, the excess tokens are initially allocated to a higher B0 but, over time, gradually shift to an adjustment of p0 instead. Thus, if the price reverts relatively quickly, the liquidity providers will have a higher amount of base tokens. However, if the price stays elevated, the reference price will be adjusted, and the target amount will revert to the original value. Depending on how much time has passed, the actual value for p0 used for new trades is calculated using a filter. From that p0 value, the corresponding base target B0 is calculated by solving 2 for B0/B and multiplying the result by B. Equation 2 is quadratic in B0/B, and again two solutions are found, out of which only one has physical meaning. When ΔQ' = ΔQ/p0 is set, the desired solution is given by 6:

$$\frac{B_0}{B}_{temp} = \frac{2k_{\text{in}} + \sqrt{1 + 4k_{\text{in}}\Delta Q'/B} - 1}{2k_{\text{in}}} \qquad (6)$$

Equation 6 is only valid for values of kin larger than zero, which are the only cases of interest here. The temporary target value calculated by this equation is used for any trades reducing IL. After a trade is completed, the permanent target value must be updated to fit the curve for the steady state value of p0 computed earlier.

Symmetrically, if moving from trading in the direction reducing IL to increasing the shortage and hence the IL, the curve also needs to be recalibrated. The recalibration of the above was based on equation 2. Here, recalibration is based on spot price (equation 1). For the outward trade direction, the spot price matches the steady-state spot price for the inward curve. To align for a given shortage, the reference price p0 needs to be temporarily changed for any outgoing trade. The value used is given by equation 7, which is found by solving equation 1 for p0:

$$p_{0_{temp}} = \frac{p_{spot}}{(1-k) + k\left(\frac{B_0}{B}\right)^2} \qquad (7)$$

Using these temporary values when switching back and forth between the curves guarantees continuity of trading while always making adjustments that benefit the liquidity providers.

2.5. Adding Liquidity
As discussed before, liquidity is tracked for each side of the reference price separately rather than lumping all tokens together like most protocols. The amount of liquidity on each side of the pair need not be equal, and there may be a difference in ROI between the two sides. In keeping with the sustainable DeFi principle, the objective is to make liquidity provisions sustainably profitable for each side or at least to significantly reduce the risk of incurring a loss. Ideally, the pair stays mostly in balance, and each side of p0 contains mostly one type of token. The pool for the token that is in short supply at any given time does contain some amount of the other token (ΔQ in the examples given). However, adding liquidity is always a single-token affair.

When adding liquidity, the CALM pair checks whether the token being added is in shortage. If there is no shortage, the liquidity provider is simply granted LP tokens in ratio to how much liquidity is added concerning how much was already present. If the token is in short supply, the trading curve is recalibrated to the new position, and the liquidity provider is granted LP tokens in ratio to the increase of the target value resulting from the reduced shortage.

2.6. Differences concerning Dodo / Curve

The decentralized exchange service builds on the predictive market platform approach to liquidity pools, which builds on the leading exchange model. Furthermore, the specialized exchange inspires some features around the reference price. The differences between CALM and the predictive market platform are listed below, concerning the specialized exchange where relevant.

1. The asymmetric liquidity model gives rise to a natural bid-ask spread. This allows LPs to profit from rapid price swings with more income than just the fees of the for- and backward trades. The size of the bid-ask spread can be configured by the ratio of concentration for IL generating/reducing trades, with the spread closing completely over a configurable period. When prices are stable, the spread will be small, whereas when there are rapid price changes, the spread will be (temporarily) large.
2. The predictive market platform implementation is focused on liquidity concentration, even though the math also allows de-concentration concerning the constant product AMM. The CALM model uses de-concentration, which reduces impermanent loss risk at the cost of a lower fraction of tokens traded and correspondingly lower fee income. Analysis in section 3 ahead will show that the impact of impermanent loss protection outweighs the reduced fee income.
3. CALM utilizes an internal price oracle—a feature inspired by the specialized exchange's v2 liquidity pool model—to eliminate the need for an external oracle. The predictive market platform uses an external price oracle. Eliminating the external price signal yields a significant improvement in safety, as Oracle pricing is a common point of failure and/or attacks in DeFi.
4. Increasing the oracle price of a token when that token is in short supply essentially incurs a loss to the liquidity providers. The price is always updated in the predictive market platform when the external oracle price updates. In the specialized exchange, the price is only updated when the fee income is more than twice the cost to update the price. In CALM, the oracle price update happens gradually over time and only to the extent that the excess tokens from the asymmetric liquidity mechanism can be afforded.
5. 5. When adding liquidity to a token in short supply, a predictive market platform liquidity provider incurs an immediate loss, with the beneficiaries being the existing LP providers. There effectively is a fee to add liquidity, which gets higher and higher the more the pool is imbalanced, and which disincentivizes adding liquidity when it is needed the most. In CALM, a fair amount of LP tokens is calculated such that there is no gain/penalty to the new liquidity provider versus existing LPs.

3. Results

The CALM algorithm was run against two specific historical datasets as a test. First, there is the historical data for ETH/USD, which is the same pair that Alex initially identified as hugely problematic for a leading exchange v3 liquidity provider. Second, BTC/ETH is taken as the prototypical crypto-to-crypto trading pair. For this pair, the price movement is assumed to be somewhat muted as both of the tokens in the pair are impacted by many of the same macro factors.

The datasets are exchange price data sampled at one interval, freely available online [14]. Trades are executed against the close price at each hour mark if the price differential between the exchange and the decentralized exchange service pair is large enough. A 0.3% margin is assumed to be required for arbitrageurs to cover their costs and execute a trade. Only this 100% toxic order flow is modeled to get a conservative estimate of fee income. The leading exchange portfolio is simulated under the same conditions to ensure the 0.3% trading fee is also considered.

Figure 1 shows the performance of 1000$ invested in a leading exchange v2 pair (ie,500$ in USDC and 500$ worth of ETH) on January 1st, 2020 (when ETH was at $129) against simply holding the same portfolio over the same time, versus investing in a CALM pair (kin = 0.15, kout = 20, fee at 1%). Despite an overall ETH price increase of more than 12x, the CALM pair is profitable concerning the HODL strategy. The leading exchange v2 pair underperforms due to impermanent loss, and from Alex's analysis, it is known that leading exchange v3 providers do even worse due to concentrated impermanent loss.

It is worth noting that during the initial extreme runup of May 2021, the CALM strategy failed to follow the HODL value. This demonstrates that if there is a strong and persistent one-directional price movement, CALM will still accumulate IL, though to a much smaller extent than other liquidity protocols, such as the leading exchange V2 pair. By the start of 2022, the CALM pair is clearly in the plus concerning the HODL strategy, while the leading exchange V2 pair still sits at around 45.

Figure 2 shows the final value of various possible portfolios over this period, assuming a 1000$ starting value for each portfolio. In CALM, single-sided liquidity can be supplied, and each liquidity type will have its ROI. Providing liquidity to CALM outperformed holding the token outright for both USD and ETH. Critically, supplying just ETH results in a higher final value than just holding ETH over the same period, despite the 12x price increase of ETH concerning USD. Supplying USD to CALM over this period results in more than 130% yield. Supplying ETH to CALM over this period would have resulted in an additional 9.2% of ETH over just holding it, representing an additional 118% of yield over the already impressive 1287% of returns from the price rise of ETH. In summary, CALM beats IL over the Jan-2020 to Sept-2023 period on the ETH/USDC pair under pure toxic order flow.

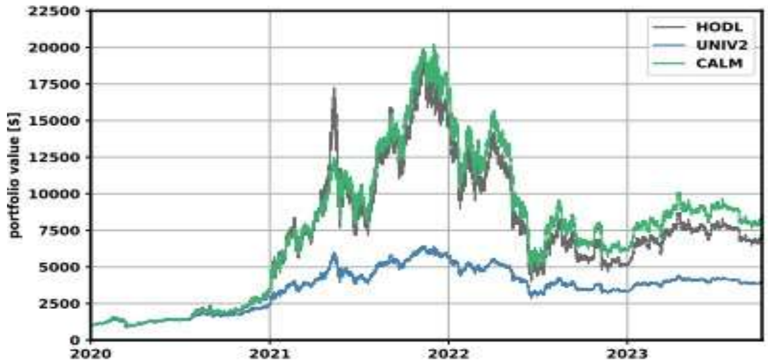

Fig 1: Superior performance of CALM concerning classic Uniswap v2 style AMM for ETH/USDC pair under heavy price volatility.

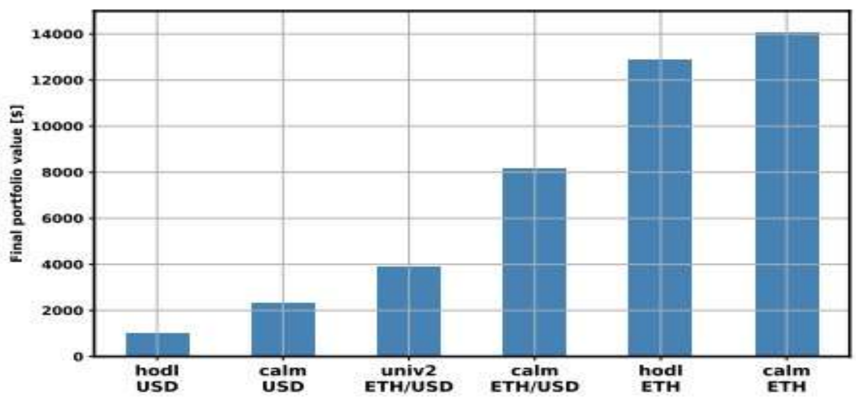

Fig 2: Final returns of various portfolios showing outperformance of the CALM liquidity model.

It is also worth noting that the 1% fee used in the CALM pair is larger than the 0.3% fee in the leading exchange v2 pair. However, suppose a 1% fee is applied to the leading exchange v2 pair. In that case, that doesn't significantly change the results, as the accumulated impermanent loss simply dwarfs the fee income for the leading exchange pair. Thus, the vastly improved performance for the CALM pair does not originate from the higher fee; it is mostly due to the IL-mitigating properties of CALM.

Finally, the analysis here was limited to one trade per hour from only toxic order flow. In reality, many trades can happen in an hour, and of course, there is not only arbitrage order flow but also genuine trading (uninformed flow) that would result in higher fee income. With the 1% trading fee, the CALM pair would likely get fewer trades from the uninformed order flow than the leading exchange pair would. However, there is a firm belief that the best path towards making money as an LP in DeFi is to stop losing money as an LP in DeFi. Thus, reducing impermanent loss to where it can reliably be expected to be smaller than LP income in the long run is more important than maximizing trading volume and fee income.

4. Conclusion

To conclude, a ground-breaking algorithm, the Concentration-Asymmetric Liquidity Model, inspired by the predictive market platform and the specialized exchange to mitigate impermanent loss risk, has been introduced. A sustainable return is not an illusion, as confirmed through backtesting with pure toxic order flow under appropriate settings. To make DeFi work sustainably a shift in the modus operandi is needed, away from focusing on high APY and trading volumes and towards focus on long-term bottom-line performance. Rather than concentrated liquidity, there may be a need to look at deconcentrated liquidity if the specter of impermanent loss is to be defeated. At Radix, the decentralized exchange service will demonstrate that the CALM model and higher fees may come at lower volumes but yield higher returns to the liquidity providers than existing protocols. For the first time that is known, a purely passive liquidity strategy may beat impermanent loss even for trading pairs with different underlying fundamentals.

Furthermore, the CALM model opens up a whole new class of algorithms for future research, where trades increasing impermanent loss are treated differently in some way from those that reduce impermanent loss. Furthermore, this design empowers the ecosystem by accommodating pure single-sided and concentrated liquidity, supported by fungible liquidity provider tokens, under one effective execution.

4.1 Radix – A Quantum Leap in UX/devX for DeFi

One of the reasons for the relatively slow adoption of DeFi in society is the user experience. Using dApps is complex and risky. When one signs a transaction, it is an unintelligible string. The same is true for accounts. Losing one's seed phrase means losing one's tokens. Hacks and exploits follow each other in rapid succession. As an end-user, it's just not a great experience. For developers, it's not much different. Building a secure dApp on a major blockchain network is hard; it's easy to make mistakes even if one is well-intentioned.

Enter a next-generation blockchain platform, which has been built from the ground up with the explicit objective to onboard a billion users onto a single global DeFi ecosystem. The next-generation ledger, released at the end of September 2023, introduces the following features to support that mission:

– A scalable platform: The ledger was designed for full-state sharding. Even though actual sharding isn't enabled in the network, the data architecture is built to support it in the next deployment. This makes the ledger future-proof.
– The Engine: Tokens and wallets behave as real physical objects, with their logic governed by the Engine. This makes the platform far more intuitive to use, making it much harder for end-users and developers to make mistakes.
– Human-readable transactions. When one signs a transaction on the wallet, it shows exactly what will happen in the wallet, giving users insight into what they're signing off on.

Another key feature making this platform a great platform for building DeFi applications is the developer royalty system. The royalty feature enables charging on-chain transactions on top of the gas fee. Royalties will enable DeFi protocols to elegantly recover their operating costs directly from consumers without requiring tokenization or adding overhead logic to the smart contracts. Apart from LP profitability, covering operating costs is another key enabler for sustainable DeFi that is frequently overlooked.

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