CHAOS LABS

PENDLE

PT Token Risk Assessment Framework

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Principal Token Risk Assessment Framework

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Abstract

This report provides a comprehensive risk assessment of Principal Tokens in the Pendle Finance ecosystem, focusing on the risks associated with using PT tokens as collateral in other protocols. PT tokens represent the principal value of yield-bearing assets and can be redeemed 1:1 for the underlying asset at maturity.

While Pendle has demonstrated robust security over three years of operation, PT tokens face specific risks related to yield volatility and liquidity constraints. The primary risk occurs when underlying asset yields exceed the AMM's maximum supported yield, potentially causing liquidity issues. However, this risk diminishes as tokens approach maturity, where prices converge to the underlying asset value. We analyze these dynamics through the lens of AMM mechanics, price stability, and protocol dependencies. Our findings suggest that PT tokens backed by assets with stable, predictable yields can be safely integrated as collateral, while those with more speculative yields require additional risk considerations.

This assessment complements Pendle's V2 general risk assessment, and readers are encouraged to review both documents together for a complete understanding of the protocol's risk profile.

Contents

Chapter 1

Introduction

Principal Tokens (PT) offered by Pendle Protocol bring a novel approach to DeFi, enabling users to achieve predictable, fixed-yield income on their assets over specified time frames. Functioning similarly to zero-coupon bonds in traditional finance, PTs represent the principal value of the standardized Yield token (SY) that matures at a predetermined future date, allowing holders to lock in a fixed yield. PTs are created by splitting SY into Principal and Yield Tokens (YT), with PT representing the locked principal value until maturity. This separation of yield and principal allows for innovative trading and investment strategies, particularly appealing for users seeking stable returns or structured products in DeFi.

Due to their predictable value at maturity, PT tokens are increasingly utilized throughout DeFi. Since PT tokens can be redeemed for the underlying assets at maturity, they exhibit reduced volatility near maturity compared to their underlying assets. This makes them ideal for traders seeking leveraged yield with a lower risk of sharp price fluctuations relative to the underlying tokens.

This risk framework divides the analysis into two main sections to address the complexities specifically related to PT tokens. First, it evaluates the risks between PT tokens and their associated underlying tokens, focusing on the Pendle AMM functioning, volatility, maturity constraints, and liquidity factors unique to PT tokens. Second, it assesses the transition from underlying assets to correlated market assets. This bifurcated approach ensures that each layer's unique risk factors are thoroughly examined, offering a comprehensive understanding of PT token collateralization across both isolated and broader DeFi markets.

Chapter 2

Glossary

To ensure this work is self-contained, it is essential to introduce some of the new concepts developed by Pendle. For more detailed explanations, readers are encouraged to refer to Pendle documentation and whitepapers.

- **Yield-Bearing Token:** A broad term for any token that generates yield, such as stETH, GLP, weETH, etc.
- **Underlying Asset:** The reference asset against which a yield-bearing token grows in value.
  - For tokens like stETH and aUSDC, the accounting asset is the token itself, since the yield generated is accrued due to rebasing.
  - For tokens like weETH or wstETH, the reference asset is the base deposit (e.g., eETH for weETH and stETH for wstETH), as these tokens increase in value relative to their deposited asset.
- **Correlated Asset:** In this work, we refer to the correlated asset as the currency that the underlying asset is supposed to be pegged to (e.g., ETH for eETH, BTC for WBTC, USD for USDe).
- **SY (Standardized Yield):** A token standard (EIP-5115) developed by Pendle to wrap yield-bearing tokens, offering several enhanced functionalities. For the purposes of this analysis, the primary feature of the SY token is its ability to be split into, or redeemed for, a PT and YT token.
- **PT (Principal Token):** A token representing the locked principal value of a yield-bearing token. For example, holding 1 PT-stETH with a 1-year maturity lets you redeem 1 ETH worth of stETH after 1 year.
- **PT price:** In this work, the price of the PT token will always refer to its value relative to the underlying asset. This means the PT price is always less than one and converges to one at maturity.
- **YT (Yield Token):** A token that grants access to the yield generated by a yield-bearing token in real time. For instance, owning 1 YT-stETH earns the yield generated by stETH, which can be claimed manually.

Chapter 3

General Risk Framework

In assessing the risks associated with PT tokens, it's essential to establish a structured framework that accurately captures the nuances of each layer of risk. Given the multi-layered nature of PT tokens, from their intrinsic characteristics to their connections with underlying and correlated assets, this framework is designed to decompose and analyze these risk factors systematically.

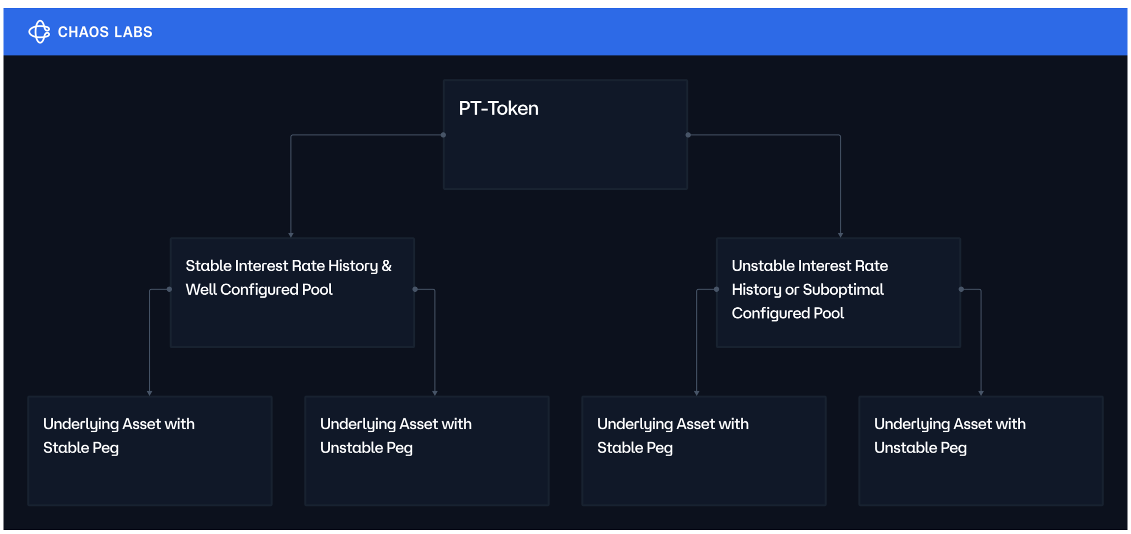

Figure 3.1: Classification of PT tokens based on interest rate stability and peg stability, resulting in four distinct risk categories: (1) Stable rate & stable peg, (2) Stable rate & unstable peg, (3) Unstable rate & stable peg, and (4) Unstable rate & unstable peg.

The redemption path, moving from PT tokens to SY tokens, then to the underlying asset, and further to the base correlated assets like BTC, ETH, or USD is analyzed as the likely liquidation flow for PT tokens. Each step in this path influences the price and volatility of PT tokens, as both the relationship between PT and SY tokens and the broader market behavior of the underlying asset impact PT value. Thus, risk analysis must account for these dynamics, splitting into two main sections:

1. **Risks from PT to SY token :**

   This includes considerations of price volatility, liquidity constraints, and the dynamics of how PT tokens interact with their corresponding SY tokens in the market. These interactions primarily occur within Pendle's AMM and order book, making these risks closely tied to Pendle's ecosystem and the effectiveness of its liquidity infrastructure. In particular, the market parameterization in terms of its *scalarRoot* is examined in detail.

2. **Risks from the underlying asset to correlated assets :**

   This includes factors such as price volatility, the dynamics of atomic and non-atomic liquidity, and protocol-specific risks, such as smart contract vulnerabilities or centralization issues.

To refine the risk framework further, we categorize PT tokens into subgroups based on their main economic risks. This structure considers the underlying token's stability, available liquidity, and yield dynamics. This categorization results in four distinct subcategories, as visualized in the diagram 3.1.

Chapter 4

PT to SY Token Risks: Yield Volatility and Liquidity Constraints

With the introduction of PT tokens and the PT-SY AMM, Pendle has revolutionized decentralized finance by enabling users to access fixed yields while isolating the principal value from the yield component of an asset, all with enhanced capital efficiency. However, fully understanding the risks associated with PT tokens necessitates a detailed exploration of their unique price volatility and liquidity dynamics. As the PT token approaches maturity, changes in the underlying yield have a diminished impact on its price, and liquidity becomes more concentrated. Conversely, early in the token's lifecycle, yield fluctuations and market sentiment can lead to more pronounced price volatility, as the fixed future value is significantly discounted by the time remaining until maturity.

In this section, we will examine these two critical concepts (price volatility and liquidity), in detail, quantifying their associated risks. Before doing so, however, it is essential to first understand how PT tokens are minted and redeemed and the mechanics of the Pendle AMM.

1 Understanding SY and PT tokens

In Pendle Finance, yield-bearing assets are first standardized into SY tokens, which can then be divided into two distinct components: Principal Tokens and Yield Tokens. This process, known as yield tokenization, allows users to manage and trade the principal and yield aspects of their assets separately. PT represents the principal value of the underlying asset, while YT entitles the holder to the yield generated until a specified maturity date.

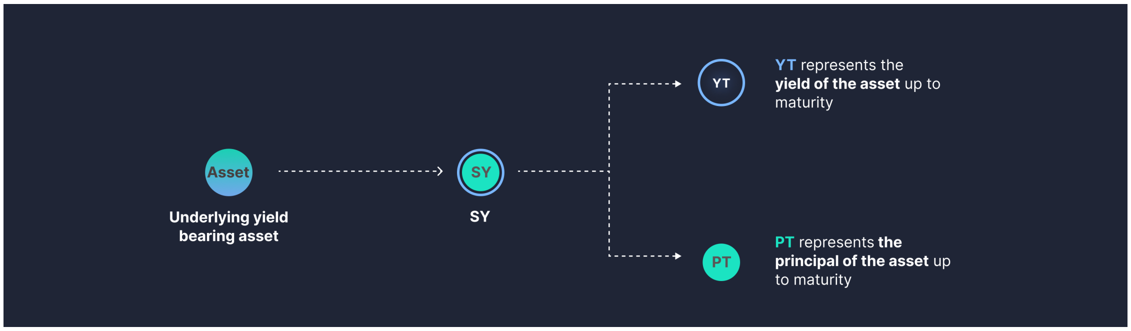

Figure 4.1: Illustration of how SY tokens are split into PT and YT tokens link

The SY token serves as a standardized tool for implementing various yield-bearing assets within the Pendle ecosystem. Both the underlying asset and its associated yield remain securely locked within the smart contract, ensuring that no additional leverage or economic risk is introduced into the system. Furthermore, holders can always redeem SY tokens for the underlying asset by combining one YT and one PT token. This mechanism guarantees that the combined value of PT and YT aligns with the price of the underlying yield-bearing asset. Pendle's AMM swapping mechanisms further ensure this parity is consistently maintained.

As detailed in the glossary, the PT token signifies the locked principal value of the underlying asset, while the YT token represents the yield. As maturity approaches, the YT token's value diminishes to zero due to the decreasing yield accrual period, whereas the PT token's price converges with that of the underlying asset. If market inefficiencies prevent this convergence within the Pendle AMM, PT holders can redeem one PT token for one unit of the underlying asset upon maturity, making holding a PT token at maturity virtually equivalent to holding the underlying asset. For more information on this process, refer to the Pendle Whitepaper or our general risk assessment of Pendle's Protocol.

While additional smart contract risks are inherent due to the system's complexity, Pendle has operated for three years without significant security issues, demonstrating the robustness of its core contracts. Furthermore, Pendle's contracts have undergone audits by reputable firms, including Spearbit and ChainSecurity, to ensure their security. Additional details are available in the general risk assessment.

2 Pendle's AMM

To provide capital-efficient liquidity for PT tokens, Pendle adapted the AMM design pioneered by Notional Finance. Readers seeking a deeper understanding can refer to Pendle's white paper. In this section, we will focus on the most critical aspects of the Pendle AMM.

PT tokens increase in value over time at their implied yield, similar to how zero-coupon bonds function in traditional finance. Another parallel to zero coupon bonds is that the longer the duration of time until expiry, the greater the impact of yield moves on the PT price.

Pendle's AMM addresses these challenges by concentrating liquidity progressively closer to 1 as maturity nears. This behavior is illustrated in the following representation of a pool's liquidity during different time to maturity:

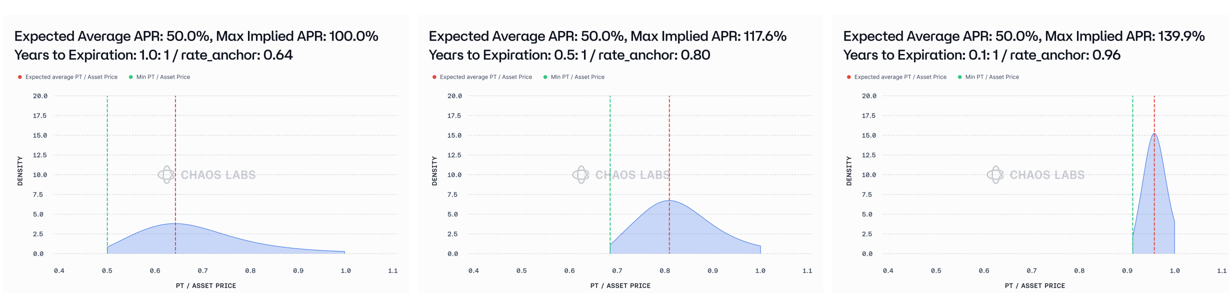

Figure 4.2: Liquidity dynamics of a pool **without trades**, with a high expected yield and a relatively small *scalarRoot*, showing how liquidity can be distributed over a broader range if necessary.

Moreover, Pendle imposes certain constraints within the AMM to ensure efficient liquidity and market behavior:

- The price of a PT token is always less than 1.
- The PT token can never exceed 96% of the total pool value. This indirectly establishes a minimum price and a maximum implied APR for the token.

The liquidity shape evolves depending on the historical trades, but it highly depends on the parameters set during the pool's initialization. Pendle's AMM have only 2 different parameters:

1. **Scalar Root** ($rateScalar$) determines how concentrated the liquidity is and, consequently, the minimum price. A larger scalar root results in more concentrated liquidity and a higher minimum PT price. This restricts the yield range covered by the AMM while concentrating liquidity to minimize price impact. Where a wider range of underlying yields are expected, the larger the $scalerRoot$ is needed. The $rateScalar$ is simply the scalar root normalized by the time remaining until maturity. This ensures that the range of yields covered by the AMM remains consistent over time in a given market.

$$rateScalar(\text{yearsToMaturity}) = \frac{scalarRoot}{\text{yearsToMaturity}}$$

2. **Initial Anchor** ($rateAnchor$) determines where liquidity is primarily concentrated, centered around $1/rateAnchor$. At the pool's inception, the $initialAnchor$ is selected to concentrate liquidity around the expected implied yield. This starting point is crucial, and actually affects the pool until maturity as we will see. Actually, the $rateAnchor$ evolves over time, it adjusts before every trade to maintain a constant implied rate between trades. This mechanism protects the pool from arbitrageurs by aligning price adjustments with the yield environment and automatically increasing the PT price as time to maturity decreases.

   In the absence of trades, the formula for $rateAnchor(\text{yearsToMaturity})$ is straightforward and very insightful:

$$rateAnchor(\text{yearsToMaturity}) = \text{initialAnchor}^{\frac{\text{yearsToMaturity}}{\text{initialYearsToMaturity}}}$$

   This implies that liquidity remains concentrated around the initial expected yield (as shown in the previous plots).

   However, the exact $rateAnchor$ dynamics depend on trade history. For completeness, we can analyze how $rateAnchor$ is updated before each trade. Let t_{last} represent the time of the last trade, and $p_{\text{last}} = \frac{\text{PTvalueMaturity}}{\text{PTvalueMaturity}+\text{SYvalue}}$ denote the pool imbalance after that trade. The new $rateAnchor(t_{\text{now}})$ is defined as:

$$\text{rateAnchor}(t_{\text{now}}) = \left(\frac{\ln\left(\frac{p_{\text{last}}}{1-p_{\text{last}}}\right)}{\text{rateScalar}(t_{\text{last}})} + \text{rateAnchor}(t_{\text{last}})\right)^{\frac{t_{\text{now}}}{t_{\text{last}}}} - \frac{\ln\left(\frac{p_{\text{last}}}{1-p_{\text{last}}}\right)}{\text{rateScalar}(t_{\text{now}})}$$

   Understanding the dynamics of $rateAnchor$ is crucial for analyzing how the minimum price and maximum implied yield change over time. While we do not explore the full complexity of these dynamics in this report, it is important to note that *rateAnchor* approximately follows the simplified formula $initialAnchor^{\frac{\text{yearsToMaturity}}{\text{initialYearsToMaturity}}}$. This, combined with the fact that liquidity is concentrated around $1/rateAnchor$, highlights the importance of an accurate estimate of the *initialAnchor*, as the pool operates more efficiently when the future underlying yield remains close to the initial expected yield.

3 Understanding PT Token Price Range in Pendle's AMM

Understanding the dynamics of *rateAnchor* is crucial for analyzing how the minimum price and maximum implied yield change over time. While we do not explore the full complexity of these dynamics in this report, it is important to note that *rateAnchor* approximately follows the simplified formula $initialAnchor^{\frac{\text{yearsToMaturity}}{\text{initialYearsToMaturity}}}$. This, combined with the fact that liquidity is concentrated around $1/rateAnchor$, highlights the importance of an accurate estimate of the *initialAnchor*, as the pool operates more efficiently when the future underlying yield remains close to the initial expected yield.

$$PTPrice = \frac{1}{\frac{\log(p/(1-p))}{rateScalar(t)} + rateAnchor(t)}, \quad p = \frac{\text{PTvalueMaturity}}{\text{PTvalueMaturity} + \text{SYvalue}}$$

Additionally, the implied yield at any time can be expressed as:

$$ImpliedYield = PTPrice^{-\frac{1}{\text{yearsToMaturity}}} - 1$$

The minimum price for the PT token is constrained by the AMM's requirement that PT tokens never represent more than 96% of the pool's value. To determine the minimum price, we substitute $p = 0.96$ into the previous equation, yielding:

$$minPTPrice = \frac{1}{\frac{\log(0.96/(1-0.96))}{rateScalar(t)} + rateAnchor(t)}$$

$$maxImpliedYield = minPTPrice^{-\frac{1}{\text{yearsToMaturity}}} - 1$$

Using these formulas, we can analyze how the initial minimum PT price and maximum implied yield change based on the pool's initial parameters. The following heatmaps illustrate how these variables are influenced by the *scalarRoot* and *initialAnchor* for a pool with a 1-year maturity.

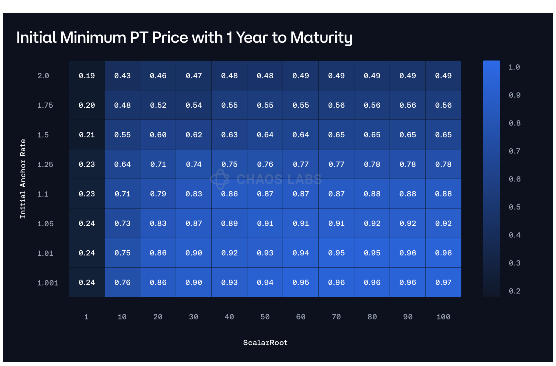

Figure 4.3: Influence of *scalarRoot* and *initialAnchor* on min PT price and max implied yield.

As expected, a larger $scalarRoot$ results in more concentrated liquidity, leading to a higher minimum PT price and smaller max implied yield. Conversely, a larger $initialAnchor$ shifts the liquidity to a lower range, which decreases the minimum PT price and increases the max implied yield.

To determine whether these limits remain valid or improve as t decreases, it is essential to understand the dynamics of $rateAnchor$. Since $rateAnchor$ dynamics depend on trading activity, the exact limits may vary. However, useful bounds can still be established to guide expectations.

As an initial analysis, we can examine the minimum PT price before and after an arbitrary trade. For simplicity let's assume that the previous trade was done at $t_1 = 1$, resulting in a pool imbalance of p_1. Then when a second trade at time t_2, independently of t_2 , p_1, $scalarRoot$ and $rateAnchor(t_1)$ we have that:

$$rateAnchor(t_2) < rateAnchor(t_1) => minPTPrice(t_2) > minPTPrice(t_1)$$

By fixing the $scalarRoot$ and the initial $rateAnchor$ we can validate these dynamics. In the following plots, we explore how the minimum PT price evolves based on the imbalance after the first trade, p, and the time of the second trade, t_2.

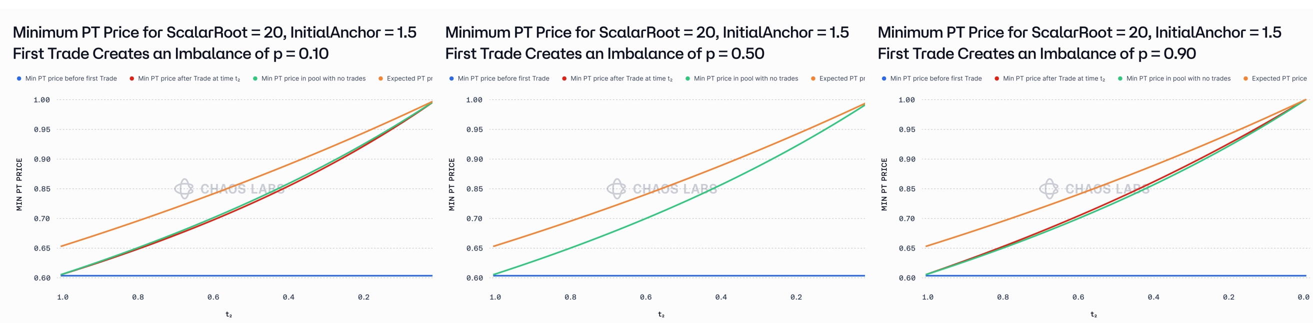

Figure 4.4: Minimum PT price evolution based on the imbalance after the first trade, p, and the time of the second trade, t_2. The blue line represents the minimum PT price at $t_1 = 1$, while the orange line shows the minimum PT price when the second trade is made at t_2 years to maturity. For comparison, we also add the liquidity concentration point ($1/rateAnchor(t)$, red line) and the minimum theoretical PT price if there was no trades in the pool (green line).

As shown, the minimum PT price rises under all scenarios, particularly when p is higher (i.e., when a large number of PT tokens are sold into the pool). Moreover, the minimum price remains very close to the scenario where no trades are made especially when p remains close to 0.5, reinforcing the relevance of the simplified formulas.

However, the key question is whether the minimum PT price increases slowly enough to prevent the maximum implied yield from decreasing. As we will discuss in the following sections, this would indicate that PT tokens become inherently safer as they approach maturity. This relationship holds true, as illustrated by the following plots.

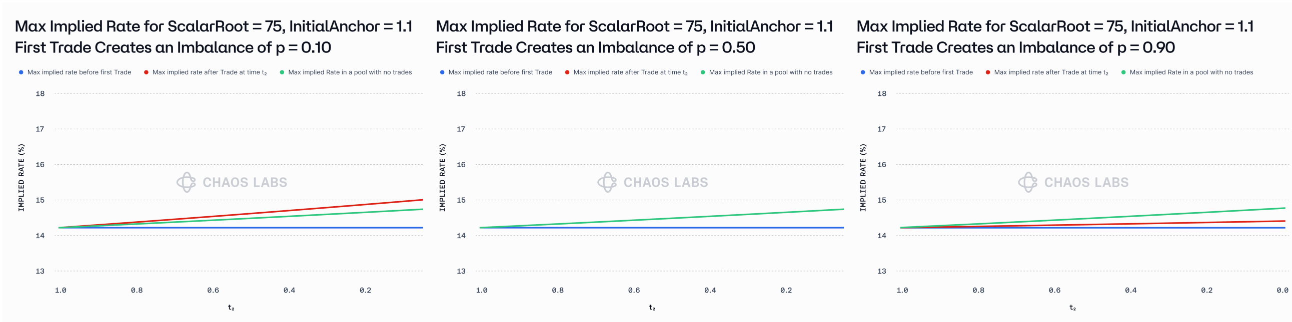

Figure 4.5: Maximum implied rate evolution based on the imbalance after the first trade, p, and the time of the second trade, t_2. The blue line represents the maximum implied rate at $t_1 = 1$, while the orange line shows the maximum implied rate after the second trade is made at t_2 years to maturity. For comparison, we also add the theoretical maximum implied rate if there was no trades in the pool (green line).

In this case, we observe that for very small p (i.e., when a significant amount of PT tokens is purchased), the maximum implied yield can increase significantly. Additionally, when the pool remains relatively balanced ($p \approx 0.5$), the maximum implied yield stays close to the values estimated in a pool with no trades. On the other hand, when $p \gg 0.5$, the maximum implied yield can increase substantially, whereas for $p \ll 0.5$, the maximum implied yield remains smaller than the expected one but does not decrease after a single trade.

This analysis considers the impact of only one trade, though multiple trades could create compounding effects. Through extensive numerical simulations across a wide range of parameters, including different initial rates, scalar roots, and trade sizes, we consistently observe these same dynamics. Moreover, these results can be proven mathematically using the formulas derived in the previous sections.

The main takeaway remains clear: the initial bounds shown in the heatmap not only hold but actually improve over time as the PT token nears maturity. The minimum PT price steadily increases, and in scenarios where p is small (indicating significant PT purchases), the maximum implied yield can also rise, underscoring the increasing robustness and dynamic safety of the pool as maturity approaches.

It is also worth noting that, by the definition of $\ln\left(\frac{p}{1-p}\right)$, price impact increases substantially when $p > 0.9$. For more conservative implementations, this bound can be used as an additional threshold to define the minimum desired price, ensuring stability and mitigating risks associated with extreme imbalances.

4 Liquidity and AMM Oracle Considerations

PT tokens are exclusively traded on Pendle, either through its AMM or order book. A key risk arises when the yield on the underlying token changes significantly, particularly if it exceeds the maximum implied yield set during pool initialization. This can push the PT token price out of the AMM's range, regardless of pool size. In this case trading is still possible on the Pendle orderbook, but liquidity is no longer guaranteed, and the PT oracle price will return the minimum PT token price of the AMM.

Smaller pools exacerbate this issue, as limited liquidity makes them more vulnerable to price manipulation, and imbalances caused by market movements. While the AMM's minimum price mechanism helps prevent manipulation and concentrates liquidity, it has the potential to complicate liquidations should the pool be misconfigured relative to the tokens yield trading range. Proper pool parameter configuration and close monitoring of the yield environment are essential to mitigate these risks.

4.1 Possible responses to Implied Yields Exceeding the AMM Maximum

When the yield on the underlying token rises above the maximum implied yield, potential responses may arise to address the issues discussed above:

- **Trading and Price Discovery Happens on the Limit Order Book:**

  For PT tokens with active market makers and deep order books, trading may occur at prices lower than the AMM's minimum price. While this can benefit PT users and potential liquidators, having the token trade below the AMM oracle price can disrupt any protocol relying on that oracle. This scenario introduces several risks:

  - **Arbitrage Risks:** Since the protocol values the PT token above its order book price, toxic arbitrage could occur. For example, in a lending protocol, a user could deposit the PT token and borrow an amount exceeding the collateral's actual value, effectively creating an undercollateralized position.
  - **Insufficient Liquidity Bonus/Margin:** If the price discrepancy between the order book and the AMM is significant, protocols relying on liquidations may be disrupted, as the liquidation bonus might not be sufficient to cover the price difference, even if liquidity is available.

- **New Pool with Updated Parameters is Created:**

  In extreme cases where the underlying yield changes significantly after pool creation, a new pool may be created with a lower *scalerRoot* reducing liquidity concentration while expanding the AMMs yield range. While this approach addresses some issues, it can introduce additional risks:

  - **Conflicting Oracle Values:** The new pool's implied exchange rate will differ from the old one, requiring protocols using the original AMM oracle to update their oracle source, causing a price jump.
  - **Split Liquidity:** If both pools remain active and in trading returns to their AMM ranges, liquidity will be divided between them. This results in less efficient markets and increased slippage for users.

However, all these cases have similar consequences for a protocol that integrates the PT token and relies on the original AMM oracle. Internally, the protocol will temporarily overvalue the PT token during periods when it is illiquid.

4.2 Intrinsic Safeguards: Redemption and Gradual Risk Reduction

While this could be a significant issue for most tokens, the unique nature of PT tokens provides a safeguard. At maturity, 1 PT token can be redeemed for exactly 1 underlying asset, making any overvaluation temporary. Moreover, this issue diminishes over time due to the following factors:

- **Max Implied Yield Increases Over Time:**

  As shown in the previous plots, the maximum 96% imbalance in the pool corresponds to an increasing maximum implied yield over time. This allows the PT price to potentially return to the AMM's range before maturity, even when the underlying yield remains constant.

- **Absolute Price Discrepancy Decreases Over Time:**

  If the underlying yield exceeds the maximum implied yield but remains constant, the absolute difference between the theoretical PT price and the minimum AMM PT price decreases over time. As a result, the oracle price gradually aligns more closely with the actual price. For example, consider an asset with a constant 15% underlying yield, while the maximum implied yield is set at only 10%. In this scenario, the premium on the PT token decreases over time, shrinking from approximately 2.5% at 6 months to maturity to just 0.36% at 1 month.

- **Reduced Speculation-Induced Volatility:**

  For tokens where the price discrepancy arises from speculative factors, such as airdrops or points-based incentives, the premium traders are willing to pay for the YT token decreases as maturity approaches, leading to less volatility.

These means that if a protocol can safeguard against temporary price discrepancies, the PT token will eventually trade at its intended value.

4.3 Strategies to Preserve PT Token Value Amid Price Discrepancies

For example, a lending protocol can mitigate bad debt risks and minimize liquidations by implementing some of the following solutions:

- **Borrow Only Correlated Assets:**

  Restrict borrowing to assets correlated with the PT token's underlying or strongly correlated assets, minimizing the impact of market volatility and ensuring more stable collateral-to-debt ratios.

- **Conservative Oracle:**

  Using an oracle that underprices PT tokens at a fixed, relatively high implied APY to maintain conservative valuations. When combined with borrowing only correlated assets, this ensures the collateral value will always increase relative to the debt under perfect conditions, effectively eliminating the possibility of liquidation.

- **Conservative Loan to Value (LTV) Ratios:**

  Set LTVs with ample buffers to account for small price depegs and the interest accrued by borrowed assets.

- **Halt Borrowing When PT Trades Outside the AMM Range:**

  By setting the LTV ratio to zero when the PT token trades outside the AMM range, the lending protocol can effectively mitigate its exposure. This measure prevents the creation of new debt against overvalued collateral, safeguarding the protocol from potential bad debt.

- **Dynamic Parameter Adjustments:**

  Instead of underpricing the PT token, consider gradually increasing the LTV and reducing the liquidity bonus over time as the PT token approaches maturity. This approach aligns with the token's decreasing risk profile and can achieve capital efficiency similar to higher LTVs with conservative oracles, while still allowing for necessary liquidations to protect the protocol.

While these measures can significantly reduce or even eliminate the risk of liquidation, the lack of liquidity for liquidations introduces additional side effects that must be considered:

- **Underlying Volatility:**

  When PT tokens are used as collateral for uncorrelated assets, a period of low liquidity coinciding with significant price movements can lead to undercollateralized positions at maturity. For instance, if a protocol allows users to use PT-eETH as collateral against USDC, a sharp drop in the price of eETH, combined with insufficient liquidity for the PT token, could prevent liquidations. This scenario increases the risk of bad debt for the protocol.

  Protocols must exercise extra caution when offering such products, implementing measures to address liquidity constraints and price volatility to mitigate these risks.

- **Underlying Depeg:**

  If the underlying asset of a PT token depegs from its correlated asset during this period, liquidity for PT positions will diminish, making it harder for holders to exit their positions. As a result, when the PT token is finally being trade in the AMM range or there is available liquidity on the lending protocol, the depeg to the correlated asset might be substantially, potentially leading to greater losses for users and potentially for the protocol.

This underscores the importance of carefully configuring the pool parameters and selecting the appropriate oracle, especially when integrating with external protocols. While a larger *scalarRoot* can enhance capital efficiency and allow smaller pools to absorb short-term market volatility, it also reduces the price range within which the pool operates effectively. This limitation becomes more pronounced for assets with higher volatility or speculative yields, as there is a greater likelihood of the implied yield deviating significantly from the expected yield.

4.4 Additional liquidity factors

Besides the PT token price moving out of range, there are additional factors to consider when assessing PT token liquidity:

- **Share of Total PT Tokens Locked in the Pool:**

  The proportion of PT and SY tokens in the AMM relative to the total supply plays a key role in determining the pool's depth and liquidity efficiency.

- **Deviation from Average Implied Yield and Initial Expected Yield:**

  When pools are established, an expected yield is chosen to optimize liquidity concentration. If the implied yield frequently diverges significantly from this expected value, it reflects dynamic market conditions or evolving yield expectations. While this isn't inherently negative for the token, it can make pools less capital-efficient, leading to greater variability in liquidity, reduced effectiveness of the AMM and higher chance of going out of range.

5 Implied Yield and PT Price Volatility

In finance, risk and volatility are inseparable concepts. In this section, we will explore the factors influencing PT token price volatility and discuss methods to estimate its future behavior.

Since PT tokens function similarly to zero-coupon bonds, traders typically express their price in terms of the discount to the underlying asset or the implied yield, calculated as $PTPrice^{-1/yearsToMaturity} - 1$.

However, analyzing historical implied yields alone may not provide sufficient insight for predicting future volatility. It is crucial to consider the nature of the underlying asset's yield (whether it is redeemable or speculative) and how its stabile or variable its source of yield is, influences the risk profile. These distinctions enable a more nuanced evaluation of how different yield types affect the PT token's value.

The intrinsic relationship between the underlying yield and the PT token price provides several methods to analyze and extrapolate its volatility:

- **Historical Token Volatility:**

  For tokens with an established track record, analyzing historical volatility provides valuable insights. However, it is crucial to account for the fact that volatility typically decreases as the token approaches maturity.

- **Historical implied APY:**

  For tokens with sufficient history, this is often the preferred method, as it allows for a more accurate estimation of future implied APY. This, in turn, enables better predictions of price volatility over time.

- **Volatility of different maturity PT:**

  For new PT tokens that have previously been listed at different maturities, analyzing the implied volatility of similar tokens at comparable times to maturity can provide useful proxies.

- **Historical underlying Asset APY maturity:**

  For new underlying tokens introduced to Pendle with a strong historical yield record, this yield data can serve as a reliable basis for estimating future volatility.

For some assets, particularly those influenced by airdrops or points-based expectations, the implied yield can become highly speculative and volatile. To estimate this risk, several factors should be considered:

- **Expected underlying yield:**

  Higher underlying yields amplify the sensitivity of the PT token price to yield changes. As discussed earlier, the AMM liquidity must also be more dispersed for assets with higher yields, exacerbating this effect. While this sensitivity is indirectly captured when deriving PT token volatility from underlying yield volatility, it is prudent to adopt a more conservative approach for tokens with elevated yields.

- **Nature of the underlying yield:**

  The risk profile of the underlying yield depends heavily on its source. Assets whose yields rely on external incentives, token emissions, or non-redeemable rewards (such as points) are inherently riskier than those with yield derived from fees or other stable mechanisms. Additionally, implied yields based on points or airdrop expectations may be susceptible to team influence, increasing uncertainty.

- **Historical gap between the underlying:**

  If the implied apr is substantially different than the underlying apr then it's a sign that traders are speculating in new yield, probably due to points or expectations on future airdrop. Such assets require careful evaluation for inclusion in lending protocols, as their future volatility can be significant, particularly if the expected rewards do not materialize before maturity.

With this in mind, we believe it is essential to categorize PT tokens based on the nature of their yield. This can be effectively assessed by evaluating the difference between the underlying yield and the implied yield, providing a clear measure of the token's risk profile and market expectations. This should then inform the PT token's expected future yield which can be evaluated against its Pendle market parameters to form an opinion on their suitability from a risk standpoint.

6 General Considerations

To finalize this risk framework, we want to highlight some last considerations to have in mind.

- **PT Token Oracle (TWAP):**

  For every PT token, the Pendle AMM provides a time weighted average oracle, with flexible look back period. When choosing the look back period is important to consider it's trade-off

  - A short TWAP window is easier to manipulate but is a better representation of the latest values traded, making it more reactive during price movements and permitting faster liquidations.
  - A long TWAP window may delay liquidations, requiring a higher liquidation bonus to maintain profitability. Potentially making the protocol react too late when the price is moving out of range.

  More information on the Pendle's TWAP mechanism can be found in Pendle v2 Mechanism Design Risk Assessment.

- **Exchange Rate:** Each SY token contract calculates an exchange rate that reflects how much of the underlying asset each SY (and thus each PT at maturity) is worth. This rate ensures accurate yield pricing and guarantees that, at maturity, 1 PT redeems for exactly 1 unit of the underlying asset. Methods for determining this exchange rate vary depending on the underlying token, some contracts use fixed rates (e.g., LBTC, where yields are not compounded), others query the yield-bearing token's smart contract directly (e.g., weETH), and certain assets rely on Pendle's custom off-chain oracles (e.g., rsETH).

- **Price Manipulation:**

  While minimum and maximum price mechanisms help minimizing attacks to inflate the collateral price permitting the creation of undercollateralized positions, low liquidity in the pool and order book can be exploited for larger liquidations, driving price movements that benefit attackers.

- **Assessing Borrowing Risks:**

  At maturity, a surge in PT token withdrawals is anticipated, which would strain liquidity if PT were borrowable. Additionally, the mechanism behind buying Y (borrowing SY from the pool, minting PT and YT, and then selling PT back to the pool) allows an attacker to depress the PT price with relatively little capital. Taken together, these factors indicate that enabling PT borrowing introduces unnecessary market risk. To mitigate these tail risks and ensure liquidity for withdrawals, we do not recommend allowing PT borrowing in any protocol.

- **Time to Maturity:**

  Although it may appear that time to maturity has not been directly addressed, it plays a critical role in all considerations before, with the obvious conclusion of, the longer the time to Maturity more risky is the asset. To take advantage of this fact, a protocol can think about adjusting their parameters periodically or leverage a risk oracle to adjust them dynamically over time.

Chapter 5

Underlying Asset Risks: Price Stability and Protocol Vulnerabilities

In addition to the risks inherent to PT token mechanisms, PT tokens are derivatives of their underlying assets and thus inherit their associated risks. Although these risks are not directly related to the Pendle protocol, it is essential to evaluate the assets backing each PT token.

When evaluating the underlying token associated with a PT token, several key risks come into play, each affecting the token's stability, liquidity, and collateral value. These risks can be categorized into two main areas: Price Stability and Liquidity and Protocol Dependencies and Smart Contract Risk.

In cases where the underlying asset is stable enough, it could be safe to use use the price of the correlated asset directly. This approach simplifies price discovery and reduces reliance on complex market mechanisms. Several lending protocols have adopted this method to enhance market efficiency, as it streamlines collateral evaluation and minimizes potential liquidations due to short term price depegs.

1 Price Stability/Liquidity

The price stability of the underlying asset relative to its correlated asset is a critical factor when considering integrating a new token into a protocol, especially in lending protocols with isolated money markets. Liquidity for a token can be provided in several ways but generally falls into three essential mechanisms:

1. **Secondary Market Liquidity:**

   This serves as the first line of defense against short-term volatility and is crucial for enabling quick and profitable liquidations. However, secondary market liquidity is finite and therefore only able to satisfy temporary demand-supply imbalances.

2. **Instant Redeemability / Hard Peg Mechanism:**

   Ideally, protocols provide a mechanism to redeem tokens for their underlying asset instantly and at a fixed rate, with minimal or no price impact. Atomic redemptions are rarely possible, so the closer a protocol can achieve near-instant redemptions, the greater confidence we can have in the stability of its peg.

3. **Soft Peg with Delayed Redeemability:**

   In this approach, tokens are redeemable at the target price but with a delay or through a queuing system. This method provides flexibility but can lead to temporary price deviations during periods of high demand or low liquidity.

4. **Redemption Dependencies:**

   Identifying any dependencies for redemptions, such as available protocol liquidity, can help to proactively manage any depeg risks.

2 Protocol Dependencies and Smart Contract Risk

On a more qualitative level, it is crucial to evaluate the technology and concepts behind the underlying token. While smart contract risks exist for all tokens, additional caution is required for newer tokens with unproven mechanisms to prevent permanent depegging. One way to quantify this risk is by analyzing the number of protocols the token depends on. Each dependency introduces another layer of potential vulnerability, such as security risks or operational reliance on external systems.

Although these risks are often reflected in the price volatility of the asset, they are significantly amplified when PT tokens are involved. Any permanent instability or depegging of the underlying token can limit liquidations due to the constrained liquidity of PT tokens prior to expiration. This limitation reduces the collateral value of the PT token, emphasizing the need for a thorough evaluation of both the stability of the underlying token and the liquidity available for PT tokens during such events.

The scope of this Risk assessment framework does not cover technical or smart contract risks. Advice on these risks should be sought elsewhere.

Chapter 6

Conclusion

PT tokens offer a novel and efficient mechanism for fixed-yield trading in decentralized finance, providing users with predictable returns and unique trading opportunities. At maturity, holding a PT token is equivalent to holding the underlying yield-bearing asset, as PT tokens can be redeemed on a 1:1 basis for the principal. This ensures that PT tokens retain their intrinsic value regardless of market inefficiencies.

Additionally, Pendle's protocol has demonstrated significant "lindiness" over three years of operation, with no major security breaches. Its robust design and multiple audits by reputable firms provide confidence in the reliability and security of its core mechanisms. This combination of innovative yield tokenization and proven resilience makes PT tokens a valuable tool in the DeFi ecosystem.

The primary risk for PT tokens arises if the underlying asset's yield surpasses the maximum implied yield supported by the AMM, which can occur due to suboptimal pool parameters or significant changes in the asset's yield characteristics. In such scenarios, PT token prices may shift out of the AMM's liquidity range, creating liquidity constraints and possibly disrupting protocols that use these tokens as collateral. Pendle's orderbook can help alleviate some of these concerns, particularly for actively traded pools. Additionally, money markets (as well as other protocols) can deploy various safeguards to reduce the impact of these events.

However, this risk diminishes as the PT token approaches maturity, where the price converges to the underlying asset's value. At maturity, the risk is fully eliminated, as each PT token can be redeemed directly for its equivalent value in the underlying asset.

This risk is inherently smaller for PT tokens with stable, less volatile yields derived from historical performance rather than speculative factors like airdrops or incentives. Protocols integrating PT tokens should prioritize assets with well-documented, predictable yields and and exercise caution when dealing with assets featuring more speculative yields.

By addressing these considerations, some PT tokens can be effectively integrated into lending protocols and DeFi applications as collateral, unlocking their full potential while minimizing systemic risks.

Important Links & References

[1] Pendle v2 Mechanism Design Risk Assessment, https://chaoslabs.xyz/posts/pendle-v2-mechanism-risk-assessment

[2] Pendle Documentation, https://docs.pendle.finance/

[3] Pendle V2 Github, https://github.com/pendle-finance

[4] SYS Whitepaper, https://github.com/pendle-finance/pendle-v2-resources/blob/main/whitepapers/SYS.pdf

[5] AMM Whitepaper, https://github.com/pendle-finance/pendle-v2-resources/blob/main/whitepapers/V2_AMM.pdf

[6] Chaos Labs Research, https://chaoslabs.xyz/research

[7] Chaos Labs Blog, https://chaoslabs.xyz/blog

Chapter 7

About Chaos Labs

Chaos Labs is a cloud-based platform that develops risk management and economic security tools for decentralized finance protocols. The platform leverages sophisticated and scalable simulations to stress test protocols in adverse and turbulent market conditions. By partnering with DeFi protocols, Chaos Labs aims to create innovative solutions that enhance the efficiency of DeFi marketplaces.

The Chaos Labs team exhibits exceptional excellence and represents diverse expertise, encompassing esteemed researchers, engineers, and security professionals. Chaos Labs has garnered its experience and skills from renowned organizations, including Google, Meta, Goldman Sachs, Instagram, Apple, Amazon, and Microsoft. Additionally, the team boasts members who have served in esteemed cyber-intelligence and security units like Israel's 8200 units, Talpiot, and the Ministry of Defense Financial Strategy Office, further contributing to their unparalleled capabilities.

Chaos Labs brings a wealth of experience in both the field of decentralized finance and the stewardship of real-world assets. You can explore our past and ongoing projects for customers like Aave, GMX, ether.fi, Jupiter, Uniswap, Venus, and more in the Research and Blog sections of our website.