DeFi Derivatives
Perpetual Futures, Options, and Structured Products
Day 6 of 10

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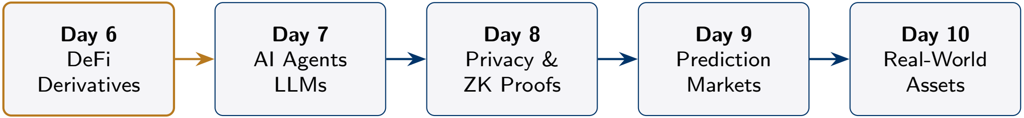
Week 2: Advanced Topics



Today: The derivatives market that crypto invented—and that now dwarfs traditional crypto spot trading.

The $80B/Day Market You Have Never Heard Of

Perpetual futures trade **more volume** than all spot crypto combined [1].

A Derivative That Does Not Exist in TradFi

- **Robert Shiller (1993):** Proposed perpetual futures in theory as a tool for hedging illiquid assets [7]
- **Arthur Hayes / BitMEX (2016):** First practical implementation for BTC—exploded to billions in daily volume within months
- Key properties that made them dominant:
  - No expiry date $\Rightarrow$ no roll costs
  - No physical delivery $\Rightarrow$ pure price exposure
  - High leverage (up to $125\times$) $\Rightarrow$ capital efficiency
  - Funding rate mechanism $\Rightarrow$ price anchoring to spot

Rhetorical Question

Why would a derivative with *no expiry* and *no delivery* dominate the entire market?

Traditional Futures vs. Perpetual Futures

Feature	CME BTC Future	BTC Perp
Expiry	Monthly/quarterly	**Never**
Settlement	Cash or physical	Funding rate
Convergence	At expiry	Continuous
Roll cost	0.05–0.2% per roll	0%
Leverage	2–10×	Up to 125×
Trading hours	CME hours	24/7/365
Regulation	CFTC regulated	Varies

The perp is a *continuously auto-rolling* futures contract where the funding rate replaces convergence at expiry.

Today: Quantify, Trade, and Understand DeFi Derivatives

1. Perpetual Futures and the Funding Rate
2. Cash-and-Carry Arbitrage
3. Power Perpetuals and Squeeth
4. Decentralized Option Vaults (DOVs)
5. CEX vs. DEX Derivatives
6. Structured Products in DeFi
7. Hands-On: Funding Rate Analysis

What Is a Perpetual Future?

Definition 1

A **perpetual future** (perp) is a derivative contract tracking an underlying asset price with *no expiry date*. A periodic **funding rate** payment between longs and shorts keeps the perp price anchored to the spot price.

Intuition: A futures contract that auto-rolls forever. Instead of delivery at expiration, traders periodically pay each other based on whether the perp trades above or below spot.

- Funding rate is the *replacement* for convergence-at-expiry
- Acts as a continuous tether pulling perp price toward spot
- Settled every 8 hours on most CEXs (00:00, 08:00, 16:00 UTC)

The Funding Rate Formula

Funding Rate

$$F = \text{clamp}\left(\frac{P_{\text{perp}} - P_{\text{spot}}}{P_{\text{spot}}},\ -0.75\%,\ +0.75\%\right) + \underbrace{r_{\text{int}}}_{\approx 0.01\%}$$

- $F > 0$: longs pay shorts (market is net bullish, perp at premium)
- $F < 0$: shorts pay longs (market is net bearish, perp at discount)
- Clamp prevents extreme costs during flash crashes or squeezes
- Interest rate component reflects the USDT-vs-crypto rate differential

Self-correcting: When everyone piles into longs, funding rises, discouraging more longs and encouraging shorts $\Rightarrow$ price converges back to spot.

Worked Example: Funding Rate in Action

Given:

- BTC spot = \$60,000; perp = \$60,300 (0.5% premium)
- Funding rate = 0.01% per 8h (positive)
- Trader is **long** 1 BTC perp

Step 1: Payment per settlement
$60{,}300 \times 0.01\% = \$6.03$

Step 2: Daily cost
$3 \times \$6.03 = \$18.09$

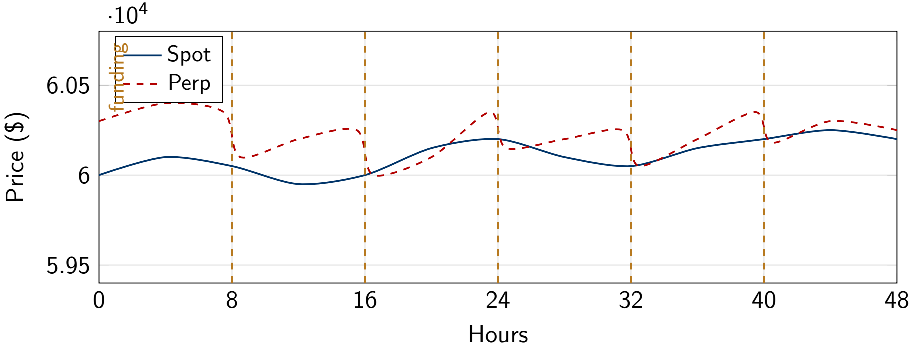
Step 3: Annualized
$0.01\% \times 3 \times 365 = \mathbf{10.95\%}$

Extreme scenario:

- Perp = \$61,000 (1.67% premium)
- Clamped to 0.75%
- $F = 0.75\% + 0.01\% = 0.76\%$
- On \$100K notional:
  \$760 per 8h $\Rightarrow$ \$2,280/day
- Annualized: **832.8%**

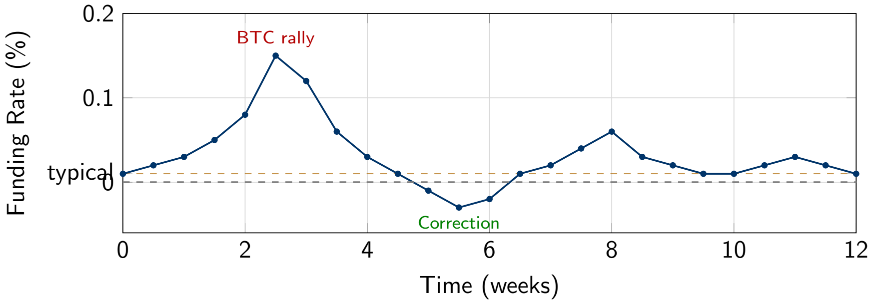
This is unsustainable by design—it forces rapid self-correction.

How Funding Anchors Price



Vertical dashed lines = funding settlements. At each settlement, the perp price is pulled back toward spot.

Funding Rate as a Sentiment Indicator



- Persistently high funding ⇒ overheated market, correction likely
- Negative funding ⇒ fear, potential buying opportunity

Cash-and-Carry Arbitrage with Perps

Definition 2

Cash-and-carry: Buy the spot asset and short the perp simultaneously. When $F > 0$, collect funding from longs while bearing *no directional price risk*.

Intuition

If the market pays you 20% annualized to be short perps (via funding), and you hedge by holding spot, you earn 20% with near-zero market risk. This is the bread-and-butter of crypto quant funds.

Conceptually identical to the **bond basis trade** in fixed income.

Cash-and-Carry: Worked Example

Setup: Capital = \$100,000 USDC

- Buy 0.833 BTC spot at \$60,000 $\Rightarrow$ \$50,000 deployed
- Short 0.833 BTC perp at \$60,300 $\Rightarrow$ \$50,000 margin
- Net exposure: **zero** (delta-neutral)

Daily funding income:

$0.833 \times \$60{,}300 \times 0.03\% \times 3$
$= \$45.19/\text{day}$

Annual return:

$\$45.19 \times 365 = \$16{,}494$
$=$ **16.5%** on \$100K capital

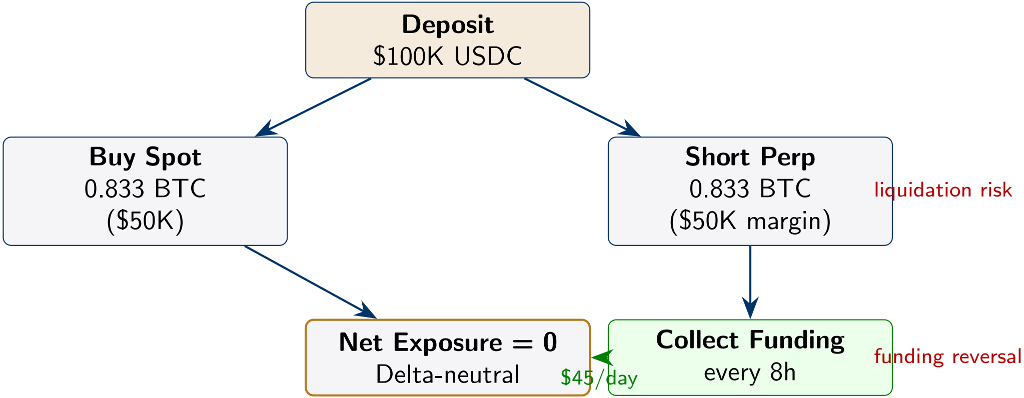
Costs:

- Trading fees: ~\$20 (one-time)
- Bridge/withdraw fees

Risks:

- Exchange insolvency (FTX)
- Margin liquidation on spike
- Funding rate reversal

Cash-and-Carry: Trade Architecture



Cash-and-Carry: Risk–Return Profile

Expected return model:

$$\mathbb{E}[R] = \int_0^T F(t)\,\mathrm{d}t - c_{\text{tx}} - c_{\text{margin}} - \lambda_{\text{exch}} \cdot L$$

- $F(t)$: funding rate path
- c_{tx}: transaction costs
- c_{margin}: opportunity cost of margin
- $\lambda_{\text{exch}} \cdot L$: exchange failure risk

Historical returns (2021–2025):

Year	Ann. Return
2021	25–40%
2022	8–15%
2023	10–20%
2024	15–25%

Sharpe ratio typically 2–4 in calm periods, but tail risk is severe (exchange failure).

Power Perpetuals: Perpetual Convexity

Definition 3

A **power perpetual** tracks S^p where S is the underlying price and p is the power exponent. For $p = 2$, the instrument is called **Squeeth** (squared ETH). Introduced by Opyn (2022) [8].

Funding rate:

$$F \approx \frac{p(p-1)}{2}\sigma^2 \Delta t \qquad \Longrightarrow \qquad \text{For Squeeth } (p=2): \quad F \approx \sigma^2 \Delta t$$

- Constant gamma exposure—like a perpetual option that never expires
- Payoff is **convex**: gains accelerate, losses decelerate
- Cost of convexity = funding rate $\propto \sigma^2$
- Essentially: *buying volatility exposure*

Squeeth: Worked Example

Given: ETH $= \$3{,}000$, $\sigma = 80\%$
Squeeth index $= \text{ETH}^2 = \$9{,}000{,}000$

Scenario A: ETH $+10\%$ to $3,300

- Squeeth $= 3300^2 = \$10{,}890{,}000$
- Return: $+21.0\%$ (vs. $+10\%$ spot)
- Ratio: **2.1**× (convexity bonus)

Scenario B: ETH -10% to $2,700

- Squeeth $= 2700^2 = \$7{,}290{,}000$
- Return: -19.0% (vs. -10% spot)
- Ratio: **1.9**× (convexity cushion)

Daily funding cost:

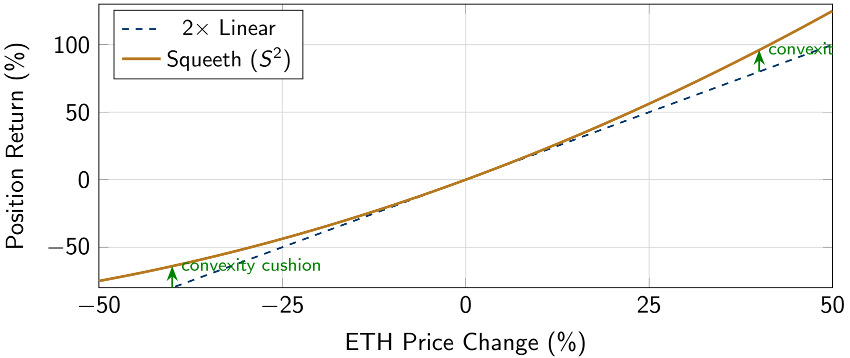
$$F_{\text{daily}} = \frac{\sigma^2}{365} = \frac{0.64}{365} = 0.175\%$$

Annualized: 64%

Key insight:
Upside $> 2\times$ levered.
Downside $< 2\times$ levered.
This asymmetry *is* the convexity.

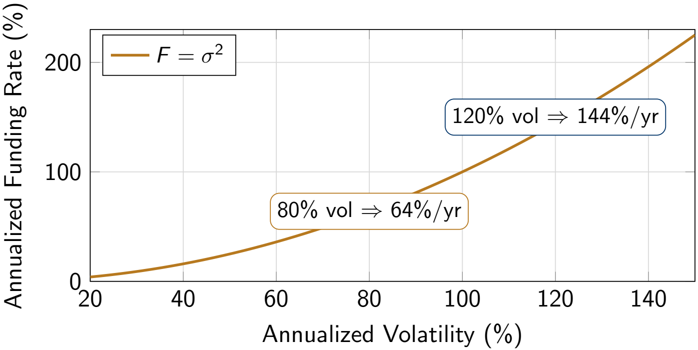
Worth it only if realized vol > funding cost—same as options premium vs. realized vol.

Squeeth Payoff vs. 2× Leverage



At extreme moves, Squeeth outperforms 2× leverage on the upside and loses *less* on the downside.

Squeeth Funding Cost vs. Volatility



Profitable when **realized volatility exceeds implied funding**—analogous to buying options below fair value.

Decentralized Option Vaults (DOVs)

Definition 4

DOVs are smart contracts that automate option-selling strategies. Depositors provide capital; the vault sells covered calls or cash-secured puts each epoch (typically weekly) via on-chain auction and distributes premium to depositors [4].

Intuition: A "set-and-forget" option selling fund.

- Pioneered by **Ribbon Finance** (2021), followed by Friktion, StakeDAO, Thetanuts
- Democratizes strategies that previously required options expertise
- Like being an insurance seller: steady premiums, occasional large claims

Covered Call Vault: Worked Example

Setup: Vault holds 10 ETH at \$3,000. Sells 10 weekly calls, strike = \$3,200 (6.7% OTM). Premium = 0.5 ETH (≈\$1,500).

Scenario A: ETH = \$3,100
Options expire worthless.
Vault value: $10 + 0.5 = 10.5$ ETH
Weekly return: 5%

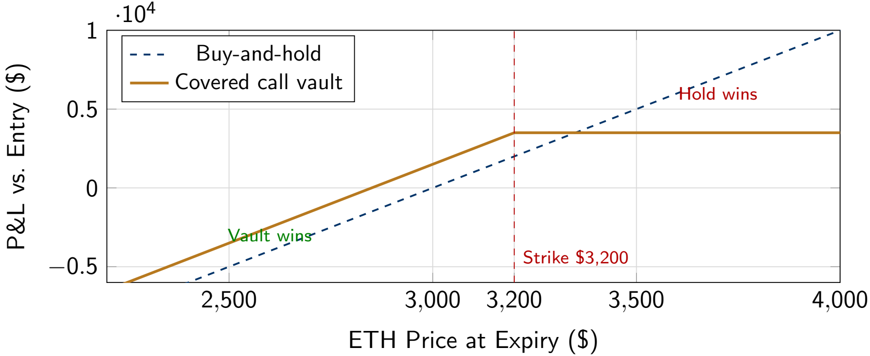
Scenario C: ETH = \$2,500
Options expire worthless.
Vault: $10 \times \$2{,}500 + \$1{,}500 = \$26{,}500$
Hold: $10 \times \$2{,}500 = \$25{,}000$
Vault outperforms by \$1,500

Scenario B: ETH = \$3,500
Options exercised at \$3,200.
Vault: $10 \times \$3{,}200 + \$1{,}500 = \$33{,}500$
Hold: $10 \times \$3{,}500 = \$35{,}000$
Missed upside: \$1,500

Historical (2022–2024):

- Premium yield: 15–30% ann.
- Underperforms in bull runs
- Outperforms sideways markets

DOV Payoff: Covered Call vs. Buy-and-Hold



The vault sacrifices upside for premium income.

DOV Risks and the Gamma Trap

- **Capped upside:** Strong rallies leave vault holders behind
- **Gamma trap:** As ETH approaches the strike near expiry, the vault's short gamma creates adverse price dynamics
- **Strike selection risk:** Too aggressive (ATM) $\Rightarrow$ frequent exercise; too conservative (deep OTM) $\Rightarrow$ low premium
- **Smart contract risk:** Entire vault value is in a single contract

Who Should Use DOVs?

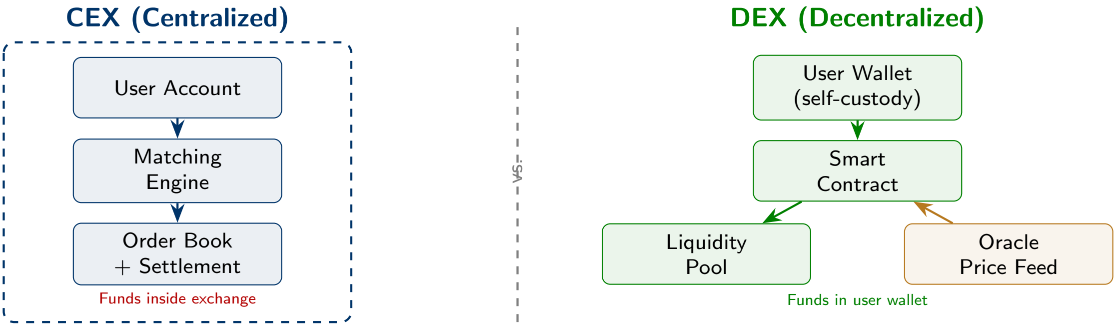
Holders with a *neutral-to-mildly-bullish* view who want yield on idle assets. Not suitable if you expect a strong breakout.

CEX vs. DEX: Feature Comparison

Feature	CEX (Binance)	DEX (GMX v2)
Daily volume	\$50B	\$1–2B
Latency	∼5ms	∼2s (block time)
Custody	Exchange holds	Self-custody
KYC	Required	None
Max leverage	$125\times$	$100\times$
Liquidation	Centralized engine	Smart contract
Counterparty risk	Exchange insolvency	Smart contract bug
Taker fee	0.02–0.05%	0.05–0.1%
Funding mechanism	Time-weighted avg	Oracle-based
Insurance fund	\$1B+ (Binance)	GLP/GM pool
Regulation	Licensed (varies)	Unregulated

Core trade-off: CEX = speed + liquidity. DEX = self-custody + censorship resistance.

CEX vs. DEX Architecture



The Post-FTX Shift to DEX Derivatives

- FTX collapse (Nov 2022): \$8B+ in customer funds lost
- DEX perp volume share: 1.5% $\Rightarrow$ 5% (2022–2025)
- Key DEX protocols:
  - **dYdX v4:** Own Cosmos chain, off-chain order book
  - **GMX v2:** Oracle-based pricing on Arbitrum
  - **Hyperliquid:** Purpose-built L1 for perp trading
  - **Synthetix v3:** Synthetic asset protocol

Key Lesson

Self-custody eliminates *exchange insolvency risk* but introduces *smart contract risk*. Different failure mode, not zero risk.

Microstructure: CEX vs. DEX

CEX order flow:

- Hidden order book (dark-pool dynamics)
- Exchange has information advantage
- Fast matching ($<$5ms)
- Payment for order flow (PFOF)

DEX order flow:

- All pending orders visible in mempool
- MEV extraction: front-running, sandwiching
- Block-time latency ($\sim$2s)
- Transparent but adversarial

Research Question

Does the transparency of DEX order flow improve or harm price discovery? Empirically: mixed evidence [2].

DeFi Structured Products

Definition 5

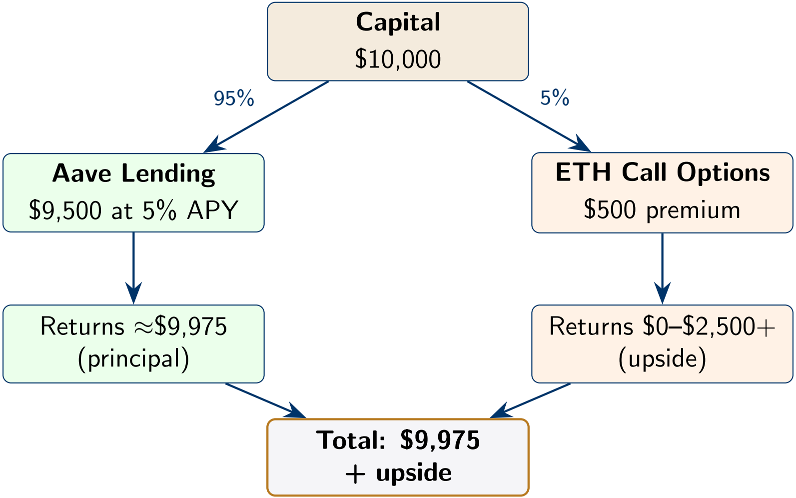
DeFi structured products combine multiple financial primitives (lending, options, perps, staking) into a single tokenized strategy. The DeFi equivalents of structured notes sold by investment banks.

Advantages over TradFi structured products:

- Transparent: read the smart contract code
- Composable: combine with other protocols
- Accessible: no minimum investment, no accredited investor gate
- No bank margin (saves 2–3% in fees)

Risk: Smart contract bugs can destroy the entire structure.

Example: Principal-Protected Yield



Principal-Protected Note: Scenarios

A: ETH flat or down

- Aave returns \$9,975
- Options expire worthless
- Total: \$9,975 (-0.25%)
- *Near-perfect principal protection*

B: ETH rises 50%

- Aave returns \$9,975
- Options: $\sim$\$2,500 profit
- Total: \$12,475 ($+24.75\%$)

Replicates a bank's capital-guaranteed note:

- No bank margin (saves 2–3%)
- Fully transparent construction
- 24/7 redeemable

Key risk:

Smart contract failure in Aave $\Rightarrow$ loss of \$9,500 principal. This is the "jump-to-default" risk unique to DeFi structured products [3].

DeFi Structured Product Landscape

Type	Strategy	Risk Profile
Principal-protected	Lending + options	Low (SC risk)
Covered call vault	Hold + sell calls	Medium
Leveraged yield	Recursive lending	High
Range accumulator	LP in narrow range	Medium–High
Basis trade vault	Spot + short perp	Medium

All share a common risk: **smart contract composability risk**—if *any* component protocol fails, the entire structure can unwind.

Hands-On Exercise: Funding Rate Arbitrage Simulator

Objective

Analyze real funding rate data and simulate a cash-and-carry arbitrage strategy.

Tools: Python (pandas, matplotlib) or spreadsheet

Data: 90 days of BTC 8-hourly funding rates from Binance

Tasks:

1. Load and visualize funding rate time series
2. Compute cumulative funding income for a $100K position
3. Simulate entry/exit rules (enter when $F > 0.01\%$, exit when $F < 0$)
4. Calculate Sharpe ratio and maximum drawdown

Task 1: Load and Visualize Funding Rates

Python starter code:

```
import pandas as pd
import matplotlib.pyplot as plt

df = pd.read_csv("btc_funding_rates_90d.csv",
                 parse_dates=["timestamp"])
df["funding_pct"] = df["funding_rate"] * 100

fig, ax = plt.subplots(figsize=(12,4))
colors = ["green" if x < 0 else "red"
          for x in df["funding_rate"]]
ax.bar(df["timestamp"], df["funding_pct"],
       color=colors, width=0.3)
ax.set_ylabel("Funding Rate (%)")
ax.axhline(y=0, color="black", linewidth=0.5)
```

Task 2: Cumulative Funding Income

```
capital = 100_000  # USD
position_size = capital / 2  # half to spot, half margin

df["income_per_period"] = (
    position_size * df["funding_rate"]
)
df["cum_income"] = df["income_per_period"].cumsum()
df["cum_return_pct"] = df["cum_income"] / capital * 100

print(f"Total income: ${df['cum_income'].iloc[-1]:,.2f}")
print(f"Annualized:   {df['cum_return_pct'].iloc[-1]"
      f" / 90 * 365:.1f}%")
```

Discussion: What do you observe about the income pattern? Is it steady or lumpy? What does that imply for risk management?

Task 3: Entry/Exit Strategy Simulation

Trading rules

```
in_position = False
total_pnl = 0

for _, row in df.iterrows():
    if not in_position and row["funding_rate"] > 0.0001:
        in_position = True          # enter
    elif in_position and row["funding_rate"] < 0:
        in_position = False         # exit
    if in_position:
        total_pnl += position_size * row["funding_rate"]
```

Questions to answer:

1. How often does the strategy enter/exit?
2. What fraction of available funding income is captured?

Task 4: Risk Metrics

Compute for both strategies (always-on vs. conditional):

Sharpe Ratio:

$$\mathrm{SR} = \frac{\bar{r} - r_f}{\sigma_r} \times \sqrt{3 \times 365}$$

where $\bar{r}$ = mean 8h return, $r_f \approx 0$, σ_r = std of 8h returns, and 3×365 = periods per year.

Maximum Drawdown:

- Track running peak of cumulative P&L
- MDD = largest peak-to-trough decline
- Dominated by periods of negative funding

Expected results:

- Always-on: higher total return, lower Sharpe (includes negative funding)
- Conditional: slightly lower return, significantly higher Sharpe

Discussion: Derivatives in DeFi

1. **Market efficiency:** If cash-and-carry earns 15–20% risk-free-ish, why does the opportunity persist?
   (Exchange risk, capital lockup, technical barriers)
2. **Squeeth adoption:** Why has Squeeth not gained wider adoption despite elegant design?
   (64% annual funding is expensive; limited liquidity)
3. **DOV risks:** Are DOV depositors being adequately compensated for the gamma and smart-contract risk they bear?
4. **Regulation:** Should perpetual futures (with 125× leverage) be regulated like traditional futures?

Day 6: Key Takeaways

1. **Perpetual futures** dominate crypto derivatives: $80B/day, no expiration, funding rate as the price anchor
2. **Funding rates** serve as both a sentiment indicator and an income source (cash-and-carry arbitrage yields 10–25% annually)
3. **Power perpetuals** (Squeeth) offer constant gamma—the first "never-expiring option"—at a cost of σ^2 per year
4. **DEX derivatives** are growing post-FTX but CEXs still dominate on volume and latency
5. **DeFi structured products** replicate bank products transparently, but smart contract risk remains the key vulnerability

Further Reading

- **Perpetuals and funding:** Alexander, Deng, and Feng [1]
- **Power perpetuals:** White, Robinson, and Koticha [8]
- **DeFi leverage:** Heimbach and Huang [5]
- **Options pricing:** Hull [6], Ch. 18–20
- **DEX microstructure:** Capponi and Jia [2]
- **DeFi overview:** Harvey et al. [4]

References I

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[2] Agostino Capponi and Ruizhe Jia. "The Adoption of Blockchain-Based Decentralized Exchanges". In: *Review of Financial Studies* 37.12 (2024), pp. 3807–3850.

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