Convexity Protocol : A Decentralised Exchange for DeFi Interest Rate Swaps on the Compound Supply Rate
Draft

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April 2021

Abstract

We introduce a novel DeFi native interest rate derivative instrument–the cToken future–and Convexity.Exchange, the decentralised exchange where cToken futures and other crypto interest rate derivatives will be traded. These two elements will serve as fundamental and essential infrastructure for a new DeFi native crypto interest rate derivatives trading industry. cToken futures are powerful, simple tools that create fixed versus floating interest rate exposure on the Compound.finance Protocol (Compound) supply rate. Combining them with floating rate Compound positions, users can create synthetic fixed supply rate positions which can then be tokenized and traded. They can also borrow from Compound at synthetic stable rates. cToken futures are easy to value, allow users to initiate both paid or received fixed interest rate positions, and enable capital efficient speculation, hedging, and market making. Interpolating and risk managing broken dates is also possible.

Index terms— DeFi interest rate derivatives, crypto interest rate swaps, DeFi interest rate swaps, cToken futures

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1 Introduction

1.1 Why now?

Over the past few years, we have witnessed the rapid development of crypto asset markets but an interest rate derivative (IRD) market does not yet exist in any meaningful sense. There are currently *hundreds* of exchanges where users can trade spot[5], margin, and futures referencing spot exchange rates (e.g. BTCUSD dated and perpetuals)[4]. Options are actively traded and crypto borrowing and lending is also emerging as a major component of the ecosystem meeting the demand for leverage (e.g. BlockFi, Celsius, Anchorage, Matrixport, Tesseract). In DeFi, there is a booming money market that is dominated by floating rate protocols such as Compound.finance(Compound) and AAVE. Given the above, I believe that it is a near certainty that an active and thriving IRD market will develop to provide market participants with tools to efficiently manage their interest rate risk.

Existing attempts at creating fixed rate and fixed maturity products have mostly focused on building parallel protocols to Compound and AAVE which face an enormous challenge of attracting liquidity. Attempts at creating derivative products seem to focus on tokenizing future yield. cToken futures would be a simple IRD product in the purest sense that will add to the development of the DeFi credit eco-system. cToken futures will create trading opportunities between the protocols mentioned above.

1.2 Why the Compound Supply Rate?

For an IRD market to develop, the first necessary ingredient is a reference index that market participants can agree to settle trades against. The index calculation must be transparent, published in a timely manner, and be resistant to manipulation. The index must also move around with the general conditions of the funding markets to be useful. We will focus our efforts on creating derivatives for one protocol to begin: Compound.

The Compound supply rate is transparent. It is determined by an interest rate model (IRM) that takes the utilisation ratio as the sole variable. I discuss the IRM in detail below. The IRM is published as a smart contract on the Ethereum blockchain and therefore it is possible for anyone to examine the underlying parameters. The parameters are determined by a public governance process.

The Compound supply rate is timely. It changes anytime the ratio of assets and loans change in the underlying liquidity pools. This means that the Compound supply rate can update as frequently as once every block, or roughly every 15 seconds.

The Compound supply rate also reflects the general funding conditions of the DeFi lending markets.

> We find evidence of cointegrating relationships between markets for DAI and USDC. In turn, this suggests that to some extent interest rate changes in one protocol are associated with interest rate changes in others, perhaps in turn providing evidence of agents being incentivized to change protocol by the rates they observe. Moreover, we also find some evidence of Compound having market power[15].

As the crypto capital markets mature and become more efficient, it is likely that the correlation of interest rates offered by DeFi protocols and centralised crypto lenders increase. As one of the largest and oldest lending protocols with a proven record of security, I believe the Compound protocol is a natural source of such an index.

1.3 Compound Supply Rate is Resistant to Manipulation

The biggest potential weakness of the Compound supply rate is that for stablecoins, a handful of accounts control nearly half the liquidity [15]. This increases the risk of manipulation. However, in the short run, attempts to manipulate the index will be impractical and uncertain to yield desired results. More importantly, it will be against the long term interest of these large accounts to hamper the development of a fair and competitive IRD market based on the Compound supply rate.

A thriving IRD market on the Compound supply rate will exponentially increase the value of COMP tokens. As I will discuss in further detail below, the cToken future mechanism will rely on cTokens to margin and settle trades. This will solidify Compound's position as the backbone of the crypto capital markets making cTokens a defacto reserve currency. Assuming that large liquidity providers hold large amounts of COMP tokens from emissions, manipulating the supply rate index to suit their derivative book will be detrimental to their long term interests.

Furthermore, manipulating the supply rate is uncertain to be profitable for the following reasons. First, in the early stages of the market, it will be difficult to build a position big enough without moving the market to make it worthwhile. Second, manipulating the supply rate in Compound by first paying fixed rates (i.e. buying cToken futures) and then removing liquidity means giving up interest earned on those balances or earning much less in a different protocol. The expected gains on the derivative positions must be large enough to offset this opportunity cost which is a significant hurdle. Third, since any one fixing[1] has a duration of 15 seconds, the bad actor would have to hold an unfavorable underlying position for longer. Removing liquidity from one protocol and supplying it in another will artificially increase the spread between the two protocols. The friction-less nature of DeFi means this spread will quickly erode as capital moves the opposite direction, cancelling out the bad actor's efforts.

1.4 What is a cToken Future?

cToken futures are simple products defined by 1) expiry block and 2) traded price which cash-settles against the cToken exchange rate at expiry. Similar to inverse futures, cToken futures will be margined and settled in cTokens. cToken futures can be used to synthetically create fixed interest rate positions when combined with floating rate Compound positions. cTokens futures have the following desirable properties:

1. They are simple in structure.
2. They are easy to value.
3. Users are able to be long (paid fixed rate) or short (received fixed rate)[2].
4. They enable levered trading. Leverage is only limited by the market volatility and liquidity.

[1] In interest rate swaps, a "fixing" is when the floating rate index is determined for the next period. A swap of one year duration on the three month USD LIBOR index will have four fixings, or once every quarter. Put another way, a bad actor would only have to manipulate the fixings four times a year to impact the outcome of a one year swap. cToken futures on the other hand will effectively have approximately 2,102,400 fixings during the same period assuming 1 block per 15 seconds. Therefore, to manipulate the fixings for one year, the bad-actor needs to manipulate the index for the entire duration, which is potentially much more costly

[2] Note that this is opposite to TradFi where "long" means receiving fixed rates and "short" means paying fixed rates

5. A few liquid fixed expiry dates on the term structure will allow for interpolation of cToken forwards for any date in between, creating a new industry of OTC DeFi interest rate derivatives trading.

As alluded to above, there are several use cases for cToken futures.

1. Mint synthetic zero coupon bonds that can be traded in a secondary market or redeemed at anytime.
2. Borrow at synthetic stable rates that can be initiated and repaid at anytime using the existing Compound liquidity pools.
3. Hedge the funding cost of levered future basis trades.
4. Hedge interest rate risk of assets and liabilities for centralised crypto lenders.
5. Macro hedge existing crypto portfolios or combine with other crypto derivatives to execute sophisticated trading strategies.

I will now briefly compare the TradFi and DeFi market structure with regards to money markets and interest rate derivatives in each. I will then dive further into the details of the cToken future mechanism and finally introduce the decentralised exchange, Convexity.

2 TradFi Interest Rate Derivatives

Interest rate derivatives are indispensable tools for TradFi market participants and the daily traded volume of interest rate derivatives are orders of magnitude larger than the underlying money markets.

For bank treasuries and pension funds, interest rate derivatives provide efficient means for hedging the cost of liabilities and optimising returns on assets. Macro investors use them to express views on the development of monetary policy, economy, inflation, and other financial assets. Relative value traders exploit inefficiencies and patterns in the interest rate complex across indices and maturities which enhances end user liquidity.

All of this activity means that the interest rate derivative market dwarfs the money markets that underpin the indices those derivatives reference. For example, on the 7 April 2021, derivatives referencing the three month USD LIBOR traded more than *300 times* the notional of the commercial paper market that provided inputs to the LIBOR calculation[3]. Derivatives on the Effective Federal Funds Rate (EFFR) show similar patterns though not as dramatic. On

[3] On 7 April 2021, US dollar primary commercial paper issuance of 81 days or more for all issuer categories was $11.95 billion [11], only a subset of which would have been used as an input for calculating 3 month USD LIBOR [2]. The total trading volume of CME Eurodollar futures on the same day was 2,273,713 contracts for a notional value of $2.27 trillion [13]. If we include the notional of USD Interest Rate Swaps, FRAs, and basis trades cleared on the LCH, the trading volume of LIBOR based derivatives is greater than $3.74 trillion[17].

7 April, the derivatives trading volume was 15 times greater than the underlying Federal Funds market[4].

Even if we acknowledge that the Federal Reserve data does not capture all transactions included in the LIBOR calculation such as Euro Commercial Paper issuance and secondary market trades, it is clear that the derivative market is orders of magnitude larger than the underlying money markets.

It is unclear that DeFi interest rate derivatives will gain similar relative importance over the underlying crypto money markets due to various different structural issues. However, it is a near certainty that DeFi interest rate derivatives will play a crucial part in the crypto infrastructure. As more sophisticated investors enter the market and larger amounts of capital is deployed, DeFi interest rate derivatives will enable efficient hedging and managing of crypto-native funding risk and execution of sophisticated trading strategies.

3 Lending Protocols in DeFi

Compound and AAVE dominate the DeFi money markets [23]. As of writing, Compound has $16.4 billion worth of assets supplied to its automated lending pools of which $6.7 billion has been lent out [19], while AAVE has $6.25 billion in its liquidity pool [1]. The authors Gudgeon et al. term them Protocols for Loanable Funds (PLFs)[15].

> In PLFs, interest rates reflect the prevailing price of funds resulting from supply and demand. The mechanism used to set these rates is therefore a crucial aspect of protocol design [...]. In traditional finance, interest rates are primarily set by central banks—via a base rate—and function as a key lever in the management of credit in economies [...]. In the context of PLFs, the interest rate setting mechanism is decided upon at the protocol level, commonly via a governance process [15].

Compound, AAVE, and dYdX all operate floating rate interest rate models to achieve equilibrium. In the absence of interest rate derivatives, this means that users are exposed to interest rate volatility with currently no way to hedge or even manage their returns or cost of capital.

At the moment, crytpo interest rates, especially for stablecoins, are substantially higher than in TradFi. The demand for capital in crypto and significant risks such as smart contract risk mean that the cost of capital is high and volatile. The details of which are beyond the scope of this paper. An excellent discussion regarding the crypto credit market structure can be found here [16].

A thriving and robust IRD market is in the interest of the underlying protocols' governance token holders. Protocols with active derivative markets will

[4] Fed Funds trading volume on 7 April was $73 billion [21] while the 30 day Federal Funds futures volume and LCH Overnight Index Swap volume together add up to $1.16 trillion [12, 17].

attract and retain more liquidity relative to ones that do not as they enable powerful strategies.

4 cToken Futures

A cToken future is simultaneously a non-deliverable Foreign Exchange (FX) Forward, a fixed versus floating interest rate swap, and a short term interest rate future all rolled into one. It provides the economic exposure of a fixed versus floating interest rate swap on the Compound Protocol's supply rate. Before discussing cToken futures in detail, here are a couple subsections that introducing the Compound protocol's cToken mechanism.

4.1 cToken Exchange Rate Mechanism

When a user deposits assets, a, in Compound, they receive–"mint"–a number of cTokens, c, of equal value to the underlying assets supplied [8]. We denote the spot exchange rate between cTokens and the underlying assets as s, and specifically, the exchange rate at "mint" as s_0. The relationship between the underlying assets a, the number of cTokens c, and the exchange rate s is expressed as following.

$$\begin{aligned} c &= a/s \\ a &= c * s \end{aligned} \tag{1}$$

When withdrawing funds, users redeem their cTokens after n blocks and receive a fixed amount of underlying assets a_n determined by the cToken exchange rate s_n at that time.

$$a_n = c * s_n \tag{2}$$

The exchange rate appreciates at the same rate as interest is compounded on the supplier's underlying asset [6]. The exchange rate at redemption s_n after n blocks is the product of each block's supply interest rate r_s multiplied by the exchange rate s_0 at mint.

$$s_n = s_0 \prod_{i=0}^{n-1}(1 + r_{s,i}) \tag{3}$$

Therefore, in underlying asset terms, the value of a depositor's position after n blocks is

$$c * s_n = c\{s_0 \prod_{i=0}^{n-1}(1 + r_{s,i})\} \tag{4}$$

4.2 Compound Protocol Interest Rate Models

Both the supply rate r_s and borrow rate r_b of each market is determined by the interest rate model. The interest rate model is a function of the utilisation ratio

U[6]. utilisation ratio U for a market m is given as the following [7]:

$$U_m = Borrows/(Cash + Borrows - Reserves)$$

The Compound cUSDC, cDAI, and cUSDT markets currently use a kinked linear curve for borrow rates in each market that can be expressed as follows[7, 15][5].

$$r_b = \begin{cases} \alpha + \beta U & \text{if } U \leq U^* \\ \alpha + \beta U^* + \gamma(U - U^*) & \text{if } U > U^* \end{cases} \tag{5}$$

α is the per-block base rate, β denotes the per-block multiplier, and γ denotes the 'jump' multiplier [15].

The supply rates are given as follows.

$$r_s = U(r_b(1 - \lambda) \tag{6}$$

where λ denotes reserve factor. Parameters such as α, β, γ, U^*, and λ are determined by the protocol governance. Given (5) and (6), we can further unpack r_s as a function of U.

$$r_s = \begin{cases} U(\alpha + \beta U)(1 - \lambda) & \text{if } U \leq U^* \\ U(\alpha + \beta U^* + \gamma(U - U^*))(1 - \lambda) & \text{if } U > U* \end{cases} \tag{7}$$

The current cUSDC interest rate model is shown in figure 1. It is also important to note that the spread between the borrow rate and the supply rate is strictly a function of the utilisation ratio U. Given (5) and (6), the Compound per-block borrow rate r_b can be expressed as a function of the per-block supply rate r_s[6].

$$r_b = \begin{cases} \frac{\alpha + \sqrt{\alpha^2 + 4\frac{r_s \beta}{(1-\lambda)}}}{2} & \text{if } r_s \leq r_s^* \\ \frac{(\alpha - U^*(\gamma - \beta)) + \sqrt{(\alpha - U^*(\gamma-\beta))^2 + 4\frac{r_s \gamma}{(1-\lambda)}}}{2} & \text{if } r_s \leq r_s^* \end{cases} \tag{8}$$

Where r^* is the supply rate at the kink U^*:

$$r_s^* = U^*(\alpha + \beta U^*)(1 - \lambda) \tag{9}$$

Subtracting r_s from r_b and plotting it against r_s shows us the spread as a function of r_s (figure 2). The shape of this curve is important because the cToken

[5]The cUSDC rate model smart contract uses parameters called "multiplierPerYear", "baseRatePerYear", "kink", "jumpMultiplierPerYear", and "reserveFactorMantissa" all scaled 10^{18}. Assuming 2,102,400 blocks per year (1 block per 15 seconds), we translate the contract parameters as the following

$$\alpha = \frac{baseRatePerYear}{blocksPerYear * 10^{18}}, \beta = \frac{multiplierPerYear}{kink * blocksPerYear}, \gamma = \frac{jumpMultiplierPerYear}{blocksPerYear * 10^{18}}$$

,

$$U^* = kink * 10^{-18}, \lambda = reserveFactorMantissa * 10^{-18}$$

[6]Work shown in Appendix

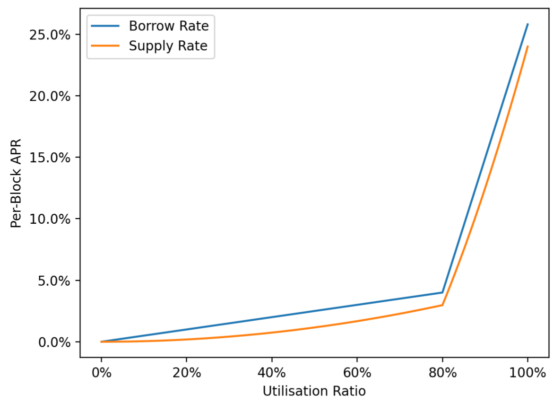

Figure 1: Compound Interest Rate Model and Utilisation Ratio

future delivers a perfect fixed rate for the suppliers by definition, but not for the borrowers. It is possible for the borrower to adjust the hedge ratios to keep the stable borrow rate within an acceptable range given the deterministic relationship between the two. Judging by figure 2, roughly speaking, if the borrower expects the supply rate to realise in a range that implies a wider(tighter) spread between the supply rate and borrow rate than implied by the future price, then she could over(under) hedge by buying more(less) cToken futures. The optimal hedging strategy requires further research.

4.3 cToken Future as a Fixed versus Floating IRS

A cToken future is a cash-settled FX forward instrument[7] because it can be used to hedge the exchange rate of cTokens versus the underlying asset. It is a future in the traditional sense because it will cash settle against an index at expiry. Economically, it creates exposure equivalent to a fixed versus floating interest rate swap where the floating index is the Compound protocol supply rate and the accumulated P&L is settled in arrears. The contract mechanism works because Compound uses an *exchange rate* to keep track of supplier balances[8].

By definition, the cToken exchange rate can only appreciate and specifically at the supply rate[9]. We've said that the cToken future will be cash-settled:

[7] The only difference between "future" and "forward" in this context is that cToken futures will have standardised expiry dates and FX forwards have customisable maturity dates.

[8] There is also the possibility of creating a physical settled version of cToken futures where the notional of the underlying asset and cTokens are exchanged. This would be similar to a fixed versus floating cross-currency basis swap. A physically settled cToken future could be used to hedge *funding* risk. I will focus on the cash-settled futures for now which can be used to hedge *interest rate* risk.

[9] This statement is "true in general unless there is a fatal bug in the system and the protocol's assets go missing"[18]

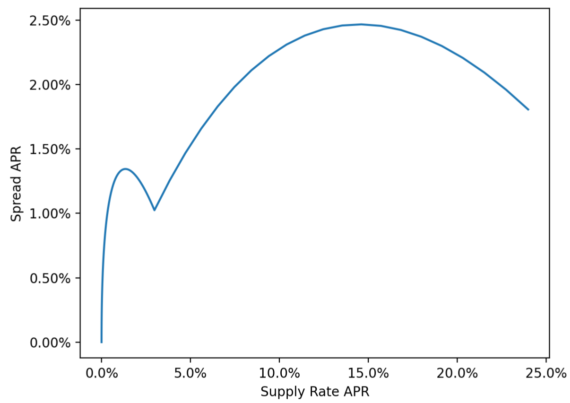

Figure 2: Borrow versus Supply Spread as a Function of Supply Rate

only the difference between the traded price and the index will be exchanged in cTokens at expiry. The index is the cToken exchange rate.

We can generalize this relationship as the following.

$$
\begin{aligned}
pl_{n,Asset} &= c_f * s_n - c_f * f_n \\
&= c_f\{\underbrace{s_0 \prod_{i=0}^{n-1}(1 + r_{s,i})}_{floating} - \underbrace{s_0(1 + r_n n)}_{fixed}\}
\end{aligned} \tag{10}
$$

The P&L in terms of the underlying asset at the future contract settlement is the difference between the exchange rate at expiry s_n and the traded future price f_n multiplied by the notional cToken amount c_f. Per (3), the exchange rate at expiry is the product of the realised floating supply rates. This is the floating leg of the interest rate swap. By locking in a cToken future price, an implied per-block interest rate is agreed and this is the fixed leg of the interest rate swap. At expiry, the accumulated difference is settled in cTokens. To calculate the P&L in cTokens, we divide (10) by the spot exchange rate at expiry s_n.

$$pl_{n,cTokens} = pl_{n,Asset}/s_n \tag{11}$$

Being short(long) the future means paying(receiving) float and receiving(paying) fixed.

The implied per block simple interest rate r_n can be derived from the future price f_n, the exchange rate at inception of trade s_0, and the number of blocks until expiry n as the following.

$$
\begin{aligned}
f_n &= s_0(1 + r_n n) \\
r_n &= (f_n/s_0 - 1)/n
\end{aligned} \tag{12}
$$

A depositor that mints cTokens in exchange for the underlying asset will be long cTokens spot. She could sell the same notional of cToken futures to lock in a fixed interest rate r_n. We can sum (10) and (4) to calculate the net portfolio value at maturity of the future in terms of the underlying asset.

$$\begin{aligned} portfolio &= c * s_n + pl_{n,Asset} \\ &= c * s_n + (c_f * s_n - c_f * f_n) \\ &= c * f_n \qquad \text{(since } c_f = \text{-}c\text{)} \end{aligned} \tag{13}$$

or in cToken terms

$$\begin{aligned} cTokenPortfolio &= c + pl_{n,cTokens} \\ &= c + (c_f * s_n - c_f * f_n)/s_n \\ &= c * f_n/s_n \qquad \text{(since } c_f = \text{-}c\text{)} \end{aligned} \tag{14}$$

4.4 cToken Future Implied Discount Factor

In foreign exchange, the forward exchange rate is the spot price multiplied by the ratio of discount factors of the two currencies involved[25].

$$forward = spot\frac{(1 + r_{quoteCcy})}{(1 + r_{baseCcy})} = spot\frac{df_{baseCcy}}{df_{quoteCcy}}$$

The cToken exchange rate is expressed using the cToken as the base currency and the underlying asset as the quoting currency. The underlying asset accrues interest but the the cToken themselves do not. This means $r_{baseCcy} = 0$ and $df_{baseCcy} = 1$. We can then re-write the first line of (12) as the following.

$$\begin{aligned} f_n &= s_0(1 + r_n n) \\ f_n &= s_0 * \frac{1}{df_{a,n}} \\ df_{a,n} &= \frac{s_0}{f_n} \end{aligned} \tag{15}$$

Where discount factor $df_{a,n}$ applies to the underlying asset. It links the future value of underlying asset at block n to the present value. Since there is only one discount factor in this context, we will denote this as df_n going forward.

4.5 Use Case 1: Creating Synthetic Bond Position

Let us assume that the current exchange rate of cUSDC is 0.02187. Today is 18 April 2021 and the **cUJ2** future[10] that expires on 18 April 2022 is trading at 0.024057.

A user simultaneously deposits 1,000 USDC in the protocol minting 45724.73708 cUSDC, and sells the same notional of cUJ2 futures at 0.024057. The pair of these transactions would lock in a 10% APY giving the user a long synthetic zero

[10] **cU** stands for cUSD, **J** is the April month code, and **2** is the last digit of 2022

coupon bond position. The implied per-block interest rate per (12) is shown below.

$$\begin{aligned} r_n &= (f_n/s_0 - 1)/n \\ r_n &= (0.024057/0.02187 - 1)/2,102,400 \\ r_n &= 4.7565 * (10^{-8}) \text{ or } 10\% \text{ APY} \end{aligned} \tag{16}$$

Lets assume a year has passed and the current exchange rate is 0.0229635. We can infer that the realised interest in the USDC pool was 5% in the past year.

$$\begin{gathered} s_n = s_0 * (1 + r) \\ 0.0229635 = 0.02187 * (1.05) \end{gathered} \tag{17}$$

The depositor's cToken holdings are redeemed for 1,050 USDC as per (2).

$$\begin{gathered} a_n = c * s_n \\ 1050 = 45724.73708 * 0.0229635 \end{gathered} \tag{18}$$

The cUJ2 future has expired and is now worth 50 USDC per (10).

$$\begin{aligned} pl_{n,Asset} &= c_f * s_n - c_f * f_n \\ &= -45724.73708 * 0.0229635 + 45724.73708 * 0.24057 \\ &= 50 \end{aligned} \tag{19}$$

or 2,177.368 cUSDC tokens as per (11):

$$2177.368 = 50/0.0229635$$

The sum of (18) and (19) which follows the form (13) is 1100 USDC. Alternatively, we can see that the depositor now has 47,902.10508 cTokens which are worth 1100 USDC.

$$45724.73708 + 2177.368 = 47,902.10508$$

$$47,902.10508 * 0.0229635 = 1100$$

Whichever way we look at it, the depositor has successfully realised the return on capital that she locked in at inception. Instead of holding the synthetic zero coupon bond until maturity, the user could have also tokenized her position and sold her interest in a secondary market.

4.6 Valuing cToken Future Positions Before Maturity

Per the no arbitrage principle, the value of a depositor's synthetic long bond position of long cTokens and short the future before maturity must equal the cost of initiating a position which produces the same underlying cash flow at maturity. Before maturity, the user can sell her synthetic bond at anytime by redeeming her cTokens at the then current exchange rate and buying back the cToken futures she was short at the prevailing market price.

At any time t before the future expiry n, the mark to market future value fv of c_f notional position of cToken futures that was traded at price $f_{n,0}$ against a current market price of $f_{n,t}$ can be expressed as the following:

$$fv_{n,Asset} = c_f(f_{n,t} - f_{n,0}) \tag{20}$$

We can multiply the future value with the discount factor df_n, t to answer the question: "how much is the P&L with the value date of block n worth *now*?" s_t is the current exchange rate. As shown in (15),

$$df_{n,t} = \frac{s_t}{f_{n,t}}$$

and we can multiply (20) with $df_{n,t}$ to calculate the present value mark to market P&L.

$$\begin{aligned} pl_{Asset} &= c_f(f_{n,t} - f_{n,0})df_{n,t} \\ &= c_f(f_{n,t} - f_{n,0})\frac{s_t}{f_{n,t}} \end{aligned} \tag{21}$$

cToken futures will be margined and settled in cTokens. To calculate P&L denominated in cTokens, we simply divide the above by the then current exchange rate s_t.

$$\begin{aligned} pl_{cToken} &= c_f(f_{n,t} - f_{n,0})\frac{df_{n,t}}{s_t} \\ &= c_f(f_{n,t} - f_{n,0})\frac{1}{f_{n,t}} \end{aligned} \tag{22}$$

cToken futures are derivatives whose mark to market at inception is zero. Only once the market moves does the future have any value. Note that at expiry when $t = n$, $f_{n,t} = s_t = s_n$, (21) is equal to (10).

Lets go back to our previous example and assume that 3 months has passed and it is now 18 July 2021. The current exchange rate s_t is 0.0225261 and the cUJ2 future price $f_{n,t}$ is 0.02472239475. This means the interest in the USDC pool realised at 12% in the past 3 months and the 9 month implied interest rate $r_{n,t}$ is 13%. We would expect the user to have a loss on her futures as she is synthetically long a bond at 10% and interest rates have gone up.

The user can redeem her cTokens for 1,030 USDC today and she has a mark-to-market loss of -27.7221 USDC on her future. Her position is now worth 1,002.2779 USDC if liquidated now.

$$\begin{aligned} portfolio &= c * s_t + pl_{Asset} \\ c * s_t &= 45724.73708 * 0.0225261 \\ &= 1030 \\ pl_{Asset} &= c_f(f_{n,t} - f_{n,0})s_t/f_{n,t} \\ &= 45724.73708 * (0.02472239475 - 0.24057)\frac{0.0225261}{0.02472239475} \\ &= -27.7221 \\ portfolio &= 1030 + (-27.7221) \\ &= 1002.2779 \end{aligned} \tag{23}$$

However, this is to be expected. The user could redeposit 1,002.2779 USDC and mint 44,494.0713 cUSDC tokens, sell the same notional amount of cUJ2 futures at 0.02472239475. This would again guarantee her 1,100 USDC in 9 months time. Thus, her position at expiry has not changed, only her current present value has.

We get the same result when calculating the portfolio value denominated in cTokens. She currently holds 45724.73708 cTokens and the loss on her futures is 1230.6656 cTokens per (11). Her position is the same as above[11].

$$\begin{aligned} pl_{cTokens} &= c_f(f_{n,t} - f_{n,0})1/f_{n,t} \\ &= 45724.73708 * \frac{0.02472239475 - 0.24057}{0.02472239475} \\ &= -1230.6656 \\ cTokenPortfolio &= 45724.73708 + (-1230.6656) \\ &= 44,494.07148 \end{aligned} \tag{24}$$

4.7 Synthetic Stable Rate Borrowing with cToken Futures

A borrower could go long cTokens futures at price f_n while simultaneously initiating a borrow position. This creates a synthetic stable rate borrow position which can be expected to stay within a range of roughly ±1.5% depending on traded implied yield, the maturity and other conditions. Unlike AAVE stable borrow rates, synthetic stable rate borrowers using cToken futures will not be re-balanced regardless of what happens to the utilisation ratio subsequently[10].

A Compound protocol borrow position alone resembles being short cTokens. However, the interest accrued on the borrow position grows at the borrow rate r_b while the cToken exchange rate grows with the supply rate r_s. The value of this floating rate borrow debt combined with a long cToken future position at expiry n can be expressed as:

$$\begin{aligned} debt &= c(\prod_{i=0}^{n-1}(1 + r_{b,i})) + pl_n \\ &= c(\underbrace{\prod_{i=0}^{n-1}(1 + r_{b,i}) - \prod_{i=0}^{n-1}(1 + r_{s,i})}_{realisedSpread} + \underbrace{f_n}_{futurePrice}) \quad \text{(assuming } c_f = \text{-}c) \end{aligned} \tag{25}$$

As shown above, the debt value is determined by the realised spread between r_b and r_s and the traded future price f_n.

Unlike the yield on a synthetic bond which is fixed by definition, The borrower's net interest cost will be determined by (a)the implied spread between the borrow rate and supply rate at inception of the fixed-rate borrow, (b)duration of the borrow, and (c)the development of realised utilisation ratios during the

[11]The results are slightly different due to rounding

life of the borrow. While the borrower is obviously exposed to the floating borrow rate, the cToken future hedges the fluctuation in the supply rate only. As mentioned in a previous subsection, The spread between the supply and borrow rates are shown in figure (2) as a function of the supply rate.

We can think of the synthetic stable rate borrower being able to lock in the general level of his borrowing, but still being exposed to the basis between the supply rate and the borrow rate. A TradFi analogy would be someone hedging a floating rate borrow position that is exposed to the Secured Overnight Financing Rate (SOFR) index[22] with a fixed Overnight Index Swap payer position that fixes on the Effective Federal Funds (EFFR) index [20]. Both indices generally move together, but the spread is dynamic, determined by idiosyncrasies in each market. Or, perhaps a better comparison would be a bank hedging an exposure to LIBID (London Interbank *Bid* Rate), with a Eurodollar future that settles on the LIBOR (London Interbank *Offer* Rate).

Where the TradFi SOFR vs EFFR analogy breaks down is that the relationship between the Compound protocol's supply rate and borrow rate is deterministic. Therefore, we can estimate the stable borrow rate APY from the future price using (8) and (12). The exact hedge ratio and hedging strategy requires further study.

4.8 Use Case 2: Synthetic Stable Rate Borrowing

Let us assume again that today is 18 April 2021 and the current cToken exchange rate of cUSDC is 0.02187 and the 18 April 2022 expiry cToken future (cUJ2) price is 0.024057. I omit the P&L calculations in cTokens for clarity for this example. A user simultaneously borrows 1,000,000 USDC from the Compound Protocol protocol and buys 45,724,737.08276 cToken futures at 0.024057 (this is the equivalent amount of cTokens to the debt at current exchange rate 0.02187). The implied per-block supply rate is 9.53102% APR[12](or 10% APY). We calculate the implied per-block borrow rate of 11.7632% APR or 12.4831% compounded APY per (8). Therefore, we expect that the borrower's interest rate to be fixed around 12.4831%.

A year has passed and It is now 18 April 2022. and we find that the cToken exchange rate is now 0.0247748. This means the realized supply rate was 13.2823% APY and the realized floating borrow rate was 16.0672%, assuming constant utilisation. The total floating interest accrued was 160,672.98 USDC and the P&L on the futures position is 32,823.28 USDC, netting interest paid of 127,849.70 USDC or 12.7850%, which is 0.3% higher than the expected fixed rate. This is because the realised spread between the borrow rate and the supply rate was 2.7849%, which was 0.3% higher than the 2.4830% spread implied by the future price at inception. The borrower was successful in largely fixing his

[12]The Current cUSDC Interest rate model has $baseRatePerYear = 0$, $multiplierPerYear = 4e16$, $jumpMultiplierPerYear = 1.09e18$, $kink = 8e17$, $reserveFactor = 7e16$. Assuming 2,102,400 blocks per year $\alpha = 0$, $\beta = 4e16/(8e17 * 2,102,400) = 23,782,343,987 * 10^{-18}$, and $\gamma = 1.09e18/(2,102,400 * 1e18) = 518,455,098,934 * 10^{-18}$, $U = 0.8$, $\lambda = 0.07$.[9][7].

cost of funds.

Valuing positions before expiry of the future works similarly with the fixed deposit rate example. Assuming the same initial conditions, lets now say 6 months has passed and it is 18 Oct 2021. The current cToken exchange rate is 0.0224496, meaning that the realised supply rate over the last 6 months was 5.3% APY. Again, assuming constant utilisation, the realized borrow rate was 6.9286%. The cUJ2 is trading at 0.0233476, implying an 8% supply APY for the remaining 6 months or 10.126% implied borrow APY. As the borrower had locked in stable borrowing at around 12.48%, we would expect a loss on the futures hedge.

The borrower's debt balance now includes the accrued floating interest of 34,643.10 USDC. The present value of the futures hedge is a loss of 31,189.46 USDC per (21). If the borrower closed out his future hedge and wanted to pay back his debt, the total value he owed would be the sum of the debt plus the loss on the futures hedge of 1,065,832.56 USDC. This is still close to the borrower's initial position of paying a fixed interest rate of 12.48%. The borrower could re-initiate a borrow position of 1,065,832.56 USDC, and buy 47,476,683.96 cToken futures at an implied supply rate of 8% or an implied borrow rate of 10.126% APY over 6 months. The expected debt balance at 18 April 2022 would be 1,119,790.34 at an interest cost of roughly 11.9% which would be 5,009.66 USDC or 0.5% less than the interest he had initially locked in.

4.9 Use Case 3: Levered Future Basis Trades

By enabling synthetically stabilized funding costs, cToken futures largely remove the floating funding risk from leveraged futures basis trades. For example, as of writing, the ETH 25 June delivery future basis is annualised at 27%[3]. With 1 unit of capital, an investor could buy 1 unit of ETH and sell an equivalent amount of coin-margined ETH futures to lock in an annualised 27% return on his capital. The investor could leverage his position by depositing ETH into Compound and borrowing USDC or DAI to repeat the process, increasing his return. However, without stable borrowing costs, the investor's returns are exposed to the volatility of the Compound borrow rate versus a fixed return on the ETH future basis. If the investors wishes to hedge this risk, he could buy cUSD futures (cUM1 in this case, as M stands for June) and lock in a borrow rate likely within a 1-3% range. If we assume that the implied stable borrow rate was 12% to the 25 June expiry and the investor had levered 1.6x, i.e. borrowed 0.6 units of USDC to do this trade, his net expected return would be 36% on his capital.

$$27\% * 1.6 - 12\% * 0.6 = 36\%$$

To avoid being liquidated in either direction, if ETH goes up, he can withdraw ETH from Compound to deposit in his Binance account. If ETH goes down, he will do the opposite. He is only exposed to the risk of the basis widening. A similar strategy can be used for BTC futures and dYdX perpetual futures.

4.10 Use Case 4: Crypto Lenders Hedging

Crypto lenders can also use the cToken futures market to manage the interest rate risk on their asset and liabilities. As the market becomes more efficient and mature, it is likely that correlation between centralised crypto lenders' deposit and borrow rates with DeFi money market interest rates will rise. If a crypto lender had engaged in classic maturity transformation by taking in short term deposits and making longer maturity loans at fixed rates, the lender can buy cToken futures to hedge the scenario of the general level of crypto interest rate rising. In that scenario, to remain liquid, the crypto lender would have to increase the deposit rates offered to its customers, erroding its net interest margin spread. A long cToken future position would offset this deterioration in profitability.

4.11 Use Case 5: Macro Hedging and Speculating

It is also possible to speculate or macro hedge a crypto portfolio by buying or selling cToken futures. Being long(short) cToken futures is equivalent to paying(receiving) fixed against receiving(paying) floating Compound supply rate. As these are derivatives, capital required upfront would be limited to the initial margin required and maintenance margin thereafter. Positions can be levered according to the liquidity and the volatility of the cToken future market which enables capital efficient hedging and speculation. Cross margining means levered curve trades are possible (i.e. cToken future calendar spreads).

For example, if we assume that demand for capital within DeFi coincides with a bull market in crypto assets in general, cToken futures could be a lower beta way to macro hedge exposure to the crypto market. A concerned investor with a crypto portfolio who wants to maintain her delta exposure may decide to hedge by selling cToken futures (receiving fixed rates) out the curve. A general malaise in the crypto market will likely bring lower interest rates in DeFi as demand for capital goes down and the investor's hedge would have paid off. Receiving crypto asset futures basis (e.g. BTCUSD 0625 Future) would be a similar trade, but the cToken future expression requires far less capital while remaining delta neutral. Further research is needed to develop a theory between the correlation between crypto interest rate curves and the broader crypto market.

4.12 cToken Future Expiry Dates and Interpolating Broken Dates

In order to concentrate market liquidity, initially 6 expiries will be introduced with two more added within 2 weeks. They will be (a) the four quarterly futures that match the existing cryptoasset futures (e.g. the third Friday of every quarter) to enable leveraged futures basis trading, and (b) two shorter dated maturities that expire on the first Friday and the forth Friday from the launch date. A new 1-week contract and 4 week contract will be launched after

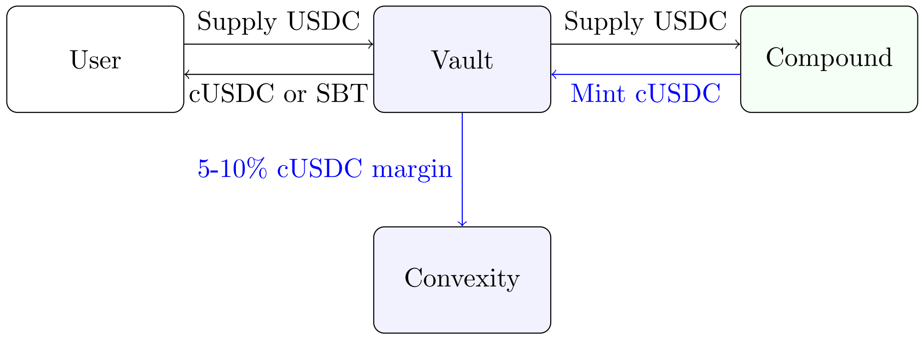

Figure 3: Fixed Rate Deposit or Minting Synthetic Bond Token[13]

each Friday for two consecutive weeks and only a new 4 week contract will be introduced weekly afterwards. After which at any given point, there will be 4 short dated maturities ranging from 1 week to 4 weeks and 4 quarterly maturities.

Using a cToken future mechanism means interpolating between liquid points is easy. Once we have 2 liquid points, we can use the ratio of the two cToken future prices to derive the implied forward starting interest rate and price broken dates in between. Risk management can be done using a combination of longs and shorts of liquid points. This will enable OTC desks to begin pricing bespoke cToken forwards and create a new industry of DeFi native interest rate derivative trading.

5 Convexity: Crypto Interest Rate Swap DEX

There will be two types of users that interact with cToken futures and the Convexity Decentralised Exchange: end users and advanced users. End users will be either fixed rate depositors or synthetic stable rate borrowers. Advanced users are speculators, hedgers, and market makers. The *Vault* will be the gateway for users to interact with both Convexity and the Compound protocol. The exchange will use a "hybrid implementation of 'off chain order relay and on-chain settlement'"[24] as described by 0x and implemented by dYdX to maintan a central limit order book (CLOB) of each cToken future. I will describe in further detail how users will interact with the protocol in each case.

5.1 Fixed Rate Deposits and Tokenized Bonds

For end users, interaction with the Convexity CLOB will be abstracted away. In the case of fixed rate supplying, the user's interface will show the expected fixed APY for a fixed set of maturity dates; one for each of the cToken future

[13]COMP emissions are not shown in figures for clarity. The Vault will pass on COMP accrued to users.

expiry dates. For each maturity date, the expected APY will be the implied notional weighted average APY of the best bids in the CLOB that sum up to the user's cToken future sell amount. The user will be able to specify slippage limits.

If the user wishes to transact, he will first create a Vault and supply USDC to the Vault. When he decides to lock in a rate, the Vault will:

1. Supply USDC to Compound and mint cUSDC.
2. Send a portion of the newly minted cUSDC to the exchange smart contract as margin and the rest to the user.
3. Send a fill or kill order of the equivalent notional of the entire supply amount in cUSDC futures based on the slippage parameters specified.

If the order is filled, then the user has created a fixed rate deposit position which is essentially a synthetic bond position. Figure 3 shows the flow of tokens, with the cTokens that will be used as margin highlighted in blue. The user could choose to withdraw the remaining cUSDC tokens from the Vault or decide to mint a Synthetic Bond Token (SBT).

The default margin will be set at a level that ensures that liquidation of an end user's position is extremely unlikely or in the case of minting the SBT, impossible. I will discuss margining in further detail in a separate subsection.

At expiry of the future, any P&L on the future will be settled to the Vault in cUSDC tokens which will continue to accrue floating interest for the user, until the he decides to re-initiate a short cToken future position again or withdraw his cTokens.

The user could choose to redeem his synthetic bond before the maturity of the trade or sell the SBT in the secondary market. If he chooses to redeem, the Vault will simultaneously redeem his cUSDC for USDC and buy back the cUSDC futures from the CLOB. The user will pay a termination fee or receive a credit based on the mark to market of the future. If the user decides to sell his SBT, then he will receive the COMP emissions accrued up to that point and relinquish ownership of the Vault.

5.2 Synthetic Stable Rate Borrowing

Similarly, the fixed rate borrower's interface will show the expected range of the fixed APY she can expect to pay for the same set of maturity dates. For each maturity date, the expected APY will be the implied notional weighted average APY of the best offers in the CLOB that add up to the number of futures the borrower must buy plus the net interest required for the margin borrowing. This will be discussed more in detail below. The user will be able to specify slippage limits.

The borrower will first create a Vault and supply collateral either in the asset or in cTokens to the Vault. If collateral received is in the underlying asset, the Vault will deposit the collateral in Compound and mint cTokens to hold them

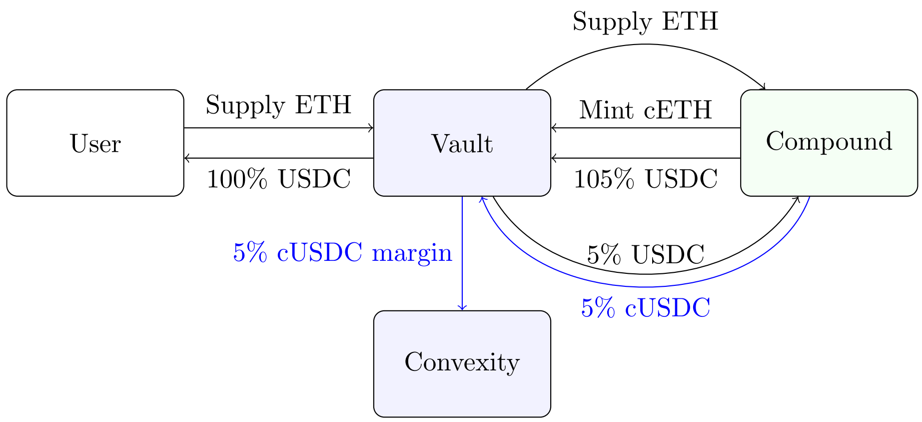

Figure 4: Synthetic Stable Rate Borrow[13]

on behalf of the user. When she decides to borrow at a fixed rate the Vault will do the following:

1. Borrow USDC from Compound which *includes* the margin that needs to be posted to the exchange.

2. Re-supply the extra borrowed amount to Compound and mint cUSDC. Send the cUSDC to the exchange smart contract as margin and the remaining USDC to the user.

3. Send a fill or kill buy order of the equivalent notional of the entire borrow amount in cUSDC futures based on the slippage parameters specified.

While the extra-borrowing will increase the stable borrower's interest cost, this will become insignificant as the market liquidity develops. The difference between the supply rate and borrow rate is less than 3%. The extra-borrowing represents less than 0.15% additional borrowing cost assuming a very conservative 5% margin requirement.

If the borrower wanted to repay her loan early, she can do so by paying back the loan and selling the cToken futures. Again, an early termination fee or credit will be assessed based on the then-current futures market price at early termination.

5.3 Advanced Users

Advanced users such as speculators, hedgers, and market makers will interact directly with the CLOB just like any other exchange. The margin required from these Advanced users will be less as they are assumed to be managing their own liquidation risk.

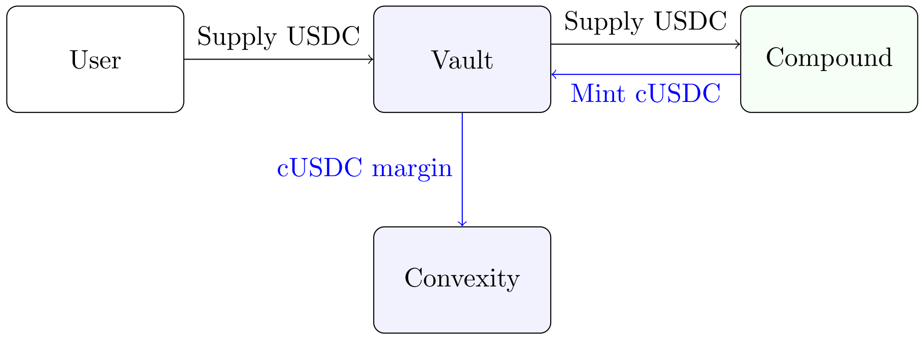

Figure 5: Hedgers, Speculators, and Market Makers[13]

5.4 Margin Requirements

The 5% margin used in the figures above for end users is a very conservative estimate for the front quarter future *given the current interest rate model*. Roughly speaking, a 1 million USDC equivalent position in the front quarter future will have a maximum Dv01 of 25 USDC[14]. The 5% margin requirement would be able to absorb a change in yield in the 3 month maturity of 20%. Given that the current interest rate model has an absolute possible range of less than 25% for the supply rate, this is very conservative.

Margin requirement for advanced users will be much less, depending on the liquidity and volatility as the market develops. Expiries with longer maturities will require increased margin as the interest rate risk increases.

As the market matures margin requirements will go down for both end and advanced users, enabling more capital efficient trading. Just as a point of reference, the Eurodollar futures margin requirement for the front contract is $200 or 0.02%[14], implying 5000X leverage. This is because of the deep liquidity and low volatility of Eurodollar futures; they move within a range of a couple basis points. cToken futures yield will probably move in daily ranges of multiple percentage points. Even with that volatility, given the short duration, it is reasonable to expect that 50X+ leverage on the front quarter future will be possible for advanced users.

5.5 Collateral

Margin and collateral will be posted in cTokens, such as cUSDC for cUSDC futures and cDAI for cDAI futures. This enables users to continue to earn interest on their margin posted while maintaining cToken futures positions. At expiry, all P&L will be settled in cTokens and not the underlying assets.

[14] Dv01 stands for Dollar Value of a basis point and is used as a measure of interest rate risk. E.g. For a 3 month maturity loan, if the interest rate changed from 5% to 5.01% (i.e. 1 basis point), the interest owed at maturity would go from $12,500 to $12,525. As the loan increases in duration, the interest rate risk goes up and the vice-versa is also true.

6 Conclusion

cToken futures are powerful, simple tools that can create fixed versus floating interest rate derivative positions on the Compound protocol supply rate. Combined with floating rate Compound positions, they give depositors a way to lock in their returns and for borrowers to manage their cost of funds. They are easy to value, allow users to initiate both paid or received fixed interest rate positions, and can be used for capital efficient speculation both outright and on the curve. The mechanism also means interpolating and risk managing broken dates is possible, enabling a new industry of DeFi native interest rate derivative trading.

The venue for trading these cTokens will be Convexity, a decentralised interest rate swap exchange. End user interaction will be intuitive and the underlying CLOB mechanism will be abstracted away. Fixed rate depositors will have the option of minting Synthetic Bond Tokens and selling them in the secondard market. Margin posted by end users will ensure minimal possibility of liquidation of their cToken future positions. Advanced users will interact directly with the CLOB with lower margin requirements. As the market matures, margin requirements will likely go down, allowing increasingly capital efficient trading. All P&L and margin will be maintained in relevant cTokens.

A Appendix

A.1 Interest Rate Model Equations

Solving for the borrow rate as a function the supply rate:

$$r_b = \begin{cases} \alpha + \beta U & \text{if } U \leq U^* \\ \alpha + \beta U^* + \gamma(U - U^*) & \text{if } U > U^* \end{cases}$$

and

$$r_s = U(r_b(1 - \lambda)$$

Solve for U if $U \leq U^*$:

$$\begin{aligned} r_b &= \alpha + \beta U \\ U &= \frac{r_b - \alpha}{\beta} \end{aligned} \tag{26}$$

and substitute to solve for r_b:

$$\begin{aligned} r_s &= \frac{r_b - \alpha}{\beta}(r_b(1 - \lambda)) \\ \frac{r_s}{(1 - \lambda)} &= \frac{r_b^2 - \alpha r_b}{\beta} \\ r_b^2 - \alpha r_b &= \frac{r_s \beta}{(1 - \lambda)} \\ r_b^2 - \alpha r_b - \frac{r_s \beta}{(1 - \lambda)} &= 0 \end{aligned} \tag{27}$$

Following the quadratic equation:

$$\frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Where $a = 1$, $b = -\alpha$, and $c = -\frac{r_s \beta}{(1-\lambda)}$, and since we know that $r_b > 0$:

$$r_b = \frac{\alpha + \sqrt{\alpha^2 + 4\frac{r_s \beta}{(1-\lambda)}}}{2}$$

Solve for U if $U > U^*$:

$$\begin{aligned} r_b &= \alpha + \beta U^* + \gamma(U - U^*) \\ U &= \frac{r_b + U^*(\gamma - \beta) - \alpha}{\gamma} \end{aligned} \tag{28}$$

again substitute to solve for r_b:

$$\begin{aligned} r_s &= \frac{r_b + U^*(\gamma - \beta) - \alpha}{\gamma} r_b(1 - \lambda) \\ \frac{r_s \gamma}{(1-\lambda)} &= r_b^2 + r_b(U^*(\gamma - \beta) - \alpha) \\ r_b^2 + r_b(U^*(\gamma - \beta) - \alpha) - \frac{r_s \gamma}{(1-\lambda)} &= 0 \end{aligned} \tag{29}$$

Again following the quadratic equation, $a = 1$, $b = -(\alpha - U^*(\gamma - \beta))$, and $c = -\frac{\gamma r_s}{(1-\lambda)}$, and since we know that $r_b > 0$:

$$r_b = \frac{(\alpha - U^*(\gamma - \beta)) + \sqrt{(\alpha - U^*(\gamma - \beta))^2 + 4\frac{r_s \gamma}{(1-\lambda)}}}{2}$$

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