

The Democratization of Wealth Management: Hedged Mutual Fund Blockchain Protocol

Ravi Kashyap (ravi.kashyap@stern.nyu.edu)¹

Estonian Business School / City University of Hong Kong

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1 Abstract

We develop several innovations designed to bring the best practices of traditional investment funds to the blockchain landscape. Our innovations combine the superior mechanisms of mutual funds and hedge funds. Specifically, we illustrate how fund prices can be updated regularly like mutual funds and performance fees can be charged like hedge funds. In addition we show how mutually hedged blockchain investment funds can operate with investor protection schemes - such as high water marks - and measures to offset trading related slippage costs when redemptions happen. We provide detailed steps - including mathematical formulations and instructive pointers - to implement these ideas as blockchain smart contracts. We discuss how our designs overcome several blockchain bottlenecks and how we can make smart contracts smarter. We provide numerical illustrations of several scenarios related to the mechanisms we have tailored for blockchain implementation. The concepts we have developed for blockchain implementation can also be useful in traditional financial funds to calculate performance fees in a simplified manner. We highlight two main issues with the operation of mutual funds and hedge funds and show how blockchain technology can alleviate those concerns. The ideas developed here illustrate on one hand, how blockchain can solve many issues faced by the traditional world and on the other hand, how many innovations from traditional finance can benefit decentralized finance and speed its adoption. This becomes an example of symbiosis between decentralized and traditional finance - bringing these two realms closer and breaking down barriers between such artificial distinctions - wherein the future will be about providing better risk adjusted wealth appreciation opportunities to end customers through secure, reliable, accessible and transparent services - without getting too caught up about how such services are being rendered.

2 Introduction: Mutually Hedging Decentralized Investment Platforms

Modern financial investment funds have evolved over a long time period to their present day form (Goetzmann & Rouwenhorst 2005; Mallaby 2010). The relatively long progression period of traditional finance funds - compared to decentralized wealth management - has given rise to numerous innovative techniques, including but not limited to : 1) to charge fees from customers for the services rendered, 2) mechanisms to provide liquidity to investors, 3) risk management techniques and diversified investment products, 4) to ensure fairness in terms of fees charged and 5) to be able to spread the costs of fund management over a large user base so that individual costs - and efforts - are minimized (Silber 1983; Levinthal & Myatt 1994; Tufano 2003; Matz & Neu 2006; Cherkes et al., 2008; Broby 2012; Kavanagh et al., 2014; Deakin 2015; Lenkey 2015; Cremers

et al., 2016; Brown & Pomerantz 2017; Lo 2017). Clearly there are wider economic implications of a well developed and robust financial landscape (Minsky 1986; 1990; De Gregorio & Guidotti 1995; Levine 1997; Rajan & Zingales 1998; Levine 2005; Ahmad et al., 2020).

To simplify our discussion we note that - two broad categories of investment vehicles - hedge funds and mutual funds, operate differently in terms of: 1) the investment strategies they choose, 2) the mechanisms they use to charge fees, 3) the benchmarks chosen to measure their performance, and 4) the inflow and outflow of investor funds (Fung & Hsieh 1999; Liang 1999; Malkiel & Saha 2005; Eling & Schuhmacher 2007; Agarwal, Boyson & Naik 2009; Eling & Faust 2010; Cici, Gibson & Moussawi 2010; End-notes 1; 2).

Mutual funds charge a variety of fees to cover their business expenses (Chordia 1996; Golec 1996; Dellva & Olson 1998; Elton, Gruber & Blake 2003; Gil-Bazo & Ruiz-Verdú 2009; Khorana, Servaes & Tufano 2009; Cuthbertson, Nitzsche & O'Sullivan 2010). To facilitate ease of blockchain implementation we categorize these fees into: 1) deposit fees (charged to investors when an investment is made), 2) redemption fees (charged when the investor makes a withdrawal request) and 3) management fees which depend on the assets under management (AUM: End-note 3).

With some abuse of terminology, AUM could also be termed the total value locked (TVL: End-note 4) using decentralized finance (DeFi: Zetzsche, Arner & Buckley 2020; Werner, et al., 2021; Grassi et al., 2022; End-notes 5; 6) lingo. Management fees do not directly depend on the growth in the value of the investments, that is on the appreciation of the asset prices. Mutual funds typically hold liquid investments and investors can buy or sell mutual fund shares (a unit) periodically (usually daily) based on the price of the shares (also know as Net Asset Value, NAV: Penman 1970; End-note 7) which is also updated on a corresponding time interval (usually also a daily basis).

Hedge funds have a key distinction since they charge some form of performance fees based explicitly on the returns they generate for investors (Agarwal, Daniel & Naik 2009; Ben-David, Birru & Rossi 2020). Performance fees - which are intrinsically tied to the growth in the value of investments that investors receive - are usually collected separately from management fees. Hedge funds have restrictions on investor redemptions and the NAV is not publicly made available like mutual funds (Aragon 2007; Cumming & Dai 2009; Hong 2014; Aiken, Clifford & Ellis 2015).

Two main issues pertaining to modern investment funds are that: 1) not all investment opportunities are available for all investors (Asness, Krail & Liew 2001; Brooks & Kat 2002; Stulz 2007), and 2) the holdings of the funds are not very transparent to outsiders (Anson 2002; Haslem 2004; 2007; Hedges 2005; Prat 2005; Goltz & Schröder 2010; Aggarwal & Jorion 2012; Aragon, Hertzal & Shi 2013; Agarwal, Vashishtha & Venkatachalam 2018). Both these issues can be solved, to a great extent, by utilizing blockchain technology. In this article we provide several innovations that will enable investment funds to operate using decentralized ledgers (Nakamoto 2008; Di Pierro 2017).

There are pros and cons to the operational dynamics of both hedge funds and mutual funds. We cherry pick the superior mechanisms from both types of funds - mutual funds and hedge funds - and take them to the blockchain investment space.

2.1 Blockchain Investment Funds: Challenges and Solutions

There are several works that describe the application of blockchain technology to fund management and also to other aspects of financial intermediation (Manda et al., 2018; 2023; Patel, Migliavacca & Oriani 2022; Ren et al., 2023). These pioneering works provide a conceptual overview regarding the procedures pertaining to fund management that can be transferred to decentralized ledger based solutions. Streamlining some of the fund management processes onto blockchain can bring about significant operational efficiencies - that will reduce costs - and improved security due to the inherent cryptographic features of decentralized technologies - while making data publicly available for both reporting and decision making. (Fiergbor 2018; Ciriello 2021; Srivastava 2023) provide detailed examples pertaining to index funds - that is mutual funds and exchange traded funds (End-note 8).

It is important to clarify that the existing works on blockchain fund management focus on providing managerial insights and high level overviews on how to approach the nuances of decentralized technology that can be applied to financial wealth management. In contrast, we have designed a complete fund management blockchain protocol - including detailed mathematical formations and pointers - that is ready for software implementation.

We have also created several innovations - related to investor protection and seamlessly levying fees - applicable to blockchain fund management in terms of adapting best practices from traditional finance to the blockchain realm. Initially, we describe the new techniques we have created at a high level so that it is easy to understand for a wide audience. Later sections give granularity steps - so that it helps participants understand the complexities involved and also to be able to build the necessary infrastructure. The outline of the various topics is given later in Section (2.3).

Our novel techniques combine the superior mechanisms of investment funds - mutual funds and hedge funds - while provide detailed steps to implement them as blockchain smart contracts (Buterin 2014; Macrinici et al., 2017; Mohanta et al., 2018; Hu et al., 2019; Negara et al., 2021; Vacca et al., 2021; Sharma et al., 2023; End-note 9). We discuss how our designs overcome several blockchain bottlenecks and how we can make smart contracts smarter. Specifically, we illustrate how fund prices can be updated regularly like mutual funds and performance fees can be charged like hedge funds. In addition we show how mutually hedged blockchain investment funds can operate with investor protection measures such as high water marks and methodologies to offset trading related slippage costs when redemptions happen. We provide numerical illustrations of several scenarios related to the mechanisms we have tailored for blockchain implementation.

The concepts we have developed for blockchain implementation can also be useful in traditional financial funds to calculate performance fees in a simplified manner. We show how blockchain technology can alleviate concerns regarding two issues we have highlighted with the operation of mutual funds and hedge funds. The ideas developed here illustrate on one hand, how blockchain can solve many issues faced by the traditional world and on the other hand, how many innovations from traditional finance can benefit decentralized finance and speed its adoption. This becomes an example of symbiosis between decentralized and traditional finance - bringing these two realms closer and breaking down barriers between such artificial distinctions - wherein the future will be about providing better risk adjusted wealth appreciation opportunities to end customers through secure, reliable, accessible and transparent services - without getting too caught up about how such services are being rendered.

Below we describe the challenges - and the corresponding solutions we have pioneered - to bring traditional financial investment fund operational models - and best practices - to the Blockchain landscape. We wish to utilize the technological developments that have happened in the many decades since hedge funds became popular and to also combine several enhancements related to the blockchain decentralization paradigm. We lay down the techniques for an investment platform that keeps all fund assets entirely on the blockchain platform at all times. Kashyap (2021) has a detailed discussion of other related topics that are aimed at making blockchain investing secure and less risky. The specific issue of maintaining assets on-chain - in a highly secure manner - is also discussed in one of the earlier sections of Kashyap (2021).

2.2 Fees for Protection with Appreciation: Quid Pro Quo

The community driven spirit of DeFi makes it essential to have some form of profit sharing, wherein part of any excess fees generated is given back to long term investors of the project (Singh & Kim 2019; Wang et al., 2019; El Faqir et al., 2020; Wu et al., 2021; Zheng & Boh 2021; Ballandies et al., 2022; Liu et al., 2022; Kitzler et al., 2023; Saurabh et al., 2023). Fueling the decentralized ethos of profit sharing are many grievances related to high fees in the traditional financial sector with counter arguments being provided about competition between funds restricting fees to reasonable levels (Golec 1996; Coates & Hubbard 2007; Khorana et al., 2009; Malkiel 2013; Philippon 2015; Feldman et al., 2020). With blockchain technology it becomes easy to assess profits, fees and related metrics - due to the transparency of operations across all types of decentralized investment vehicles - given that making information publicly available is a foundational principle built right into the genes.

While the importance of sharing the proceeds - profits from operations - with all the participants cannot be emphasized enough, it is equally - if not more - important to ensure that the community understand the need to have funds set aside for a rainy day and the necessity of being able to invest in projects that can prepare the community for the a better tomorrow. Most protocols that wish to follow the mechanisms

designed here need to emphasize to investors - community - that the performance fees are to ensure that there are enough funds to sustain operating expenses and fund future growth plans. The performance fees will ensure that investments remains stable across market cycles - and continue to grow - rewarding investors over the long term. Additional performance fees above a threshold will be the returned back to the community (Kashyap 2021).

An extremely popular investor protection mechanism in the traditional finance world is the idea of a high water mark (HWM: Goetzmann, et al., 2003; Guasoni & Obłój 2016; End-note 10). The simple summary of this concept is that performance fees are charged only when investors are entitled to a profit derived from their original principal. This is perhaps best clarified with a simple numerical illustration.

For example, let us say an investor deposits 10,000 USD. After some time, the invested amount grows to 14,000 USD, at which a high water mark is established. The profit in this case is 4,000 USD. A part of this profit is taken as performance fees. After this, if the value of the investment goes down to say 12,000 no performance fees are charged until the value of investment climbs back above 14,000, the high water mark. The bottomline is that unless a tangible wealth increase is generated for every investor - at a holistic level - no performance fees are paid. This creates a strong incentive for the team to produce solid - and quantifiable measurable - returns for the investors.

This simple scenario can get extremely complicated when there are multiple investors who deposit at different levels of the fund price. Tracking all this in a smart contract - with the current state of blockchain technology - is extremely hard and can be deemed almost impossible (Giancaspro 2017; Wang, et al., 2018; Huang et a., 2019; Zou, et al., 2019; Sayeed et al., 2020; Zheng, et al., 2020; Tolmach et al., 2021; Kannengießler et al., 2021). To be able to accommodate these complexities we have found a novel solution that works elegantly - is rather straightforward to implement as a smart contract - and provides the same level of protection to every single investor. Our solution - which utilizes weighed average calculations - is also mathematically identical - in terms of aggregate fees and proceeds - to what investment funds in the traditional world have been doing for decades.

In addition, the detailed algorithm we have developed - to create a fund management protocol - ensures that other investor protection schemes are incorporated. In particular we have created techniques to maintain fairness while investors enter or exit the fund. Limits - maximum amounts - are set on the total amounts that can enter or leave the fund during any time interval. The overall objective is to reward investor loyalty and their preference for the staying longer with the fund, which will benefit all participants - the entire community.

Incentivizing investor allegiance is done by letting investor money into the fund using a queue - on a first come first served basis (Kruse 1984; Andrew & Herbert 2015; End-note 11). Exiting the fund is done so that at each rebalancing interval, the maximum redemption amount for the entire fund is allocated across

all investors wanting to take out their money on a proportionate basis. That is, if a full redemption cannot be made, then everyone gets the same percentage of their withdraw amount satisfied. This is to be take care of the possibility that market runs - and other fund liquidation issues - are avoided during panic driven sell offs (Renshaw 1984; Kitamura 2010; Kleinnijenhuis et al., 2013; Chen & Huang 2018; Huynh & Xia 2023).

Also, the buying and selling of assets affects asset prices and is known as slippage (Bertsimas & Lo 1998; Kashyap 2020; End-note 12). We distribute the price appreciation - and the depreciation - when investor money enters - or leaves - the fund across all participants using the treasury - to finance shortfalls or to collect surplus amounts - so that no one benefits from large deposits or gets penalized when large sells are made.

2.3 Outline of the Sections Arranged Inline

Section (2) - which we have already seen - provides an introductory overview of modern investment funds, the motivations for bringing such investment vehicles to blockchain and the innovations we are creating to apply traditional finance principles to the blockchain realm. Section (2.1) describes specifically how our contributions add to the various efforts being undertaken to bring traditional wealth management to blockchain. Section (2.2) discuss the intuitions behind the innovations we are adopting in the blockchain wealth management realm to protect investors and charge fees. Later sections provide detailed mathematical steps and technical pointers.

Section (3) gives an algorithm to accept deposits and withdrawal requests from investors after calculating the price of fund shares or tokens. Section (4) is a discussion of a novel technique to charge performance fees, and maintain high water marks, despite the limitations of smart contracts. Section (4.1) considers the challenges of performance fee calculations in a decentralized environment. Section (4.2) outline issues that funds face when the NAV - due to falling market prices - trends lower than the fund water mark for charging fees. Section (4.3) outlines our solutions to address the problem in Section (4.2) tailored to perform seamlessly on blockchain networks. Section (4.4) is a discussion of how fee levies can happen in the absence of our solutions in Section (4.3) and to help readers understand the significance of the techniques we have developed.

Section (6) explains the numerical results we have obtained, which illustrate how our innovations compare to existing wealth management techniques. Section (5) has the flow charts related to the material discussed in Sections (3; 4). The diagram in Section (5) is given for completion and for helping readers obtain a better understanding of the concepts involved. Sections (7; 8) suggest further avenues for improvement and the conclusions respectively.

3 Periodic Blockchain Fund Management Methods: Sequences of Steps

Algorithm 1. *The following algorithm captures the sequence of steps that need to be carried out at periodic intervals to accomplish secure fund management entirely on a blockchain environment. The interaction of the various processes described in the following points facilitate secure movement of assets, rigorous risk management and rebalancing the portfolio to adhere to asset weights that match risk and return objectives.*

For some steps, there might be further sub steps, making these sub steps a sequence of steps within a sequence of steps and as a consequence the entire thing becomes “Sequences of Steps”.

- Figure (1) in Section (5) has the flow chart corresponding to the steps given in Algorithm (1).
 - Figures (2; 3; 4) in Section (6) give several scenarios pertaining to the steps and calculations given here. The figures illustrate different variables corresponding to inputs and calculated variables, which should help in monitoring how the system is performing.
1. Calculate Total Fund Value across all chains. This is the sum of each asset quantity multiplied by the corresponding asset price. For vaults and liquidity pools, this will be the dollar value invested in that investment opportunity. Note that we specify “across all chains” since assets will be held on multiple chains with funds invested accordingly. We call this fund Alpha going forward for ease of reference.
 2. Check Existing Number of Tokens for the Alpha investment fund (across all chains). Tokens represent the number of units or the quantity of any asset. They are the same as shares of stocks in the traditional financial world.
 3. Calculate new NAV - or Alpha Price or Fund Price - based on Step (1) and Step (2). The Alpha price will be the same for the entire fund and across all the chains.
 4. Calculate Performance Fees and Management Fees based on new NAV from Step (3) on each chain separately. The calculation of performance fees has several steps of its own and is discussed in detail in Section (4).
 5. Issue new Alpha Tokens, as necessary for performance fees and management fees, for Step (4) on each chain separately.
 6. Adjust NAV based on Alpha Tokens issued for performance fees and management fees in Step (5) across all chain separately.
 7. Aggregate the deposit amounts and withdrawal amounts so that the net total amount received for investment or for redemption is less than the corresponding maximum amount.

- Note that deposit requests are made in dollar denominations and withdraw requests are based on the number of tokens.
- The maximum amounts for deposit or withdraw for any rebalancing event is to ensure that there is a limit to how much funds can be taken out or invested into the fund during any given time interval.
- Also, note that the maximum deposit amount and maximum withdrawal amount per rebalance event could be different.
- We have to look at two cases depending on whether money will flow into the fund or out of the fund during this rebalancing sequence of events. That is we set flags $NETDPSTIND_t$ or $NETWDRWIND_t$ which will indicate whether the net amount is positive (net deposit) or negative (net withdrawal).

$$NETDPSTIND_t = \begin{cases} 1, & TOTALDPSTUSD_t \geq (TOTALWDRWTOKENS_t * ALPHAPRICE_t) \\ 0, & TOTALDPSTUSD_t < (TOTALWDRWTOKENS_t * ALPHAPRICE_t) \end{cases} \quad (1)$$

$$NETWDRWIND_t = \neg(NETDEPOSIT_t) \quad (2)$$

Here,

$$TOTALWDRWTOKENS_t = \sum_{i=1}^{W_t} WDRWREQUEST_{it} \quad (3)$$

$$TOTALDPSTUSD_t = \sum_{i=1}^{D_t} DPSTREQUEST_{it} \quad (4)$$

- W_t is the total number of withdrawals requested at time t before this particular rebalance sequence of events has started.
- D_t is the total number of deposit requests at time t before this particular rebalance sequence of events has started.
- $ALPHAPRICE_t$ is the adjusted Alpha price - or fund price - calculated at Step (6).
- $WDRWREQUEST_{it}$ is the number of tokens requested for withdraw by request i at time t .
- $DPSTREQUEST_{it}$ is the dollar amount requested for deposit by request i at time t .
- $TOTALWDRWTOKENS_t$ is the total number of Alpha tokens requested for withdrawal at time t before this particular rebalance sequence of events started.
- $TOTALDPSTUSD_t$ is the total amount in USD requested for deposit at time t before this particular rebalance sequence of events started.

- We also calculate the net amount per rebalance event, $NETAMOUNTEVENT_t$ as follows,

$$NETAMOUNTEVENT_t = (NETDPSTIND_t) * \quad (5)$$

$$\min \{NETDPSTORWDRW_t, MAXDPSTUSD_t\} \quad (6)$$

$$- (NETWDRWIND_t) * \quad (7)$$

$$\min \{|NETDPSTORWDRW_t|, MAXWDRWUSD_t\} \quad (8)$$

$$NETDPSTORWDRW_t = TOTALDPSTUSD_t - (TOTALWDRWTOKENS_t * ALPHAPRICE_t) \quad (9)$$

- $MAXWDRWUSD_t$ is the maximum amount in USD that can be accepted for redemptions at time t during any one rebalancing sequence or event.
 - $MAXDPSTUSD_t$ is the maximum amount in USD that can be accepted for investment at time t during any one rebalancing event.
- (a) Case: $NETDPSTIND_t = 1$. The deposit amounts accepted for investment are aggregated based on the first in and first out principle depending on the time stamp the deposit request is made. This is given by the formula,

$$DPSTACCEPT_{it} = \begin{cases} DPSTREQUEST_{it}, & i \leq DA_t \\ DPSTREQUEST_{it} + \sum_{i=1}^{DA_t} DPSTREQUEST_{it} & i > DA_t \\ - |NETAMOUNTEVENT_t| \\ - |TOTALWDRWTOKENS_t * ALPHAPRICE_t|, \end{cases} \quad (10)$$

- $DPSTACCEPT_{it}$ is the USD amount that will be accepted for deposit from the total amount requested for deposit from request i , $DPSTREQUEST_{it}$ at time t .
- DA_t is the total number of deposit requests at time t that satisfy the below conditions.

$$\sum_{i=1}^{DA_t} DPSTREQUEST_{it} < |NETAMOUNTEVENT_t| \quad (11)$$

$$+ |TOTALWDRWTOKENS_t * ALPHAPRICE_t| \quad (12)$$

$$\sum_{i=1}^{DA_t+1} DPSTREQUEST_{it} \geq |NETAMOUNTEVENT_t| \quad (13)$$

$$+ |TOTALWDRWTOKENS_t * ALPHAPRICE_t| \quad (14)$$

- $DPSTACCEPTRATIO_t$ is the deposit accept ratio which gives the percentage of the total requested deposit amount accepted for investment into the fund at this rebalance event, that is at time t . It is a helpful variable for monitoring the system performance given by the formulation,

$$DPSTACCEPTRATIO_t = \min \left(\left\{ \frac{|NETAMOUNTEVENT_t|}{TOTALDPSTUSD_t} \right. \right. \quad (15)$$

$$\left. \left. + \frac{|TOTALWDRWTOKENS_t * ALPHAPRICE_t|}{TOTALDPSTUSD_t} \right\}, 1 \right) \quad (16)$$

- Issue (mint) new Alpha Tokens to fulfill the deposit requests that were accepted for investment and remove (burn) Alpha tokens to fulfill the withdraw requests that were accepted for redemption as necessary using the NAV from Step (6).
 - Rebalance the portfolio using the net amount for deployment, $NETAMOUNTEVENT_t$, based on corresponding portfolio asset weights using the rebalancing algorithm from Kashyap (2021).
 - Update the Alpha price again using the first three Steps (1; 2; 3). Note that the total number of tokens now includes the tokens issued for the amount, $NETAMOUNTEVENT_t$, that just got invested.
- (b) Case: $NETWDRWIND_t = 1$. The withdrawal tokens accepted for redemption are aggregated based on the total number of requests with each request being filled a certain percentage of the requested tokens depending on the available capacity. This is given by the formula,

$$WDRWACCEPT_{it} = \min \left[\left\{ \frac{|NETAMOUNTEVENT_t| + |TOTALDPSTUSD_t|}{(TOTALWDRWTOKENS_t * ALPHAPRICE_t)} \right\}, 1 \right] \quad (17)$$

$$* WDRWREQUEST_{it} \quad (18)$$

- $WDRWACCEPT_{it}$ is the number of tokens that will be accepted for redemption from the total tokens requested for withdraw from request i , $WDRWREQUEST_{it}$ at time t .
- $WDRWACCEPTRATIO_t$ is the withdraw accept ratio which gives the percentage of the total requested withdraw quantity accepted for redemption at this rebalance event, that is at time t . It is a helpful variable for monitoring the system performance given by the formulation,

$$WDRWACCEPTRATIO_t = \min \left[\left\{ \frac{|NETAMOUNTEVENT_t| + |TOTALDPSTUSD_t|}{(TOTALWDRWTOKENS_t * ALPHAPRICE_t)} \right\}, 1 \right] \quad (19)$$

- Rebalance the portfolio using the net amount for deployment, $NETAMOUNTEVENT_t$,

based on the corresponding portfolio asset weights, using the rebalancing algorithm from Kashyap (2021).

- The proceeds from this rebalancing will be denoted as $RBLNCPROCEEDS_t$ which can be different from $NETAMOUNTEVENT_t$ due to market impact or slippage (Kashyap 2020). $RBLNCPROCEEDS_t$ are the proceeds obtained from trading - denominated in USD - at this rebalancing event.
- ii. If the percentage difference between the $NETAMOUNTEVENT_t$ and $RBLNCPROCEEDS_t$ is higher than the withdrawal slippage tolerance, $WDRWSLIPTOLERANCE_t$ as shown below, PLEASE STOP AND DO NOT GO TO NEXT STEP. $WDRWSLIPTOLERANCE_t$ is a tolerance level we can set in percentage that shows how much withdraw related trading slippage we are willing to accept at this rebalancing event.
- We might have to manually intervene and decide what to do next.
 - If the assets were not sold, then we have to go back to Step (1) and restart all over again at a more favorable market time.
 - If the assets are not sold, then we might have to revert back the performance or management fees.
 - If the assets were actually sold for a very low price - or partially sold - we have to again manually intervene and decide how to proceed.

$$\frac{|RBLNCPROCEEDS_t| - |NETAMOUNTEVENT_t|}{|NETAMOUNTEVENT_t|} < (-1) * WDRWSLIPTOLERANCE_t \quad (20)$$

- iii. We consider the difference, $RBLNCSLIPPAGE_t$ between $NETAMOUNTEVENT_t$ and $RBLNCPROCEEDS_t$, and handle the two cases that arise accordingly as per below (Sub-Steps 7(b)iv; 7(b)v),

$$RBLNCSLIPPAGE_t = |RBLNCPROCEEDS_t| - |NETAMOUNTEVENT_t| \quad (21)$$

- iv. If $RBLNCSLIPPAGE_t > 0$ is positive, send this amount to the treasury and burn or remove Alpha tokens equal to this amount from the treasury using the NAV or Alpha Price calculated in Step (6).
- If the treasury does not have enough Alpha tokens then send to the treasury the amount that is covered by the Alpha tokens in the treasury, burn the corresponding number of Alpha tokens and reinvest the rest of the money into the fund in the next rebalance sequence.

- v. If $RBLNCSLIPPAGE_t < 0$ is negative, take stable coins (Ante, Fiedler & Strehle 2021; End-note 13) from the treasury equal to this amount and issue new Alpha tokens equal to this amount using the NAV or Alpha Price calculated in Step (6). Send the tokens to the treasury.
 - If the treasury does not have enough stable coins PLEASE STOP.
- vi. If we calculate the Alpha price at this time using the first three Steps (1; 2; 3), it will be different from the Alpha price calculated earlier in Step (6).
 - This is because the total number of tokens now includes the tokens burned or minted for the amount, $RBLNCSLIPPAGE_t$, that were removed or issued in Sub-Steps (7(b)iv; 7(b)v).
 - This shows the effect of the slippage on the Alpha price, but this new Alpha price cannot be used to fulfill withdraw requests since with this changed price, we might not have enough stable tokens to satisfy the redemptions.
 - This Alpha price is for reference alone to show the impact of the slippage, but it can be used to update the Alpha price after the withdraw requests (also deposit requests) are fulfilled.
- vii. Remove (burn) Alpha tokens to fulfill the withdraw requests that were accepted for redemption and issue (mint) new Alpha Tokens to fulfill the deposit requests that were accepted for investment as necessary using the NAV or Alpha Price calculated in Step (6).
 - Note that the Alpha price in Step (6) can be quite different from the Alpha price after the adjustments from Step (7(b)vi).
- Note that when we mint new Alpha tokens we accept stable tokens (or other currencies at later stage, Kashyap 2021) in exchange for the Alpha tokens. Similarly when we burn Alpha tokens we send stable tokens back to the investor.
- We prefer the method described above (Sub-Steps 7(b)iii; 7(b)iv; 7(b)v; 7(b)vi). But another option for the withdrawal case is to transfer cash between chains and update the Alpha price using the following formula,

$$ALPHAPRICE_t = \frac{|RBLNCPROCEEDS_t| + |TOTALDPSTUSD_t|}{\left(\sum_{i=1}^{W_t} WDRWACCEPT_{it}\right)} \quad (22)$$

4 Automated Performance Fee Levy Techniques

In any wealth management fund, to calculate performance fees properly, all the transactions done by all investors have to be recorded and utilized when we perform the corresponding computations to levy the fees.

To give an example, an investor could be holding 10000 tokens of the Alpha fund in his wallet, but he could have done several buy and sell transactions - at different prices - to arrive at this overall position. That is, a position for an investor is comprised of multiple transactions. Taking into account the transactions from different investors implies a large amount of transaction level data.

The management fee is relatively simpler to calculate and can be done periodically on the total value locked in the fund when rebalance events are done - as discussed in Algorithm (1). To calculate performance fees as part of the algorithm - Algorithm (1) - a significant software infrastructure becomes necessary, which then has to be triggered in one of the corresponding steps.

In traditional hedge funds, accountants look at all investor positions - also the transactions as necessary - every quarter - or other such infrequent intervals - and calculate how much performance fees are due. Most hedge funds allow new investments - or redemptions - only at certain times. This fund entry and exit is usually not very often, perhaps at quarterly or larger durations. Hence the tasks of the fund accountants are relatively straightforward and they do performance fee calculations easily using specialized software or even using excel based tools.

When the operations of a hedge fund become transparent and accessible to a wide audience - with the connectivity and visibility provided by blockchain technology - there will be many transactions happening. Also to provide the liquidity of mutual funds we have to allow investors to deposit or withdraw funds at regular intervals, perhaps once a day. This leads to a lot of investor transactions that become necessary to calculate performance fees. When investors have the flexibility to arrive and leave frequently, a similar time frame has to be maintained for calculating performance fees. Hence we need frequent performance fee calculations to be happening and having to do these computations in a blockchain environment compounds the issue.

We next discuss the nuances of calculating the performance fees and the blockchain constraints that make this a challenging problem.

4.1 Blockchain Bottlenecks and Making Smart Contracts Smarter

There are two broad approaches to blockchain performance fee calculations. They can be done off-chain or on-chain. Off-chain computations refer to using software routines or calculations outside the blockchain. On-chain calculations are done entirely within the blockchain environment. As we know from the foundations of computing science, if we store a lot of data in the computer memory we can reduce the data we have to store external to the computer on databases or other file based storage systems. If we do not store data within the computer, we have to expend resources reading and writing data to external infrastructure. Also, the more data we have, the more intensive the calculations or the computation time of the corresponding algorithms increases with increasing data size. Hence, we need more sophisticated or complex algorithms when we have

to handle large data-sets (Knuth 1973; 1997; Aho & Hopcroft 1974; Horowitz & Sahni 1982; Aho 2012).

The problem with off-chain calculations are two fold. One is that there is less visibility in the calculations. Investors are not able to see easily the details regarding the fees they are getting charged. It is not easy to reflect calculations done outside onto the blockchain environment. Many issues - including security breaches - can arise due to the use of off-chain software infrastructure. This lack of security and decentralization defeats the very fundamental reasons for using blockchain technology.

Secondly when performance fee calculations - or other computations - are done outside blockchain they have to be synchronized with on-chain infrastructure with secondary computations or some synchronization mechanism. This part of bringing a simplified state of external transactions - so that fees can be levied at appropriate times, such as when doing rebalance events - onto the blockchain is not very simple (Eberhardt & Tai 2017; 2018; López-Pimentel et al., 2020; Mühlberger et al., 2020; Emami et al., 2023).

On-chain calculations are done in smart contracts - or within the blockchain infrastructure, which then needs to be validated by blockchain validators. This can be extremely costly - in terms of gas fees (Tikhomirov 2018; Pierro & Rocha 2019; Faqir-Rhazoui et al., 2021; Donmez & Karaivanov 2022; Laurent et al., 2022) - especially when large amounts of data need to be retrieved - or stored - and calculations have to be done on such large data-sets.

It would be extremely computationally demanding to do transaction level performance fee calculations on-chain. It is resource intensive to record wallet information - or the address for all investors and to capture all the transactions done from all the different addresses - and to use that information for various calculations including the levy of performance fees. This resource requirement is in terms of both computational times and memory requirements especially with the limitations of most blockchain networks (Zheng et al., 2017; Ismail & Materwala 2019; Syed et al., 2019; Fan et al., 2020).

Despite the issues with both approaches - on-chain and off-chain - the benefits of blockchain accrue only if we make use of the decentralized infrastructure for our computation needs. Going the on-chain way also brings reassurance to investors in terms of making it transparent to them about how they are paying for the services they receive combined with the cryptographic security of blockchain. We can do on-chain computations if we find some ways to capture the essence of large data-sets needed for the specific purpose at hand. In our case, this is about finding a way to extract the necessary information from a lot of transactions towards calculating performance fees.

Kashyap (2021) has a discussion of certain novel security features and overall architectural designs that have been developed to perform off-chain computations - given the current blockchain performance capabilities - for portfolio optimization and risk management purposes. Such portfolio management decisions are greatly aided by off-chain calculation routines. It is important to emphasize that these operations are part of the intrinsic mechanisms of running a portfolio - some of which provide the fund competitive advantages and

rely on proprietary trading strategies - with less direct need for constant investor scrutiny. These intensive costly calculations cannot be done on-chain at this time without significant simplifications - that could affect how the fund performs in terms of risk and outperforming the market or other benchmarks - and having them off-chain also ensures that trading strategies are not easily replicated by others. Though, moving these on-chain at a later stage should not be ruled out completely.

4.2 High Water Markets During Low Market Prices

An alternative to storing all transactions from all investors separately - transaction level processing - on the blockchain, we can keep one record for each investor that combines the information from all the transactions done by that investor. Essentially this greatly reduces the overall number of records we need to work with. This simplification - wallet or address level processing - still requires us to iterate through all investors every time we do performance fee calculations. We would still need to maintain a HWM for each investor so that each investor obtains the desired level of protection.

An additional improvement would be to combine transactions across investors and hence aggregate different investor transactions. Instead of calculating and maintaining the high water mark at the individual wallet - address level or the position level, that is an aggregation of the transaction level data - we present various alternatives below, which keep track of only one HWM benchmark for all investors. Another reason for pursuing this approach is because in the DeFi world performing wallet level levy of fees without an action from the user is not possible. If we do wallet level calculations of performance fees, we must synchronize the levy of fees to whenever the owner of the wallet deposits or withdraws from the investment fund. A wallet - and even a smart contract - is essentially a unique blockchain address with the corresponding owners being the ones that have access to the private keys to that address.

We can view blockchain operations as read or write transactions in public or private domains (Dinh et al., 2018; Thakkar et al., 2018; Bhushan & Sharma 2021; End-note 14). We understand this further with respect to a wallet belonging to an investor on a public blockchain. Read transactions read the state of the blockchain and can be done at anytime without any cost by anyone. Reading the contents of a wallet - which is reading the state of the blockchain associated with that wallet - can be done by anyone. Write transactions change the state of the blockchain and there is a cost involved to effect this change. Writing or changing the contents of a wallet - which is changing the state of the blockchain associated with that wallet - can be done only by the owner of that wallet by paying gas fees.

Most of the actions required below can be performed depending on when the user enters or exits the fund or for the entire TVL at other times without having to access the individual wallet, or know the corresponding information. When the investor performs a deposit or withdraw user action driven, either cash or tokens are being sent to the fund and they can be used towards fees. We can simply maintain one high water mark

(HWM) - and the corresponding time when the HWM is reached - for the entire fund. The main issue with this fund level HWM approach is that once a HWM is established - and the net asset value (NAV) is below that for a long time period - the new entrants will not pay a performance fee till the NAV goes above the HWM (End-notes 7; 10).

There are two broad categories of solutions that can be used to overcome the issue of the HWM being above the NAV for long periods of time:

1. The first solution category clubs together different transactions - both across different investors and within the transactions from an investor - and maintains some sort of benchmark price or averaged (weighted average) high water mark corresponding to the positions that are aggregated together (Section 4.3).
2. The second solution category keeps investor transactions - and hence positions - separately and tracks the high water mark separately for the transactions - and positions - that are kept separate (Section 4.4).

4.3 Performance Fees Across Aggregated Positions

This first solution category is **recommended** since it is closely aligned to most existing DeFi protocols that club transactions together across a wallet or address. Section (4.4) has a discussion of alternatives to this section which are not recommended but are given for completeness to help obtain a deeper understanding of the concepts involved.

Whenever we rebalance - or perform the periodic sequence of steps (Section 3) - we calculate the performance fees and update the high water mark to the new NAV if the NAV (Alpha price) is above the high water mark. The performance fee each time is a liability that is used to adjust the NAV accordingly.

There are three further possibilities using this approach where we club together positions and maintain a HWM for the overall clubbed position.

1. In the first case, we club together certain transactions for some investors - or wallet addresses - based on the following criteria. The group of investor transactions we merge together would depend on whether these transactions happened when the current NAV is below the corresponding HWM. We maintain the fund NAV and also track one HWM for the entire fund. But we keep track of a weighted average NAV for the transactions that enter when the NAV is below the HWM. We also track the amount of tokens that have entered below the HWM.
 - The performance fees are calculated based on the NAV and the number of tokens at each rebalance event discussed in Section (3).

- There will be a performance fee at the fund level and also at the level of the transactions that have been combined together. The clubbed transactions fees depends on the transactions that enter when the NAV is below the HWM.
- There will also be performance fees that apply to the tokens that are being withdrawn and this fees depends on the weighted average NAV that is being tracked for the transactions that enter when the NAV is below the HWM.
- The advantage of this method compared to the second scenario in Point (2) - which is discussed next - is that we still have a reference HWM for the entire fund. Having the HWM provides a reference point which helps with understanding the performance fees calculations and also explaining to investors more easily how the performance fees applies to them.
- For ease of understanding, we can view this approach as clubbing together only transactions for a particular investor - that have entered when the NAV is below the HWM - and hence maintaining the weighted average NAV for the transactions corresponding to that investor. We can also club together several investor transactions and use this method across all those transactions. This would mean that we have to maintain a weighted averaged NAV for all the transactions - for the relevant investors - that enter when the NAV is below the HWM.
- The extent of granularity desired would depend on how many variables - and memory - we wish to utilize. Greater the granularity the easier it is to see and understand the corresponding computations. The trade-off would depend on the specific blockchain network being used and the corresponding gas fees and other system dependencies.

2. In the second case, we club together transactions - and hence the positions - across all investors or wallet addresses. We maintain the fund NAV and only a weighted average NAV that applies to all the tokens that are in the fund right now.

- The performance fees are calculated based on the NAV and the number of tokens at each rebalance event discussed in Section (3).
- The weighted average NAV and the number of tokens are also updated at each rebalance event. The performance fees are calculated only at the fund level and there are no performance fees for the tokens that are being withdrawn since the entire performance fees liability is levied at the fund level.
- The advantage of this method compared to the first case in Point (1) is that we have less calculations to perform and less variables to track.

3. In the third case, we increase the accuracy of performance fees collection so that it is identical to collecting fees based on individual transactions. With the first and second cases - Points (1; 2) - there is a possibility of missing out on performance fees when a certain scenario occurs.

- This happens when when the NAV is below the HWM and transactions - or positions - are made when the weighted average NAV is above the NAV. Then if the NAV goes up - but still remains lower than the weighted average NAV - and some withdraw transactions happen they will not get charged a performance fee. These positions that are getting redeemed have enjoyed positive performance since the price they entered is lower than the price they are exiting, but they are paying a performance fee.
- The performance fees are calculated based on the NAV and the number of tokens at each rebalance event discussed in Section (3).
- We handle this scenario by keeping track of two additional variables that track the NAV movement as follows. We would to know the previous NAV at each time period and we would need to note down the weighted average NAV when the NAV dips below the weighted average NAV and then subsequently raises further - but still remains below the weighted average NAV.
- Solutions given in Points (1; 2) are weighted average simplifications and would suffice when a lot of transactions are happening and markets do not enter into prolonged downtrends with partial uptrends. But with the use of two additional variables - and what we have outlined above - this additional scenario can also be covered.

We discuss all the cases in Points (1; 2; 3) in greater detail below in Sections (4.3.1; 4.3.2; 4.3.3).

4.3.1 Investor Level Clubbed Positions

We discuss the first scenario - where we aggregate transactions that have happened when the NAV is below the HWM - for one investor or wallet address. The case for adding all investors is a simple extension of this and would be about performing aggregations and weighted average calculations across transactions from all investors.

- Figure (5) in Section (6) shows numerical examples related to this method. This illustration makes it clear why this approach requires more computations and storage, but can help with easier understanding, compared to the simpler approach discussed in Point (2) in Section (4.3) and the discussion in Section (4.3.2).
 - Since transactions are clubbed together, the issues that need to be addressed carefully are related to when an investor adds or removes money at any time and the NAV information to be used to calculate the corresponding performance fees.

- We need additional indicators that track how much of any new money invested - since the last HWM was established - is above its point of entry in terms of fund price and hence liable for a performance fee. Also, we need to know how much of the invested money entered before the HWM was established to ensure that it does not get charged multiple performance fees.
- We keep track of the cumulative sum of money that gets invested by any investor when the NAV is below the HWM. We also calculate and maintain a weighted average NAV per investor (or wallet) since the last HWM was established.
- **We provide the formula (Equation: 24) for the HWM Liability, HWM_{Ljt} , for investor j at time t .**

$$HWM_{Ljt} = \max [0, (NAV_t - HWM_t)] * PFP_t * (AMOUNTTOTAL_{jt} - AMOUNTBHWM_{jt}) \quad (23)$$

$$+ \max [0, (NAV_t - NAVWAVGLHWM_{jt})] * PFP_t * (AMOUNTBHWM_{jt}) \quad (24)$$

Here, NAV_t is the net asset value of the fund at time t . This is also to be understood as the price of the fund at time t . All investors invest in or exit the fund at one or more NAV prices. Section (3) provides details on the steps regarding how the NAV is updated periodically.

HWM_t represents the HWM at time t . It is to be understood that this is the last HWM established before time t . $HWMLE_t$ is the time of the last HWM event until time t . This is the time when the last HWM was established until time t . That is the time, $t = HWMLE_t$, when the last HWM was established or the time when the HWM was last updated.

PFP_t is the performance fee percentage at time t .

$AMOUNTTOTAL_{jt}$ is the total amount in USD corresponding to investor j invested at time t . It is to be understood that each investor can have multiple transactions - adding or withdrawing money - that result in this net positive position at time t .

$$AMOUNTTOTAL_{jt} = \sum_{l=0}^{NRBE_t} [INVEST_{jT(l)} + WITHDRAW_{jT(l)}] \quad (25)$$

$INVEST_{jt}$ is the amount in USD corresponding to investor j being invested at time t . $INVEST_{jt} \geq 0$. $WITHDRAW_{jt}$ is the amount in USD corresponding to investor j being withdrawn at time t . $WITHDRAW_{jt} \leq 0$. If an investor j does not participate in a rebalancing event at time t , $INVEST_{jt} = WITHDRAW_{jt} = 0$.

At any rebalancing event, only one of the two will be non-zero if netting across deposits and redemptions are done before the rebalancing. We retain two variables since it is useful for some of the below

formulations. For simplicity, we are assuming that the investor will only invest once between rebalance events, since the rebalancing frequency is quite high.

$T(n)$ is the time when the n^{th} rebalancing was done. n is a natural number that includes 0 and is less than or equal to the number of rebalancing events until a particular time, t . We set $T(0) = 0$ and $T(-1) = 0$.

$NRBE_t$ is the total number of rebalancing events until a particular time, t . That is, $0 \leq n \leq NRBE_t$. Based on our convention, that time starts ($t = 0$) when the fund is launched, $NRBE_t = 0$ until the next rebalancing event happens, which becomes the first rebalancing event and $NRBE_t = 1$ after that is completed. **$NRBE_t$ increases by one only after a rebalancing event is completed.** For example, $NAV_{T(NRBE_t)}$ represents the NAV at the last rebalancing event until time t .

Note that, $AMOUNTTOTAL_{jt}$ is equivalently calculated using the below formulae,

$$AMOUNTTOTAL_{jt} = AMOUNTTOTAL_{jT(NRBE_t-1)} \quad (26)$$

$$+ [INVEST_{jT(NRBE_t)} + WITHDRAW_{jT(NRBE_t)}] \quad (27)$$

$AMOUNTBHM_{jt}$ is the amount in USD at time t corresponding to investor j invested after the last HWM, HWM_t , was established such that the corresponding subscription prices were below the HWM, HWM_t . Note that if the NAV goes up, a new HWM will be established and the new NAV will become the subscription price.

$$AMOUNTBHM_{jt} = \sum_{l=LASTHWMRBE_t}^{NRBE_t} [INVEST_{jT(l)}] \quad (28)$$

$$+ \sum_{l=LASTHWMRBE_t}^{NRBE_t} [WITHDRAW_{jT(l)}] \quad (29)$$

$LASTHWMRBE_t$ is the last rebalancing event when the last HWM, HWM_t , was established until a particular time, t .

Note that, $AMOUNTBHM_{jt}$ is equivalently calculated using the below formulae,

$$AMOUNTBHM_{jt} = \sum_{l=0}^{NRBE_t} [INVEST_{jT(l)}] \{ \mathbf{1}(t \geq HWMLE_t) \} \wedge \{ \mathbf{1}(NAV_{T(l)} \leq HWM_t) \} \quad (30)$$

$$+ \sum_{l=0}^{NRBE_t} [WITHDRAW_{jT(l)}] \{ \mathbf{1}(t \geq HWMLE_t) \} \wedge \{ \mathbf{1}(NAV_{T(l)} \leq HWM_t) \} \quad (31)$$

$$AMOUNTBHM_{jt} = AMOUNTBHM_{jT(NRBE_t-1)} \quad (32)$$

$$+ [INVEST_{jT(NRBE_t)} + WITHDRAW_{jT(NRBE_t)}] \quad (33)$$

\wedge represents the “and” criteria. $\{\mathbf{1}(A)\}$ is the indicator function, which gives 1 if condition A is TRUE or 0 otherwise.

$$\mathbf{1}(A) := \begin{cases} 1 & \text{if } A \text{ is } \mathbf{TRUE} , \\ 0 & \text{if } A \text{ is } \mathbf{FALSE} . \end{cases} \quad (34)$$

$NAVWAVGLHM_{jt}$ represents the weighted averaged NAV for investor j from the time the last HWM, HWM_t , was established until a particular time, t based on the amounts invested or withdrawn by this investor. The formula to calculate this is,

$$NAVWAVGLHM_{jt} = \left\{ \frac{\sum_{l=LASTHWMRBE_t}^{NRBE_t} [INVEST_{jT(l)}] [NAV_{T(l)}]}{\sum_{l=LASTHWMRBE_t}^{NRBE_t} [INVEST_{jT(l)}]} \right\} \quad (35)$$

Note that, $NAVWAVGLHM_{jt}$ is equivalently calculated using the below formula,

$$NAVWAVGLHM_{jt} = \left\{ \frac{[NAVWAVGLHM_{jT(NRBE_t-1)}] \sum_{l=LASTHWMRBE_t}^{(NRBE_t-1)} [INVEST_{jT(l)}]}{\sum_{l=LASTHWMRBE_t}^{NRBE_t} [INVEST_{jT(l)}]} \right\} \quad (36)$$

$$+ \left\{ \frac{[INVEST_{jT(NRBE_t)}] [NAV_{T(NRBE_t)}]}{\sum_{l=LASTHWMRBE_t}^{NRBE_t} [INVEST_{jT(l)}]} \right\} \quad (37)$$

After any rebalancing event is completed, the following updates need to be done,

$$HWM_t := \begin{cases} NAV_{T(NRBE_t)} & \text{if } NAV_{T(NRBE_t)} > HWM_{T(NRBE_t-1)} , \\ HWM_{T(NRBE_t-1)} & \text{Otherwise.} \end{cases} \quad (38)$$

$$LASTHWMRBE_t := \begin{cases} NRBE_t & \text{if } NAV_{T(NRBE_t)} > HWM_{T(NRBE_t-1)} , \\ LASTHWMRBE_{T(NRBE_t-1)} & \text{Otherwise.} \end{cases} \quad (39)$$

$$AMOUNTBHM_{jt} := \begin{cases} 0 & \text{if } NAV_{T(NRBE_t)} > HWM_{T(NRBE_t-1)} , \\ \text{Equation (31) Above} & \text{Otherwise.} \end{cases} \quad (40)$$

$$NAVWAVGLHM_{jt} := \begin{cases} 0 & \text{if } NAV_{T(NRBE_t)} > HWM_{T(NRBE_t-1)} , \\ \text{Equation (35) Above} & \text{Otherwise.} \end{cases} \quad (41)$$

4.3.2 Fund Level Clubbed Positions

The solution in Point (4.3.1) in Section (4.3.1) can be significantly simplified further - without storing the HWM per investor - by simply updating the weight average NAV price for all the new money that enters the fund during the current time period.

- The performance fee is then simply calculated at the end of every time period by first updating the NAV - or Fund price - and then checking if it is above the weighted average NAV that is being maintained. If the NAV is above the weighted average price, then weighted average price is set to the NAV that was just calculated.
 - Storing the HWM provides a narrative which can be easily understood and explained to investors, but in a DeFi environment, it requires many additional calculations and gas fees. A simple weighted average calculation renders the same logic that provides protection to investors similar to the HWM.
 - Figure (6) in Section (6) illustrates how this simplified approach works compared to the approach discussed in Point (1) in Section (4.3) and the discussion in Section (4.3.1) with the corresponding illustration in Figure (5).

4.3.3 Complete Solution Including the Scenario when NAV Falls and Rises Partially

The solution outlined here is the most accurate, complete and recommended solution. The techniques in Points (1; 2) and Sections (4.3.1; 4.3.2) are simpler to implement and work satisfactorily under most scenarios except one situation which is considered here in greater detail.

- When the NAV falls and rises up later - but stays below the weighted average NAV - and redemptions happen performance fees will not be assessed as outlined in the intuitive explanations provided under Point (3).
- When the NAV falls and rises up, the deposit transactions that have happened between the fall and the rise have to incur a performance fee. But if the NAV stays below the weighted average NAV, and redemptions happen, they are do not get charged a performance fee.
- Figures (7; 8) in Section (6) show how performance fees will not get charged when the NAV falls - to stay below the weighed NAV - and rises later but stays below the weighted NAV.
- Figures (9; 10) in Section (6) show how the solution presented in this section handle the scenario shown in Figures (7; 8) relevant to Points (1; 2) in Sections (4.3.1; 4.3.2) regarding how performance fees will not be levied when the NAV falls - to stay below the weighed NAV - and rises later but stays below the weighted NAV.

- Here, we add the extra conditions to handle the rise and fall scenario to the Solution outlined in Point (1). The same extension can also easily be applied to the approach in Point (2).
- The essential idea to handle this situation is to bring down the weighted NAV tracker to the level of the NAV after it has risen subsequent to falling before the rise. When the weighted NAV is lowered the performance fees corresponding to the lowering is returned back to the fund. Since we create new tokens when charging performance fees, we have to burn back tokens when returning the performance fees as discussed in Section (3).
- We also levy a performance fee - based on the weighted average and the new NAV - on the transactions that are getting redeemed.
- We need to keep track of the weighted average NAV when the NAV is below the weighted average NAV and the NAV is higher than the NAV at the previous time period. Using the notation similar to Section (4.3.1), we get the following additional variables we need to monitor.

$$NAVWAVGPB_t := \begin{cases} NAV_{T(NBRE_t)} & \text{if } \{ NAV_{T(NBRE_t)} > NAV_{T(NBRE_{t-1})} \} \\ \wedge \{ NAVWAVG_{T(NBRE_t)} > NAV_{T(NBRE_t)} \}, & (42) \\ 0 & \text{Otherwise.} \end{cases}$$

$NAVWAVGPB_t$ is the weighted average NAV that keeps track of how much we need to plough back into the fund at time t .

$NAV_{T(NBRE_t)}$ is the NAV at time $T(NBRE_t)$ or the the NAV set at the rebalancing event $NBRE_t$.

$NAV_{T(NBRE_{t-1})}$ is the NAV at time $T(NBRE_{t-1})$ or the the NAV set at the rebalancing event one before $NBRE_t$, that is at the rebalancing event $NBRE_{t-1}$.

$NAVWAVG_{T(NBRE_t)}$ is the weighted average NAV at time time $T(NBRE_t)$ or the the NAV set at the rebalancing event $NBRE_t$.

- Note that the weighted average NAV is updated to be $NAVWAVGPB_t$ when it is non-zero and is otherwise updated similar to the logic used in Section (4.3.1).

$$NAVWAVG_{T(NBRE_t)} := \begin{cases} NAVWAVGPB_t & \text{if } \{ NAVWAVGPB_t > 0 \} \\ \text{Similar to Equation (35) Above} & \text{Otherwise.} \end{cases} \quad (43)$$

- The transactions that are getting redeemed are levied a performance fee according to the formula,

$$RDMPHWMML_{jt} := \begin{cases} \max [0, (NAV_{T(NBRE_t)} - NAVWAVG_{T(NBRE_t)})] \\ *PFP_t * (AMOUNTRDMPT_{jt}) & \text{if } \{ NAVWAVGPB_t = 0 \} \\ \max [0, (NAV_{T(NBRE_t)} - NAVWAVG_{T(NBRE_{t-1})})] \\ *PFP_t * (AMOUNTRDMPT_{jt}) & \text{Otherwise.} \end{cases} \quad (44)$$

$RDMPHWMML_{jt}$ is the performance fees charged on the amount being redeemed $AMOUNTRDMPT_{jt}$ at time t .

- The performance fees to be ploughed back - or returned to the fund - is based on the difference between the weighted average NAV to be ploughed back and the weighted average NAV at the previous rebalancing event. It is given according to the formula,

$$PBHWMML_{jt} := \begin{cases} 0 & \text{if } \{ NAVWAVGPB_t = 0 \} \\ \max [0, (NAVWAVG_{T(NBRE_{t-1})} - NAVWAVGPB_t)] \\ *PFP_t * (AMOUNTTOTAL_{jt} - AMOUNTRDMPT_{jt}) & \text{Otherwise.} \end{cases} \quad (45)$$

$PBHWMML_{jt}$ is the performance fees to be returned back at time t .

$(AMOUNTTOTAL_{jt} - AMOUNTRDMPT_{jt})$ gives the amount still invested in the fund net of the redemption amount at the time t .

- The fees that is returned back to the fund will be re-levied as the NAV improves or as redemptions happen. Time value of money adjustments can be done if the amount of fees to be returned back are somewhat large and rebalancing frequencies are not too often (Ross, Westerfield & Jaffe 1999; End-note 15). These time value adjustments can also be done when the market stays low such that the NAV is below the weighted average NAV for a long time period.

4.4 Performance Fees Across Separate Positions

This second approach, **which is not recommended, is given for completeness so that we are aware of different alternatives.** This requires that transactions be kept separate within a wallet or we need to know the entry and exit price for the transactions - that make up a position for the address - when the performance fees are calculated. Section (4.3) has a discussion of the recommended alternatives to this

section. All the below calculations if done at the transaction level will work satisfactorily. Whenever we rebalance we calculate the performance fee if the net asset value (Alpha price) NAV is above the high water mark and update the high water mark to the new NAV. The performance fee each time is a liability that is used to adjust the NAV accordingly. In this case, the HWM above NAV issue can be solved using three options below:

1. Free Ride Option: We simply let the new transactions free ride till the fund moves above the HWM. This acts as an incentive for new money to flow into the fund since the newly entered investments do not have to pay performance fees till the fund moves above the HWM.

- Also, we can take a performance fee when a transactions is on a free ride but when that transaction is withdrawn. This is done if the transaction entered the fund after the time when the previous HWM was established and the corresponding subscription price (SP) or NAV was below HWM. When this transaction leaves, if the entry point was below HWM, the transaction is charged performance fees based on the point of entry and exit.
- Note that a position can have some transactions from before the NAV has slipped below the HWM. So when redemptions happen some portion of the transaction may be liable for a performance fee and the rest might not have any liability. Care has to be taken to charge fees only for the liable amounts when investors have several transactions.
- We can also raise the deposit fee for new money if the slump has continued for a long time. This mitigates the loss of performance fees to a certain extent.

2. New Money Liability: When new money enters below the HWM, their liability corresponding to their point of entry and the HWM is moved to a liability account - and reinvested into the fund from that account. This is because the new entrant will not pay any performance fees till the HWM is reestablished.

- When a new HWM is established the liabilities are cleared accordingly, that is we collect the liability outstanding. The liabilities can also be collected periodically.
- Again care has to be taken to ensure that performance fees are only levied for portions of a position that are made of transactions that enter when the NAV is below the HWM.
- If the investor leaves before a new HWM is reestablished, they pay corresponding performance fees based on their point of entry and exit. When this position exits, if the corresponding entry point was below HWM, they pay performance fees based on their point of entry and exit. We can also raise the deposit fee for new money if the slump has continued for a long time.

We provide the formula for the HWM Liability, $HWML_{kt}$, for position k that is entering at time t . It is to be understood that each position is tracked separately and any investor can have multiple positions.

$$HWML_{kt} = \max(0, HWM_t - SP_{kt}) * PFP_t * INVEST_{kt} * HWMLRATIO_t \quad (46)$$

Here, HWM_t represents the HWM at time t . It is to be understood that this is the last HWM established before or during time t .

SP_{kt} is the NAV that applies to position k when it is subscribing to (investing in) the fund at time t .

PFP_t is the performance fee percentage at time t .

$INVEST_{kt}$ is the amount in USD corresponding to position k being invested at time t . It is to be understood that the investor can have several investments done at multiple time periods. But this formula applies only to the investment being done at time t .

$HWMLRATIO_t$ is the HWM Liability ratio percentage at time t . This indicates that we wish to only collect part of the liability. When this is set to zero, we are providing the free ride option or charging performance fee upon exit. Note that the performance fee on exit applies only to those discussed in Option (1) above.

Note that if $HWMLRATIO_t = 0$ we should collect the performance fee when the position exits. Care should be taken that either the HWM liability is charged or the fee is collected upon withdrawal. So when $HWMLRATIO_t = 0$ the performance fee is to be charged upon exit and if $0 < HWMLRATIO_t \leq 1$ the performance fee on exit should be turned off. There are at-least two sub cases to be taken care to ensure there is no free riding or overcharging.

- When $HWMLRATIO_t$ is changed to zero at time t , the liabilities should be returned since there will be an exit fee after time t .
- When $HWMLRATIO_t$ is changed to more than zero at time t , this is difficult to handle and some entrants will get free rides. These are the entrants who came after the HWM was established, but did not pay the HWM liability when they entered and now they will not pay the exit fee since $0 < HWMLRATIO_t \leq 1$. But we can ignore this case for now for ease of implementation.
- Note that we do not need a case when NAV is above HWM and positions enter at the high NAV. This is because we charge performance fees only when we rebalance and new money enters only when we rebalance. Hence, new money will enter at the NAV at that time, which will become the new HWM. This is the reason also why frequent rebalancing, along with performance fee calculations, is recommended in addition to other risk management benefits.

- There could be other cases, so it is important to pay careful attention to understand the above paths.
3. Lower HWM and Compensate Older Positions: If the slump continues for a long time and we do not wish to utilize Option (2). The third option is that we lower the HWM and compensate the older positions - and corresponding transactions across investors - based on their point of entry and the HWM for which they have paid the fees. The way to do this would be to calculate for each transaction its point of entry and the corresponding performance fees. Then some compensation scheme for them has to be worked out. This could be an airdrop, or, any scheme with a reward plan that extends over several months (Harrigan et al., 2018; Li et al., 2024; Allen et al., 2024; End-note 16). This can be very expensive both on the treasury and also in terms of gas fees, manual intervention needed perhaps etc.
- A combination of Options (1) and (2) is the most recommended when transaction level information is used. Option (3) is the least recommended.

The above are meant to be helpful guidelines. Many cases and error conditions need to be handled appropriately during implementation. Alternate time conventions and counters are possible and can be accommodated accordingly. There might even be issues with the counters and timing. Constructing detailed examples for different cases can help identify and eliminate any issues. Such issues arise due to the limitations of not actually testing scenarios using a software system (Beizer 1984; Sneed & Merey 1985; Livson 1988; Kajihara, Amamiya & Saya 1993; Bertram et al., 2010; Khanjani & Sulaiman 2011).

5 Periodic Blockchain Fund Management Algorithm: Fund Flow Flow Chart

- The flow chart in Figure (1) is a visual illustration corresponding to all the steps mentioned in Algorithm (1) in Section (3).
- Figures (2; 3; 4) in Section (6) give several scenarios pertaining to the steps and calculations given in Section (3) and illustrated with the flow chart here in Figure (1). The figures illustrate different variables corresponding to inputs and calculated variables, which should help in monitoring how the system is performing.

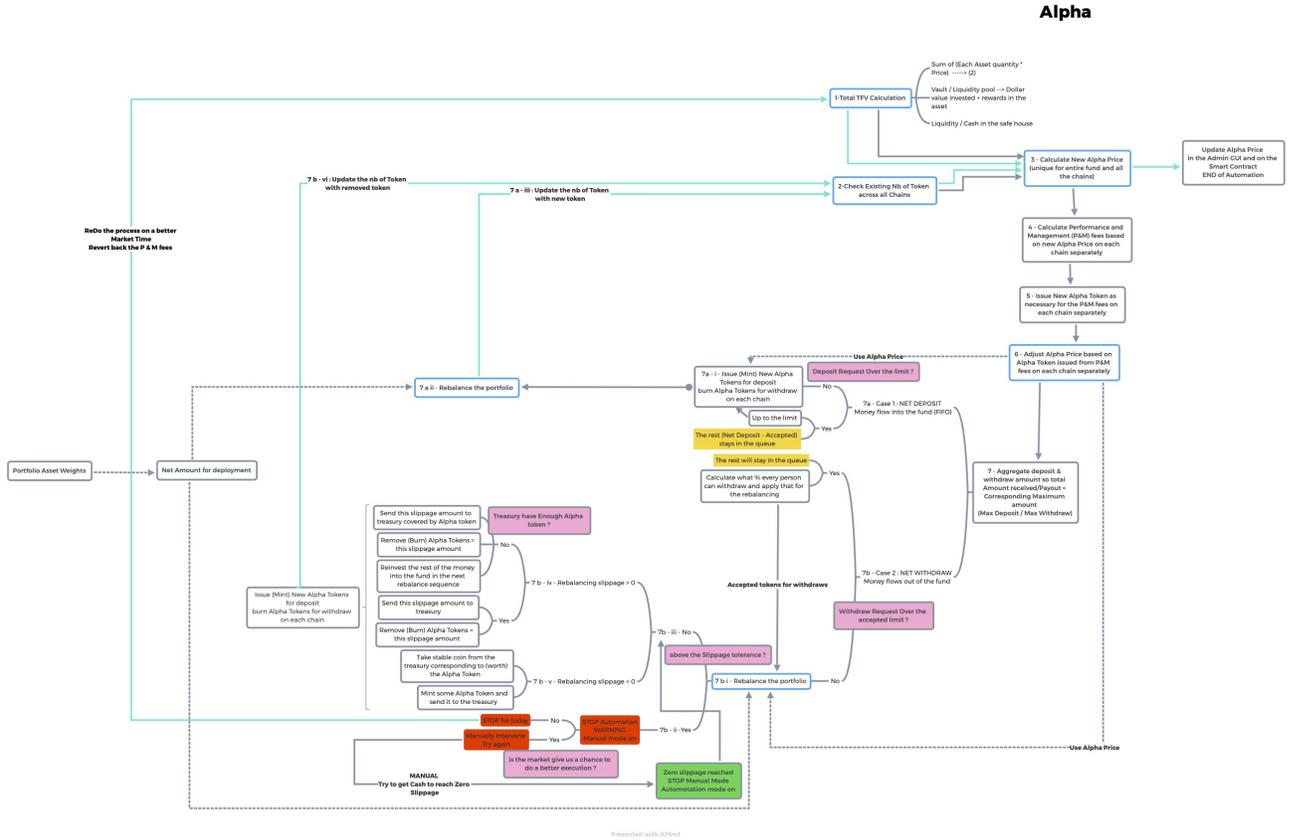


Figure 1: Fund Flow Flow Chart: Sequences of Steps for Periodic Fund Management

6 Numerical Results

Each of the tables in this section are referenced in the main body of the article. Below, we provide supplementary descriptions for each table.

- The Table in Figure (2) shows numerical examples related to the sequence of steps discussed in Section (3).
- The variables in Figure (2) are input variables which can be changed - or exogenous variables such as the fund value, which cannot be changed but simulated to understand its impact on the system and its corresponding performance - to control how the system is working.
- The output calculated variables are given in Figures (3; 4) which can be observed to gauge system performance and the input variables can be tweaked to obtain the desired outcomes. Figure (3) are general system variables and Figure (4) has variable related to how deposit and withdraw requests are being handled.
- It should be understood that the values in Figure (2) are just before the rebalance event is about to

begin. Many of these variables can be changed once the system is implemented and we have given several different scenarios corresponding to different rows by changing some of these variables in each row. The variables that cannot be changed are: fund value - which depends on market prices; number of tokens - which depends on deposits, redemptions, fees and how the system evolves; rebalance proceeds - market and trading dependent; and deposits and withdraw requests - which depend on client interactions and their preferences.

- The columns in Figure (2) represent the following information respectively:
 1. **Scenario Number** gives the scenario given in this row, which corresponds to one rebalance event given in to Algorithm (1) in Section (3).
 2. **Fund Value (USD)** gives the total value of this fund at this rebalance event.
 3. **Number of Fund Tokens** gives the number of tokens issued by the fund at this rebalance event.
 4. **Max Deposit (USD)** is the maximum deposit amount in USD we accept for investment into the fund at this rebalance event.
 5. **Max Withdraw (USD)** is the maximum amount in USD that can be sold from the fund to redeem investors at this rebalance event.
 6. **Rebalance Proceeds** are the proceeds obtained from trading - denominated in USD - at this rebalance event.
 7. **Withdraw Slippage Tolerance** is a tolerance level we can set in percentage that shows how much withdraw related trading slippage we are willing to accept at this rebalance event.
 8. **Management Fee Percent** is the percent value of management fees that will be charged annually on the fund value under management.
 9. **Deposit One (USD)** is the deposit request made from investor one in USD. We assume there are three deposit and withdraw requests for simplicity. Also if proper netting is implemented the deposit and withdraw investors will be different.
 10. **Deposit Two (USD)** is the deposit request made from investor two in USD.
 11. **Deposit Three (USD)** is the deposit request made from investor three in USD.
 12. **Withdraw One (Tokens)** is the withdraw request made from investor one in number of tokens.
 13. **Withdraw Two (Tokens)** is the withdraw request made from investor two in number of tokens.
 14. **Withdraw Three (Tokens)** is the withdraw request made from investor three in number of tokens.

| Input or Exogenous Variables | | | | | | | | | | | | |
|------------------------------|-----------------------|-------------------|--------------------|--------------------|-----------------------------|------------------------|-------------------|-------------------|---------------------|-----------------------|-----------------------|-------------------------|
| Fund Value (USD) | Number of Fund Tokens | Max Deposit (USD) | Max Withdraw (USD) | Rebalance Proceeds | Withdraw Slippage Tolerance | Management Fee Percent | Deposit One (USD) | Deposit Two (USD) | Deposit Three (USD) | Withdraw One (Tokens) | Withdraw Two (Tokens) | Withdraw Three (Tokens) |
| 10,000,000 | 500,000 | 1,000,000 | 1,000,000 | 100,000 | 2.00% | 2.00% | 100,000 | 100,000 | 100,000 | 50,000 | 50,000 | 50,000 |
| 11,000,000 | 500,000 | 1,000,000 | 1,000,000 | 100,000 | 2.00% | 2.00% | 3,000,000 | 100,000 | 100,000 | 50,000 | 50,000 | 50,000 |
| 12,000,000 | 500,000 | 1,000,000 | 1,000,000 | 100,000 | 2.00% | 2.00% | 100,000 | 100,000 | 100,000 | 200,000 | 50,000 | 50,000 |
| 10,500,000 | 500,000 | 1,000,000 | 1,000,000 | 100,000 | 2.00% | 2.00% | 100,000 | 200,000 | 300,000 | 50,000 | 50,000 | 50,000 |
| 14,000,000 | 500,000 | 1,000,000 | 1,000,000 | 100,000 | 2.00% | 2.00% | 5,000,000 | 100,000 | 100,000 | 50,000 | 50,000 | 50,000 |
| 12,500,000 | 500,000 | 1,000,000 | 1,000,000 | 100,000 | 2.00% | 2.00% | 3,000,000 | 100,000 | 100,000 | 300,000 | 50,000 | 50,000 |
| 15,000,000 | 500,000 | 1,000,000 | 1,000,000 | 100,000 | 2.00% | 2.00% | 4,000,000 | 100,000 | 100,000 | 20,000 | 50,000 | 50,000 |
| 10,000,000 | 600,000 | 1,000,000 | 1,000,000 | 100,000 | 2.00% | 2.00% | 4,500,000 | 100,000 | 100,000 | 20,000 | 50,000 | 50,000 |
| 10,000,000 | 3,000,000 | 1,000,000 | 1,000,000 | 100,000 | 2.00% | 2.00% | 3,750,000 | 100,000 | 100,000 | 20,000 | 50,000 | 50,000 |
| 10,000,000 | 2,500,000 | 1,000,000 | 1,000,000 | 100,000 | 2.00% | 2.00% | 4,250,000 | 100,000 | 100,000 | 20,000 | 50,000 | 50,000 |
| 10,000,000 | 250,000 | 1,000,000 | 1,000,000 | 100,000 | 2.00% | 2.00% | 100,000 | 100,000 | 100,000 | 50,000 | 50,000 | 50,000 |
| 23,000,000 | 700,000 | 1,000,000 | 1,000,000 | 100,000 | 2.00% | 2.00% | 100,000 | 100,000 | 100,000 | 500,000 | 50,000 | 50,000 |
| 25,000,000 | 400,000 | 1,000,000 | 1,000,000 | 100,000 | 2.00% | 2.00% | 100,000 | 100,000 | 100,000 | 50,000 | 50,000 | 50,000 |
| 10,000,000 | 500,000 | 1,000,000 | 1,000,000 | 100,000 | 2.00% | 2.00% | 100,000 | 100,000 | 100,000 | 50,000 | 50,000 | 50,000 |
| 11,000,000 | 200,000 | 1,000,000 | 1,000,000 | 100,000 | 2.00% | 2.00% | 100,000 | 100,000 | 100,000 | 50,000 | 50,000 | 50,000 |
| 12,000,000 | 300,000 | 1,000,000 | 1,000,000 | 100,000 | 2.00% | 2.00% | 100,000 | 100,000 | 100,000 | 50,000 | 50,000 | 50,000 |
| 10,500,000 | 1,000,000 | 1,000,000 | 1,000,000 | 100,000 | 2.00% | 2.00% | 100,000 | 100,000 | 100,000 | 50,000 | 50,000 | 50,000 |
| 14,000,000 | 500,000 | 1,000,000 | 1,000,000 | 100,000 | 2.00% | 2.00% | 100,000 | 100,000 | 100,000 | 400,000 | 50,000 | 50,000 |
| 12,500,000 | 500,000 | 100,000 | 100,000 | 100,000 | 2.00% | 2.00% | 100,000 | 100,000 | 100,000 | 50,000 | 50,000 | 50,000 |
| 15,000,000 | 500,000 | 100,000 | 500,000 | 100,000 | 2.00% | 2.00% | 100,000 | 100,000 | 100,000 | 50,000 | 50,000 | 50,000 |
| 75,000,000 | 15,000,000 | 1,000,000 | 1,000,000 | 100,000 | 2.00% | 2.00% | 100,000 | 100,000 | 100,000 | 50,000 | 50,000 | 50,000 |

Figure 2: Sequences of Steps for Periodic Fund Management: Input and Exogenous Variables

- The Table in Figure (3) shows numerical examples related to the sequence of steps discussed in Section (3).
- The variables in Figure (2) are input variables which can be changed - or exogenous variables such as the fund value, which cannot be changed but simulated to its impact on the system and its corresponding performance - to control how the system is working.
- The output calculated variables are given in Figures (3; 4) which can be observed to gauge system performance and the input variables can be tweaked to obtain the desired outcomes. Figure (3) are general system variables and Figure (4) has variable related to how deposit and withdraw requests are being handled.
- It should be understood that the values in Figure (3) are just after the rebalance event has started and after we have performed the corresponding calculations.
- The columns in Figure (3) represent the following information respectively:
 1. **NAV (USD)** is the fund price or Net Asset Value at this rebalance event. It is calculated as the total fund value divided by the number of tokens.
 2. **Total Deposit (USD)** is the total deposit requests - in USD - received for investment into the fund at this rebalance event.
 3. **Total Withdraw Tokens** is the total withdraw requests - in number of tokens - received from investors requesting to take money out of the fund at this rebalance event.

4. **Total Withdraw (USD)** is the total withdraw requests - in USD - received from investors requesting to take money out of the fund at this rebalance event.
5. **Net Deposit Indicator** is an indicator which is 1 - 0 otherwise - if we are doing a net deposit or investment into the fund.
6. **Net Withdraw Indicator** is an indicator which is 1 - 0 otherwise - if we are doing a net withdraw or outflow from the fund.
7. **Net Deposit or Withdraw (USD)** is the value of the total amount in USD either being invested or withdrawn from the fund at this rebalance event.
8. **Net Amount Event (USD)** is the value of the total amount in USD either being invested or withdrawn from the fund after considering the maximum values we can invest or take out from the fund during this rebalance event.
9. **Rebalance Slippage (USD)** is the difference between the rebalance proceeds and the net amount event.
10. **Management Fees (USD)** is the management fees collected in USD at this rebalance event. It is given as the fund value multiplied by the management fee percent and applied over the duration since the last rebalance event.
11. **Performance Fees (USD)** is the performance fees collected in USD at this rebalance event. Detailed illustrations and several scenarios for this calculation are given in later Figures. The values shown here - for simplicity - are obtained by applying a random percentage value to the total fund value.
12. **Management Fees Tokens** is the management fees expressed in tokens. This is added to the total number of fund tokens.
13. **Performance Fees Tokens** is the performance fees expressed in tokens. This is added to the total number of fund tokens.

| Calculated Variables for System Monitoring | | | | | | | | | | | | | |
|--|---------------------|-----------------------|----------------------|-----------------------|------------------------|-------------------------------|------------------------|--------------------------|-----------------------|------------------------|------------------------|-------------------------|--|
| NAV (USD) | Total Deposit (USD) | Total Withdraw Tokens | Total Withdraw (USD) | Net Deposit Indicator | Net Withdraw Indicator | Net Deposit or Withdraw (USD) | Net Amount Event (USD) | Rebalance Slippage (USD) | Management Fees (USD) | Performance Fees (USD) | Management Fees Tokens | Performance Fees Tokens | |
| 20.00 | 300,000 | 150,000 | 3,000,000 | 0 | 1 | -2,700,000 | -1,000,000 | -900,000 | 200,000 | 200,000 | 10,000.00 | 500.00 | |
| 22.00 | 3,200,000 | 150,000 | 3,300,000 | 0 | 1 | -100,000 | -100,000 | 0 | 220,000 | 220,000 | 10,000.00 | 454.55 | |
| 24.00 | 300,000 | 300,000 | 7,200,000 | 0 | 1 | -6,900,000 | -1,000,000 | -900,000 | 240,000 | 600,000 | 10,000.00 | 416.67 | |
| 21.00 | 600,000 | 150,000 | 3,150,000 | 0 | 1 | -2,550,000 | -1,000,000 | -900,000 | 210,000 | 0 | 10,000.00 | 476.19 | |
| 28.00 | 5,200,000 | 150,000 | 4,200,000 | 1 | 0 | 1,000,000 | 1,000,000 | -900,000 | 280,000 | 700,000 | 10,000.00 | 357.14 | |
| 25.00 | 3,200,000 | 400,000 | 10,000,000 | 0 | 1 | -6,800,000 | -1,000,000 | -900,000 | 250,000 | 625,000 | 10,000.00 | 400.00 | |
| 30.00 | 4,200,000 | 120,000 | 3,600,000 | 1 | 0 | 600,000 | 600,000 | -500,000 | 300,000 | 750,000 | 10,000.00 | 333.33 | |
| 16.67 | 4,700,000 | 120,000 | 2,000,000 | 1 | 0 | 2,700,000 | 1,000,000 | -900,000 | 200,000 | 200,000 | 12,000.00 | 720.00 | |
| 3.33 | 3,950,000 | 120,000 | 400,000 | 1 | 0 | 3,550,000 | 1,000,000 | -900,000 | 200,000 | 100,000 | 60,000.00 | 18,000.00 | |
| 4.00 | 4,450,000 | 120,000 | 480,000 | 1 | 0 | 3,970,000 | 1,000,000 | -900,000 | 200,000 | 200,000 | 50,000.00 | 12,500.00 | |
| 40.00 | 300,000 | 150,000 | 6,000,000 | 0 | 1 | -5,700,000 | -1,000,000 | -900,000 | 200,000 | 400,000 | 5,000.00 | 125.00 | |
| 32.86 | 300,000 | 600,000 | 19,714,286 | 0 | 1 | -19,414,286 | -1,000,000 | -900,000 | 460,000 | 1,150,000 | 14,000.00 | 426.09 | |
| 62.50 | 300,000 | 150,000 | 9,375,000 | 0 | 1 | -9,075,000 | -1,000,000 | -900,000 | 500,000 | 750,000 | 8,000.00 | 128.00 | |
| 20.00 | 300,000 | 150,000 | 3,000,000 | 0 | 1 | -2,700,000 | -1,000,000 | -900,000 | 200,000 | 0 | 10,000.00 | 500.00 | |
| 55.00 | 300,000 | 150,000 | 8,250,000 | 0 | 1 | -7,950,000 | -1,000,000 | -900,000 | 220,000 | 110,000 | 4,000.00 | 72.73 | |
| 40.00 | 300,000 | 150,000 | 6,000,000 | 0 | 1 | -5,700,000 | -1,000,000 | -900,000 | 240,000 | 120,000 | 6,000.00 | 150.00 | |
| 10.50 | 300,000 | 150,000 | 1,575,000 | 0 | 1 | -1,275,000 | -1,000,000 | -900,000 | 210,000 | 420,000 | 20,000.00 | 1,904.76 | |
| 28.00 | 300,000 | 500,000 | 14,000,000 | 0 | 1 | -13,700,000 | -1,000,000 | -900,000 | 280,000 | 420,000 | 10,000.00 | 357.14 | |
| 25.00 | 300,000 | 150,000 | 3,750,000 | 0 | 1 | -3,450,000 | -100,000 | 0 | 250,000 | 250,000 | 10,000.00 | 400.00 | |
| 30.00 | 300,000 | 150,000 | 4,500,000 | 0 | 1 | -4,200,000 | -500,000 | -400,000 | 300,000 | 600,000 | 10,000.00 | 333.33 | |
| 5.00 | 300,000 | 150,000 | 750,000 | 0 | 1 | -450,000 | -450,000 | -350,000 | 1,500,000 | 3,750,000 | 300,000.00 | 60,000.00 | |

Figure 3: Sequences of Steps for Periodic Fund Management: Calculated Variables for System Monitoring

- The Table in Figure (4) shows numerical examples related to the sequence of steps discussed in Section (3).
- The variables in Figure (2) are input variables which can be changed - or exogenous variables such as the fund value, which cannot be changed but simulated to its impact on the system and its corresponding performance - to control how the system is working.
- The output calculated variables are given in Figures (3; 4) which can be observed to gauge system performance and the input variables can be tweaked to obtain the desired outcomes. Figure (3) are general system variables and Figure (4) has variable related to how deposit and withdraw requests are being handled.
- It should be understood that the values in Figure (4) are just after the rebalance event has started and after we have performed the corresponding calculations.
- The columns in Figure (4) represent the following information respectively:
 1. **Deposit Accept Ratio** is the deposit accept ratio which gives the percentage of the total requested deposit amount accepted for investment into the fund at this rebalance event.
 2. **Total Deposits Accepted (USD)** is the total deposits accepted - in USD - for investment into the fund at this rebalance event.
 3. **Deposit One Accept** is the amount of deposits accepted - in USD - from investor one into the fund at this rebalance event.

4. **Deposit Two Accept** is the amount of deposits accepted - in USD - from investor one into the fund at this rebalance event.
5. **Deposit Three Accept** is the amount of deposits accepted - in USD - from investor one into the fund at this rebalance event.
6. **Withdraw Accept Ratio** is the withdraw accept ratio which gives the percentage of the total requested withdraw quantity accepted for redemption at this rebalance event.
7. **Total Withdraws Accepted (USD)** is the total withdraw amount accepted - in USD - to be withdrawn from the fund and distributed to investors at this rebalance event.
8. **Total Withdraws Accepted** is the total withdraw amount accepted - in tokens - to be withdrawn from the fund and distributed to investors at this rebalance event.
9. **Withdraw One Accept** is the number of tokens accepted for withdrawal from investor one and to be redeemed from the fund at this rebalance event.
10. **Withdraw Two Accept** is the number of tokens accepted for withdrawal from investor two and to be redeemed from the fund at this rebalance event.
11. **Withdraw Three Accept** is the number of tokens accepted for withdrawal from investor three and to be redeemed from the fund at this rebalance event.

| Deposit or Withdraw Accepted Variables | | | | | | | | | | |
|--|-------------------------------|--------------------|--------------------|----------------------|-----------------------|--------------------------------|--------------------------|---------------------|---------------------|-----------------------|
| Deposit Accept Ratio | Total Deposits Accepted (USD) | Deposit One Accept | Deposit Two Accept | Deposit Three Accept | Withdraw Accept Ratio | Total Withdraws Accepted (USD) | Total Withdraws Accepted | Withdraw One Accept | Withdraw Two Accept | Withdraw Three Accept |
| 1.00 | 300,000 | 100,000 | 100,000 | 100,000 | 0.43 | 1,300,000 | 65,000 | 21,667 | 21,667 | 21,667 |
| 1.00 | 3,200,000 | 3,000,000 | 100,000 | 100,000 | 1.00 | 3,300,000 | 150,000 | 50,000 | 50,000 | 50,000 |
| 1.00 | 300,000 | 100,000 | 100,000 | 100,000 | 0.18 | 1,300,000 | 54,167 | 36,111 | 9,028 | 9,028 |
| 1.00 | 600,000 | 100,000 | 200,000 | 200,000 | 0.51 | 1,600,000 | 76,190 | 25,397 | 25,397 | 25,397 |
| 1.00 | 5,200,000 | 5,000,000 | 100,000 | 100,000 | 1.00 | 4,200,000 | 150,000 | 50,000 | 50,000 | 50,000 |
| 1.00 | 3,200,000 | 3,000,000 | 100,000 | 100,000 | 0.42 | 4,200,000 | 168,000 | 126,000 | 21,000 | 21,000 |
| 1.00 | 4,200,000 | 4,000,000 | 100,000 | 100,000 | 1.00 | 3,600,000 | 120,000 | 20,000 | 50,000 | 50,000 |
| 0.64 | 3,000,000 | 3,000,000 | 0 | 0 | 1.00 | 2,000,000 | 120,000 | 20,000 | 50,000 | 50,000 |
| 0.35 | 1,400,000 | 1,400,000 | 0 | 0 | 1.00 | 400,000 | 120,000 | 20,000 | 50,000 | 50,000 |
| 0.33 | 1,480,000 | 1,480,000 | 0 | 0 | 1.00 | 480,000 | 120,000 | 20,000 | 50,000 | 50,000 |
| 1.00 | 300,000 | 100,000 | 100,000 | 100,000 | 0.22 | 1,300,000 | 32,500 | 10,833 | 10,833 | 10,833 |
| 1.00 | 300,000 | 100,000 | 100,000 | 100,000 | 0.07 | 1,300,000 | 39,565 | 32,971 | 3,297 | 3,297 |
| 1.00 | 300,000 | 100,000 | 100,000 | 100,000 | 0.14 | 1,300,000 | 20,800 | 6,933 | 6,933 | 6,933 |
| 1.00 | 300,000 | 100,000 | 100,000 | 100,000 | 0.43 | 1,300,000 | 65,000 | 21,667 | 21,667 | 21,667 |
| 1.00 | 300,000 | 100,000 | 100,000 | 100,000 | 0.16 | 1,300,000 | 23,636 | 7,879 | 7,879 | 7,879 |
| 1.00 | 300,000 | 100,000 | 100,000 | 100,000 | 0.22 | 1,300,000 | 32,500 | 10,833 | 10,833 | 10,833 |
| 1.00 | 300,000 | 100,000 | 100,000 | 100,000 | 0.83 | 1,300,000 | 123,810 | 41,270 | 41,270 | 41,270 |
| 1.00 | 300,000 | 100,000 | 100,000 | 100,000 | 0.09 | 1,300,000 | 46,429 | 37,143 | 4,643 | 4,643 |
| 1.00 | 300,000 | 100,000 | 100,000 | 100,000 | 0.11 | 400,000 | 16,000 | 5,333 | 5,333 | 5,333 |
| 1.00 | 300,000 | 100,000 | 100,000 | 100,000 | 0.18 | 800,000 | 26,667 | 8,889 | 8,889 | 8,889 |
| 1.00 | 300,000 | 100,000 | 100,000 | 100,000 | 1.00 | 750,000 | 150,000 | 50,000 | 50,000 | 50,000 |

Figure 4: Sequences of Steps for Periodic Fund Management: Deposit and Withdraw Accept Variables

- The Table in Figure (5) shows numerical examples related to the method described in Point (1) in Section (4.3) and the material in Section (4.3.1). This illustration makes it clear why this approach requires more computations and storage, but can help with easier understanding, compared to the simpler approach from Figure (6) discussed in Point (2) in Section (4.3) and the discussion in Section (4.3.2).
- The columns in Figure (5) represent the following information respectively:
 1. **Time** corresponds to each rebalance event corresponding to Algorithm (1) in Section (3). The periodicity could be daily or even intraday intervals.
 2. **Total-Tokens-Till-Now (TN)** shows the total number of tokens in the fund till this point in time or till now.
 3. **Buy-Tokens-Till-Now (RN)** shows the number of tokens, of the fund, being bought at this point in time or right now.
 4. **Sell-Tokens-Till-Now (RN)** shows the number of tokens, of the fund, being sold at this point in time or right now.
 5. **NAV-RN** shows the NAV (Net Asset Value) of the fund at this point in time or right now.
 6. **HWM-RN** shows the HWM (High Water Mark) of the fund at this point in time or right now.
 7. **WNAV-BHWM-RN** shows the weighted average NAV for the transactions corresponding to this investor (or group of investors) that have entered the fund below the HWM at this point in time or right now.
 8. **Amount-BHWM-RN** shows the total quantity across the transactions corresponding to this investor (or group of investors) that have entered the fund below the HWM at this point in time or right now.
 9. **Fund Level Performance Fees** shows the performance fees that applies to all the tokens in the fund at this point in time or right now.
 10. **Investor Level Performance Fees** shows the performance fees that applies to the investor tokens in the fund, across the transactions corresponding to this investor (or group of investors) that have entered the fund below the HWM, at this point in time or right now.
 11. **Performance Fees on Withdraw** shows the performance fees that applies to the tokens being withdraw from the fund at this point in time or right now.
 12. **Fee Tokens Issued** shows the number of tokens issued corresponding to the total performance fees that has been levied at this point in time or right now.

| Time | Total-Tokens-Till-Now (TN) | Buy-Tokens-Right-Now (RN) | Sell-Tokens-Right-Now (RN) | NAV-RN | HWM-RN | WNAV-BHWM-RN | Amount-BHWM-RN | Fund Level Performance Fees | Investor Level Performance Fees | Performance Fees on Withdraw | Fee Tokens Issued |
|------|----------------------------|---------------------------|----------------------------|--------|--------|--------------|----------------|-----------------------------|---------------------------------|------------------------------|-------------------|
| | | | | | 3.00 | 0.00 | 0 | | | | |
| 1 | 10,000 | 1,000 | 0 | 4.00 | 4.00 | 4.00 | 1,000 | 2,000 | 0 | 0 | 500 |
| 2 | 11,000 | 1,000 | 0 | 3.00 | 4.00 | 3.50 | 2,000 | 0 | 0 | 0 | 0 |
| 3 | 12,000 | 1,000 | 0 | 3.00 | 4.00 | 3.33 | 3,000 | 0 | 0 | 0 | 0 |
| 4 | 13,000 | 0 | -1,000 | 4.00 | 4.00 | 3.33 | 2,000 | 0 | 0 | 133 | 33 |
| 5 | 12,000 | 1,000 | 0 | 3.00 | 4.00 | 3.22 | 3,000 | 0 | 0 | 0 | 0 |
| 6 | 13,000 | 1,000 | 0 | 3.00 | 4.00 | 3.17 | 4,000 | 0 | 0 | 0 | 0 |
| 7 | 14,000 | 1,000 | 0 | 3.00 | 4.00 | 3.13 | 5,000 | 0 | 0 | 0 | 0 |
| 8 | 15,000 | 0 | -1,000 | 4.00 | 4.00 | 3.13 | 4,000 | 0 | 0 | 173 | 43 |
| 9 | 14,000 | 1,000 | 0 | 3.00 | 4.00 | 3.11 | 5,000 | 0 | 0 | 0 | 0 |
| 10 | 15,000 | 1,000 | -1,000 | 3.00 | 4.00 | 3.09 | 5,000 | 0 | 0 | 0 | 0 |
| 11 | 15,000 | 1,000 | 0 | 5.00 | 5.00 | 5.00 | 1,000 | 2,000 | 1,911 | 0 | 782 |
| 12 | 16,000 | 1,000 | -700 | 2.00 | 5.00 | 3.50 | 1,300 | 0 | 0 | 0 | 0 |
| 13 | 16,300 | 1,000 | 0 | 1.00 | 5.00 | 2.41 | 2,300 | 0 | 0 | 0 | 0 |
| 14 | 17,300 | 0 | 0 | 5.00 | 5.00 | 2.41 | 2,300 | 0 | 0 | 0 | 0 |
| 15 | 17,300 | 0 | -1,200 | 2.50 | 5.00 | 2.41 | 1,100 | 0 | 0 | 21 | 8 |
| 16 | 16,100 | 1,000 | 0 | 3.50 | 5.00 | 2.93 | 2,100 | 0 | 0 | 0 | 0 |
| 17 | 17,100 | 1,000 | 0 | 6.50 | 6.50 | 6.50 | 1,000 | 4,500 | 1,499 | 0 | 923 |
| 18 | 18,100 | 1,000 | -500 | 1.00 | 6.50 | 3.75 | 1,500 | 0 | 0 | 0 | 0 |
| 19 | 18,600 | 1,000 | 0 | 1.40 | 6.50 | 2.81 | 2,500 | 0 | 0 | 0 | 0 |
| 20 | 19,600 | 1,000 | -900 | 1.23 | 6.50 | 2.36 | 2,600 | 0 | 0 | 0 | 0 |
| 21 | 19,700 | 1,000 | 0 | 2.45 | 6.50 | 2.38 | 3,600 | 0 | 0 | 0 | 0 |

Figure 5: Performance Fees Illustration: Weighted Average Below High Water Mark

- The Table in Figure (6) shows numerical examples related to the method described in Point (2) in Section (4.3) and the material in Section (4.3.2). This figure illustrates how this simplified approach works compared to the approach discussed in Point (1) in Section (4.3) and the discussion in Section (4.3.1).
- The columns in Figure (6) represent the following information respectively:
 1. **Time** corresponds to each rebalance event corresponding to Algorithm (1) in Section (3). The periodicity could be daily or even intraday intervals.
 2. **Total-Tokens-Till-Now (TN)** shows the total number of tokens in the fund till this point in time or till now.
 3. **Buy-Tokens-Till-Now (RN)** shows the number of tokens, of the fund, being bought at this point in time or right now.
 4. **Sell-Tokens-Till-Now (RN)** shows the number of tokens, of the fund, being sold at this point in time or right now.
 5. **WNAV-RN** shows the weighted average NAV (Net Asset Value) of the fund at this point in time or right now.
 6. **Fund Level Performance Fees** shows the performance fees that applies to all the tokens in the fund at this point in time or right now.
 7. **Performance Fees on Withdraw** shows the performance fees that applies to the tokens being

withdraw from the fund at this point in time or right now. This is zero for all scenarios in this simplified approach.

8. **Fee Tokens Issued** shows the number of tokens issued corresponding to the total performance fees that has been levied at this point in time or right now.

| Time | Total-Tokens-Till-Now (TN) | Buy-Tokens-Right-Now (RN) | Sell-Tokens-Right-Now (RN) | NAV-RN | WNAV-RN | Fund Level Performance Fees | Performance Fees on Withdraw | Fee Tokens Issued |
|------|----------------------------|---------------------------|----------------------------|--------|---------|-----------------------------|------------------------------|-------------------|
| | | | | | 0.00 | | | |
| 1 | 0 | 4,000 | 0 | 1.00 | 1.00 | 0 | 0 | 0 |
| 2 | 4,000 | 1,333 | 0 | 1.50 | 1.50 | 400 | 0 | 267 |
| 3 | 5,600 | 6,000 | -2,000 | 1.25 | 1.37 | 0 | 0 | 0 |
| 4 | 9,600 | 5,556 | 0 | 0.90 | 1.20 | 0 | 0 | 0 |
| 5 | 15,156 | 12,000 | -4,000 | 1.25 | 1.25 | 157 | 0 | 126 |
| 6 | 23,281 | 1,000 | 0 | 2.00 | 2.00 | 3,492 | 0 | 1,746 |
| 7 | 26,028 | 1,000 | 0 | 3.00 | 3.00 | 5,206 | 0 | 1,735 |
| 8 | 28,763 | 1,000 | -1,000 | 2.00 | 2.97 | 0 | 0 | 0 |
| 9 | 28,763 | 1,000 | -1,000 | 3.00 | 3.00 | 193 | 0 | 64 |
| 10 | 28,827 | 1,000 | 0 | 4.00 | 4.00 | 5,765 | 0 | 1,441 |
| 11 | 31,268 | 1,000 | -3,000 | 2.00 | 3.94 | 0 | 0 | 0 |
| 12 | 29,268 | 1,000 | 0 | 1.00 | 3.84 | 0 | 0 | 0 |
| 13 | 30,268 | 1,000 | 0 | 5.00 | 5.00 | 7,017 | 0 | 1,403 |
| 14 | 32,672 | 1,000 | -12,000 | 2.50 | 4.93 | 0 | 0 | 0 |
| 15 | 21,672 | 1,000 | 0 | 3.50 | 4.86 | 0 | 0 | 0 |
| 16 | 22,672 | 1,000 | 0 | 6.50 | 6.50 | 7,423 | 0 | 1,142 |
| 17 | 24,814 | 1,000 | -500 | 1.00 | 6.29 | 0 | 0 | 0 |
| 18 | 25,314 | 1,000 | 0 | 1.40 | 6.10 | 0 | 0 | 0 |
| 19 | 26,314 | 1,000 | -900 | 1.23 | 5.92 | 0 | 0 | 0 |
| 20 | 26,414 | 1,000 | 0 | 2.45 | 5.80 | 0 | 0 | 0 |
| 21 | 27,414 | 1,000 | 0 | 2.00 | 5.66 | 0 | 0 | 0 |

Figure 6: Performance Fees Illustration: Weighted Average Fund Level

- The Table in Figure (7) shows numerical examples related to the rise and fall scenario described in Point (3) in Section (4.3). The rise and fall scenario is illustrated with respect to the solution approach outlined in Section (4.3.1).
- The same scenarios are also illustrated in Figure (9) for the solution approach in Section (4.3.3). The additional performance fee cash flows in Figure (9) shows that the criteria discussed in Section (4.3.1) handle the rise and fall situation seamlessly.
- The columns in Figure (6) represent the same information as the columns in Figure (5) explained earlier.

| Time | Total-Tokens-Till-Now (TN) | Buy-Tokens-Right-Now (RN) | Sell-Tokens-Right-Now (RN) | NAV-RN | HWM-RN | WNAV-BHWM-RN | Amount-BHWM-RN | Fund Level Performance Fees | Investor Level Performance Fees | Performance Fees on Withdraw | Fee Tokens Issued |
|------|----------------------------|---------------------------|----------------------------|--------|--------|--------------|----------------|-----------------------------|---------------------------------|------------------------------|-------------------|
| | | | | | 0.00 | 0.00 | 0 | | | | |
| 1 | 0 | 100 | 0 | 1.50 | 1.50 | 1.50 | 0 | 0 | 0 | 0 | 0 |
| 2 | 100 | 200 | 0 | 1.75 | 1.75 | 1.75 | 0 | 5 | 0 | 0 | 3 |
| 3 | 303 | 0 | -50 | 1.65 | 1.75 | 1.65 | 0 | 0 | 0 | 0 | 0 |
| 4 | 253 | 750 | 0 | 1.95 | 1.95 | 1.95 | 0 | 10 | 0 | 0 | 5 |
| 5 | 1,008 | 275 | 0 | 1.75 | 1.95 | 1.75 | 275 | 0 | 0 | 0 | 0 |
| 6 | 1,283 | 100 | 0 | 1.65 | 1.95 | 1.72 | 375 | 0 | 0 | 0 | 0 |
| 7 | 1,383 | 0 | -100 | 1.50 | 1.95 | 1.72 | 275 | 0 | 0 | 0 | 0 |
| 8 | 1,283 | 0 | -225 | 1.55 | 1.95 | 1.72 | 50 | 0 | 0 | 0 | 0 |
| 9 | 1,058 | 0 | -300 | 1.75 | 1.95 | 1.72 | 0 | 0 | 0 | 0 | 0 |
| 10 | 758 | 100 | 0 | 1.40 | 1.95 | 1.40 | 100 | 0 | 0 | 0 | 0 |
| 11 | 858 | 0 | -200 | 2.00 | 2.00 | 2.00 | 0 | 8 | 12 | 0 | 10 |
| 12 | 668 | 0 | -115 | 2.15 | 2.15 | 2.15 | 0 | 20 | 0 | 0 | 9 |
| 13 | 562 | 250 | 0 | 1.45 | 2.15 | 1.45 | 250 | 0 | 0 | 0 | 0 |
| 14 | 812 | 0 | -175 | 1.55 | 2.15 | 1.45 | 75 | 0 | 0 | 4 | 2 |
| 15 | 640 | 350 | -100 | 1.40 | 2.15 | 1.41 | 325 | 0 | 0 | 0 | 0 |
| 16 | 890 | 50 | 0 | 2.05 | 2.15 | 1.49 | 375 | 0 | 0 | 0 | 0 |
| 17 | 940 | 0 | -250 | 2.10 | 2.15 | 1.49 | 125 | 0 | 0 | 30 | 14 |
| 18 | 704 | 0 | -400 | 1.65 | 2.15 | 1.49 | 0 | 0 | 0 | 4 | 2 |
| 19 | 306 | 0 | 0 | 1.35 | 2.15 | 1.35 | 0 | 0 | 0 | 0 | 0 |
| 20 | 306 | 0 | 0 | 1.55 | 2.15 | 1.55 | 0 | 0 | 0 | 0 | 0 |
| 21 | 306 | 0 | 0 | 1.85 | 2.15 | 1.85 | 0 | 0 | 0 | 0 | 0 |

Figure 7: Performance Fees Illustration: WA Below HWM Fall-Rise Scenario One

- The Table in Figure (8) shows numerical examples related to the rise and fall scenario described in Point (3) in Section (4.3). The rise and fall scenario is illustrated with respect to the solution approach outlined in Section (4.3.2).
- The same scenarios are also illustrated in Figure (10) for the solution approach in Section (4.3.3). The additional performance fee cash flows in Figure (10) shows that the criteria discussed in Section (4.3.1) handle the rise and fall situation seamlessly.
- The columns in Figure (8) represent the same information as the columns in Figure (6) explained earlier.

| Time | Total-Tokens-Till-Now (TN) | Buy-Tokens-Right-Now (RN) | Sell-Tokens-Right-Now (RN) | NAV-RN | WNAV-RN | Fund Level Performance Fees | Performance Fees on Withdraw | Fee Tokens Issued |
|------|----------------------------|---------------------------|----------------------------|--------|---------|-----------------------------|------------------------------|-------------------|
| 1 | 0 | 100 | 0 | 1.50 | 1.50 | 0 | 0 | 0 |
| 2 | 100 | 200 | 0 | 1.75 | 1.75 | 5 | 0 | 3 |
| 3 | 303 | 0 | -50 | 1.65 | 1.75 | 0 | 0 | 0 |
| 4 | 253 | 450 | 0 | 1.95 | 1.95 | 10 | 0 | 5 |
| 5 | 708 | 275 | 0 | 0.80 | 1.63 | 0 | 0 | 0 |
| 6 | 983 | 100 | 0 | 0.75 | 1.55 | 0 | 0 | 0 |
| 7 | 1,083 | 0 | -100 | 1.50 | 1.55 | 0 | 0 | 0 |
| 8 | 983 | 0 | -225 | 1.55 | 1.55 | 1 | 0 | 0 |
| 9 | 758 | 0 | -300 | 1.75 | 1.75 | 30 | 0 | 17 |
| 10 | 476 | 100 | 0 | 1.40 | 1.69 | 0 | 0 | 0 |
| 11 | 576 | 0 | -200 | 2.00 | 2.00 | 36 | 0 | 18 |
| 12 | 394 | 0 | -115 | 2.15 | 2.15 | 12 | 0 | 5 |
| 13 | 284 | 250 | 0 | 1.45 | 1.82 | 0 | 0 | 0 |
| 14 | 534 | 0 | -175 | 1.55 | 1.82 | 0 | 0 | 0 |
| 15 | 359 | 350 | -100 | 1.40 | 1.61 | 0 | 0 | 0 |
| 16 | 609 | 50 | 0 | 2.05 | 2.05 | 53 | 0 | 26 |
| 17 | 685 | 0 | -250 | 2.10 | 2.10 | 7 | 0 | 3 |
| 18 | 438 | 0 | -400 | 1.65 | 2.10 | 0 | 0 | 0 |
| 19 | 38 | 0 | 0 | 1.35 | 2.10 | 0 | 0 | 0 |
| 20 | 38 | 0 | 0 | 1.55 | 2.10 | 0 | 0 | 0 |
| 21 | 38 | 0 | 0 | 1.85 | 2.10 | 0 | 0 | 0 |

Figure 8: Performance Fees Illustration: WA Fund Level Fall-Rise Scenario Two

- The Table in Figure (9) shows numerical examples related to the rise and fall scenario described in Point (3) in Section (4.3). The additional columns - and variables - are added to the solution approach in Section (4.3.2).
- The same scenarios are also illustrated in Figure (7) for the solution approach in Section (4.3.1). The additional performance fee cash flows in Figure (9) show that the criteria discussed in Section (4.3.1) handle the rise and fall situation seamlessly.
- The columns in Figure (9) represent the same information as the columns in Figure (6) explained earlier, with two additional columns:
 1. **WNAV-PB** shows the weighted average NAV (Net Asset Value) to be used to plough back - or return - the performance fees back into the fund as explained in Section (4.3) and Point (3) and with the formulations given in Section (4.3.3).
 2. **Fees Plough Back** shows the dollar value of the performance fees to be ploughed back - or returned - into the fund as explained in Section (4.3) and Point (3) and with the formulations given in Section (4.3.3).

| Time | Total-Tokens-Till-Now (TN) | Buy-Tokens-Right-Now (RN) | Sell-Tokens-Right-Now (RN) | NAV-RN | WNAV-RN | WNAV-PB | Fund Level Performance Fees | Performance Fees on Withdraw | Fees Plough Back | Fee Tokens Issued |
|------|----------------------------|---------------------------|----------------------------|--------|---------|---------|-----------------------------|------------------------------|------------------|-------------------|
| | | | | 0.00 | 0.00 | 0.00 | | | | |
| 1 | 0 | 100 | 0 | 1.50 | 1.50 | 0.00 | 0 | 0 | 0 | 0 |
| 2 | 100 | 200 | 0 | 1.75 | 1.75 | 0.00 | 5 | 0 | 0 | 3 |
| 3 | 303 | 0 | -50 | 1.65 | 1.75 | 0.00 | 0 | 0 | 0 | 0 |
| 4 | 253 | 750 | 0 | 1.95 | 1.95 | 0.00 | 10 | 0 | 0 | 5 |
| 5 | 1,008 | 275 | 0 | 1.75 | 1.91 | 0.00 | 0 | 0 | 0 | 0 |
| 6 | 1,283 | 100 | 0 | 1.65 | 1.89 | 0.00 | 0 | 0 | 0 | 0 |
| 7 | 1,383 | 0 | -100 | 1.50 | 1.89 | 0.00 | 0 | 0 | 0 | 0 |
| 8 | 1,283 | 0 | -225 | 1.55 | 1.55 | 1.55 | 0 | 15 | -72 | -36 |
| 9 | 1,022 | 0 | -300 | 1.75 | 1.75 | 0.00 | 41 | 0 | 0 | 23 |
| 10 | 745 | 100 | 0 | 1.40 | 1.71 | 0.00 | 0 | 0 | 0 | 0 |
| 11 | 845 | 0 | -200 | 2.00 | 2.00 | 0.00 | 49 | 0 | 0 | 25 |
| 12 | 670 | 0 | -115 | 2.15 | 2.15 | 0.00 | 20 | 0 | 0 | 9 |
| 13 | 564 | 250 | 0 | 1.45 | 1.94 | 0.00 | 0 | 0 | 0 | 0 |
| 14 | 814 | 0 | -175 | 1.55 | 1.55 | 1.55 | 0 | 13 | -49 | -23 |
| 15 | 616 | 350 | -100 | 1.40 | 1.50 | 1.55 | 0 | 0 | 0 | 0 |
| 16 | 866 | 50 | 0 | 2.05 | 2.05 | 0.00 | 87 | 0 | 0 | 42 |
| 17 | 958 | 0 | -250 | 2.10 | 2.10 | 0.00 | 10 | 0 | 0 | 5 |
| 18 | 713 | 0 | -400 | 1.65 | 2.10 | 0.00 | 0 | 0 | 0 | 0 |
| 19 | 313 | 0 | 0 | 1.35 | 2.10 | 0.00 | 0 | 0 | 0 | 0 |
| 20 | 313 | 0 | 0 | 1.55 | 1.55 | 1.55 | 0 | 0 | -34 | -22 |
| 21 | 291 | 0 | 0 | 1.85 | 1.85 | 0.00 | 17 | 0 | 0 | 9 |

Figure 9: Performance Fees Illustration: WAFL Plough Back Fall-Rise Scenario One

- The Table in Figure (10) shows numerical examples related to the rise and fall scenario described in Point (3) in Section (4.3). The additional columns - and variables - are added to the solution approach in Section (4.3.2).
- The same scenarios are also illustrated in Figure (8) for the solution approach in Section (4.3.2). The additional performance fee cash flows in Figure (10) show that the criteria discussed in Section (4.3.1) handle the rise and fall situation seamlessly.
- The columns in Figure (10) represent the same information as the columns in Figure (9) explained earlier.

| Time | Total-Tokens-Till-Now (TN) | Buy-Tokens-Right-Now (RN) | Sell-Tokens-Right-Now (RN) | NAV-RN | WNAV-RN | WNAV-PB | Fund Level Performance Fees | Performance Fees on Withdraw | Fees Plough Back | Fee Tokens Issued |
|------|----------------------------|---------------------------|----------------------------|--------|---------|---------|-----------------------------|------------------------------|------------------|-------------------|
| | | | | 0.00 | 0.00 | 0.00 | | | | |
| 1 | 0 | 100 | 0 | 1.50 | 1.50 | 0.00 | 0 | 0 | 0 | 0 |
| 2 | 100 | 200 | 0 | 1.75 | 1.75 | 0.00 | 5 | 0 | 0 | 3 |
| 3 | 303 | 0 | -50 | 1.65 | 1.75 | 0.00 | 0 | 0 | 0 | 0 |
| 4 | 253 | 750 | 0 | 1.95 | 1.95 | 0.00 | 10 | 0 | 0 | 5 |
| 5 | 1,008 | 275 | 0 | 1.75 | 1.91 | 0.00 | 0 | 0 | 0 | 0 |
| 6 | 1,283 | 100 | 0 | 1.65 | 1.89 | 0.00 | 0 | 0 | 0 | 0 |
| 7 | 1,383 | 0 | -100 | 1.50 | 1.89 | 0.00 | 0 | 0 | 0 | 0 |
| 8 | 1,283 | 0 | -225 | 1.55 | 1.55 | 1.55 | 0 | 15 | -72 | -36 |
| 9 | 1,022 | 0 | -300 | 1.75 | 1.75 | 0.00 | 41 | 0 | 0 | 23 |
| 10 | 745 | 100 | 0 | 1.40 | 1.71 | 0.00 | 0 | 0 | 0 | 0 |
| 11 | 845 | 0 | -200 | 2.00 | 2.00 | 0.00 | 49 | 0 | 0 | 25 |
| 12 | 670 | 0 | -115 | 2.15 | 2.15 | 0.00 | 20 | 0 | 0 | 9 |
| 13 | 564 | 250 | 0 | 1.45 | 1.94 | 0.00 | 0 | 0 | 0 | 0 |
| 14 | 814 | 0 | -175 | 1.55 | 1.55 | 1.55 | 0 | 13 | -49 | -23 |
| 15 | 616 | 350 | -100 | 1.40 | 1.50 | 1.55 | 0 | 0 | 0 | 0 |
| 16 | 866 | 50 | 0 | 2.05 | 2.05 | 0.00 | 87 | 0 | 0 | 42 |
| 17 | 958 | 0 | -250 | 2.10 | 2.10 | 0.00 | 10 | 0 | 0 | 5 |
| 18 | 713 | 0 | -400 | 1.65 | 2.10 | 0.00 | 0 | 0 | 0 | 0 |
| 19 | 313 | 0 | 0 | 1.35 | 2.10 | 0.00 | 0 | 0 | 0 | 0 |
| 20 | 313 | 0 | 0 | 1.55 | 1.55 | 1.55 | 0 | 0 | -34 | -22 |
| 21 | 291 | 0 | 0 | 1.85 | 1.85 | 0.00 | 17 | 0 | 0 | 9 |

Figure 10: Performance Fees Illustration: WAFL Plough Back Fall-Rise Scenario One

7 Areas for Further Research

As better blockchain networks develop, we will need to see if the above techniques we have created need modification. It might be possible to use thousands of transactions for calculations on a blockchain computing platform. Then the need to do weighted averages will be mitigated since averages are approximations to some extent and having granular information will yield more accuracy.

To emphasize, committing thousands of transactions to the blockchain record, or into a block, is already possible (Pierro & Tonelli 2022). The basics of computing make it clear that the more data we wish to store and the more computations we need to perform, the associated costs will increase (Dromey 1982). To perform the calculations we have discussed, using the averaging techniques we have outlined, requires being able to access a large number of historical transactions as well. Providing such a large amount of input data to the decentralized computer is still an area of active research (Wu et al., 2019; Kurt Peker et al., 2020; Fan, Niu & Liu 2022; End-note 17).

Any investment fund, whether on blockchain or outside, exists to generate excess returns for its investors. Several excellent investment strategies have been utilized in traditional investment funds to obtain higher returns. To implement similar investment ideas on blockchain would require considering each strategy as an overlay within a larger fund (Mulvey, Ural & Zhang 2007; Mohanty, Mohanty & Ivanof 2021). As time

goes on, several overlay strategies can be added to the basic fund so that we can benefit from any potential opportunities that open up.

A team of researchers and investment specialists need to continually scour the blockchain investment landscape to identify ways to generate profits. Another set of bridges that need to be actively built are strategic partnerships to ensure that the crypto environment can be highly inclusive, and connect investing to several real world platforms, solving many problems that plague humanity along the way. Inclusion of such assets into the portfolio can be similar to socially responsible investing in the traditional world (Berry & Junkus 2013; Junkus & Berry 2015; End-note 18) but with special attention to how such projects might aid the evolution of the blockchain realm. These will be ongoing and some focus on these initiatives will be required once the fundamental techniques discussed here are tested thoroughly and deployed.

Any intensive computations needed, to clarify the decision process and arrive at the decision outcomes, can be done outside the blockchain world, but the essential fund movements are better suited to happen on a blockchain environment for security reasons. The interaction between on-chain and off-chain components is a delicate balance involving several trade-offs such as blockchain computational cost and not revealing proprietary investment strategies (Garvey & Murphy 2005; Pardo 2011; Nuti et al., 2011).

We have only considered mutual funds and hedge funds as our motivating vehicles, but other types of funds have numerous innovations that can be considered in later iterations. For example, exchange traded funds (ETFs) are a very small extension to what we have discussed here. The fund tokens provided by the protocols we have discussed above, can be listed on decentralized exchanges (Jensen, Wachter & Ross 2021; Mohan 2022) and the whole system starts behaving like an ETF.

Further overlays can be based on specific allocations to sectors we see as promising. This would be similar to sector themed sub-indices or ETFs but within a larger grouping of assets (Healy & Lo 2009; Mohanty, Mohanty & Ivanof 2021). These developments can allow investors to customize their preferences in a basket or theme. Initially it will be easier to accept investments made only in stable coins (USDT, USDC and BUSD: End-note 13). We are developing mechanisms through which investors can participate in blockchain investment vehicles by making deposits denominated in a larger set of assets (Kashyap 2021). The stability of stable coins is itself a topic of significant concern and hence the inclusion of additional assets for taking deposits, and making redemptions, would be a welcome pursuit (Hoang & Baur 2021; Lyons & Viswanath-Natraj 2023; End-note 19).

As more sophisticated derivatives start to become available as decentralized securities, incorporating them could be challenging yet rewarding. The development of new networks, and derivative providers within networks, will enable the use of options as a hedging mechanism (Hull 2003). This will help to protect from market crashes and to reduce the portfolio volatility. Also, derivative strategies combined with rigorous risk management can help to gain additional returns (Huberts 2004; Madan & Sharaiha 2015). Numerous

other areas for improvement, in terms of portfolio weight calculations, rebalancing, trade execution risk management and so on, are listed in Kashyap (2021).

8 Conclusion

We have created several novel techniques to bring many mechanisms that have worked well in the traditional financial wealth management arena to the blockchain space. We have given detailed algorithmic steps to help with technical implementation of the methodologies we have developed. Mutual funds, hedge funds and other traditional investments have had a significant impact in the lives of many individuals across the world. Despite their popularity, there are many concerns regarding their transparency and ease of access for everyone. Blockchain technology is extremely well suited to mitigate - if not entirely eliminate - those concerns. Decentralized ledger concepts and the technological advancements over the last several decades allow us to combine the best features of both hedge funds and mutual funds.

We have given detailed mathematical formulations, and technical pointers, to be able to implement the mechanisms we have created as blockchain smart contracts. Our approach overcomes numerous blockchain bottlenecks and takes the power of smart contracts much further. We have shown how fund prices can be updated regularly like mutual funds and performance fees can be charged like hedge funds. In addition blockchain investment funds - as we have described - can operate with investor protection schemes such as high water marks and measures to offset trading related slippage costs when redemptions happen.

Equal access to transparent wealth creation opportunities for everyone are finally around the corner.

9 End-notes

1. Open-end mutual funds are purchased from or sold to the issuer at the net asset value of each share as of the close of the trading day in which the order was placed, as long as the order was placed within a specified period before the close of trading. They can be traded directly with the issuer. Mutual Fund, Wikipedia Link
2. A hedge fund is a pooled investment fund that trades in relatively liquid assets and is able to make extensive use of more complex trading, portfolio-construction, and risk management techniques in an attempt to improve performance, such as short selling, leverage, and derivatives. Hedge Fund, Wikipedia Link
3. In finance, assets under management (AUM), sometimes called fund under management, measures the total market value of all the financial assets which an individual or financial institution—such as

a mutual fund, venture capital firm, or depository institution—or a decentralized network protocol controls, typically on behalf of a client. [Assets Under Management, Wikipedia Link](#)

4. In decentralized finance, Total value locked represents the number of assets that are currently being staked in a specific protocol. [Total Value Locked, CoinMarketCap Link](#)

5. Decentralized finance (often stylized as DeFi) offers financial instruments without relying on intermediaries such as brokerages, exchanges, or banks by using smart contracts on a blockchain. [Decentralized Finance \(DeFi\), Wikipedia Link](#)

6. The following are the four main types of blockchain decentralized financial products or services. We can also consider them as the main types of yield enhancement, or return generation, vehicles available in decentralized finance:

(a) **Single-Sided Staking:** This allows users to earn yield by providing liquidity for one type of asset, in contrast to liquidity provisioning on AMMs, which requires a pair of assets. [Single Sided Staking, SuacerSwap Link](#)

i. Bancor is an example of a provider who supports single sided staking. Bancor natively supports Single-Sided Liquidity Provision of tokens in a liquidity pool. This is one of the main benefits to liquidity providers that distinguishes Bancor from other DeFi staking protocols. Typical AMM liquidity pools require a liquidity provider to provide two assets. Meaning, if you wish to deposit "TKN1" into a pool, you would be forced to sell 50% of that token and trade it for "TKN2". When providing liquidity, your deposit is composed of both TKN1 and TKN2 in the pool. Bancor Single-Side Staking changes this and enables liquidity providers to: Provide only the token they hold (TKN1 from the example above) Collect liquidity providers fees in TKN1. [Single Sided Staking, Bancor Link](#)

(b) **AMM Liquidity Pairs (AMM LP):** A constant-function market maker (CFMM) is a market maker with the property that that the amount of any asset held in its inventory is completely described by a well-defined function of the amounts of the other assets in its inventory (Hanson 2007). [Constant Function Market Maker, Wikipedia Link](#)

This is the most common type of market maker liquidity pool. Other types of market makers are discussed in Mohan (2022). All of them can be grouped under the category Automated Market Makers. Hence the name AMM Liquidity Pairs. A more general discussion of AMMs, without being restricted only to the blockchain environment, is given in (Slamka, Skiera & Spann 2012).

(c) **LP Token Staking:** LP staking is a valuable way to incentivize token holders to provide liquidity. When a token holder provides liquidity as mentioned earlier in Point (6b) they receive LP tokens.

LP staking allows the liquidity providers to stake their LP tokens and receive project tokens tokens as rewards. This mitigates the risk of impermanent loss and compensates for the loss. Liquidity Provider Staking, DeFactor Link

- i. Note that this is also a type of single sided staking discussed in Point (6a). The key point to remember is that the LP Tokens can be considered as receipts for the crypto assets deposits in an AMM LP Point (6b). These LP Token receipts can be further staked to generate additional yield.
- (d) Lending: Crypto lending is the process of depositing cryptocurrency that is lent out to borrowers in return for regular interest payments. Payments are typically made in the form of the cryptocurrency that is deposited and can be compounded on a daily, weekly, or monthly basis. Crypto Lending, Investopedia Link; DeFi Lending, DeFiPrime Link; Top Lending Coins by Market Capitalization, Crypto.com Link.
- i. Crypto lending is very common on decentralized finance projects and also in centralized exchanges. Centralized cryptocurrency exchanges are online platforms used to buy and sell cryptocurrencies. They are the most common means that investors use to buy and sell cryptocurrency holdings. Centralized Cryptocurrency Exchanges, Investopedia Link
 - ii. Lending is a very active area of research both on blockchain and off chain (traditional finance) as well (Cai 2018; Zeng et al., 2019; Bartoletti, Chiang & Lafuente 2021; Gonzalez 2020; Hassija et al., 2020; Patel et al. , 2020).
 - iii. Lending is also a highly profitable business in the traditional financial world (Kashyap 2022-I). Investment funds, especially hedge funds, engage in borrowing securities to put on short positions depending on their investment strategies. Long only investment funds typically supply securities or lend their assets for a fee.
 - iv. In finance, a long position in a financial instrument means the holder of the position owns a positive amount of the instrument. Long Position in Finance, Wikipedia Link
 - v. In finance, being short in an asset means investing in such a way that the investor will profit if the value of the asset falls. This is the opposite of a more conventional "long" position, where the investor will profit if the value of the asset rises. Short Position in Finance, Wikipedia Link

7. Net Asset Value is the net value of an investment fund's assets less its liabilities, divided by the number of shares outstanding. NAV, Investopedia Link

8. An index fund (also index tracker) is a mutual fund or exchange-traded fund (ETF) designed to follow certain preset rules so that it can replicate the performance ("track") of a specified basket of underlying

investments. [Index Fund](#), [Wikipedia Link](#)

(a) A mutual fund is an investment fund that pools money from many investors to purchase securities. Mutual Funds typically pay their regular and recurring, fund-wide operating expenses out of fund assets, rather than by imposing separate fees and charges directly on investors. [Mutual Fund Fees](#), [Wikipedia Link](#)

(b) An exchange-traded fund (ETF) is a type of investment fund and exchange-traded product, i.e. they are traded on stock exchanges. ETFs are similar in many ways to mutual funds, except that ETFs are bought and sold from other owners throughout the day on stock exchanges whereas mutual funds are bought and sold from the issuer based on their price at day's end. [Exchange Traded Fund](#), [Wikipedia Link](#)

9. A smart contract is a computer program or a transaction protocol that is intended to automatically execute, control or document events and actions according to the terms of a contract or an agreement. The objectives of smart contracts are the reduction of need for trusted intermediators, arbitration costs, and fraud losses, as well as the reduction of malicious and accidental exceptions. Smart contracts are commonly associated with cryptocurrencies, and the smart contracts introduced by Ethereum are generally considered a fundamental building block for decentralized finance (DeFi) and NFT applications. [Smart Contract](#), [Wikipedia Link](#)

10. High-water mark is the highest level of value reached by an investment account or portfolio. It is often used as a threshold to determine whether a fund manager can gain a performance fee. Investors benefit from a high-water mark by avoiding paying performance-based bonuses for poor performance or for the same performance twice. [High Water Mark \(HWM\)](#), [Corporate Finance Institute Link](#)

11. In computing and in systems theory, first in, first out (the first in is the first out), acronymized as FIFO, is a method for organizing the manipulation of a data structure (often, specifically a data buffer) where the oldest (first) entry, or "head" of the queue, is processed first. Such processing is analogous to servicing people in a queue area on a first-come, first-served (FCFS) basis, i.e. in the same sequence in which they arrive at the queue's tail. [First in First Out \(Computing\)](#), [Wikipedia Link](#)

12. In financial markets, implementation shortfall is the difference between the decision price and the final execution price (including commissions, taxes, etc.) for a trade. This is also known as the "slippage". Agency trading is largely concerned with minimizing implementation shortfall and finding liquidity. [Implementation Shortfall](#), [Wikipedia Link](#)

13. A Stable-coin is a type of cryptocurrency where the value of the digital asset is supposed to be pegged to a reference asset, which is either fiat money, exchange-traded commodities (such as precious metals

- or industrial metals), or another cryptocurrency. [Stable Coin, Wikipedia Link](#)
14. A public blockchain has absolutely no access restrictions. Anyone with an Internet connection can send transactions to it as well as become a validator. [Blockchain Types, Wikipedia Link](#)
- A private blockchain is permissioned. One cannot join it unless invited by the network administrators. Participant and validator access is restricted.
15. The time value of money is the widely accepted conjecture that there is greater benefit to receiving a sum of money now rather than an identical sum later. It may be seen as an implication of the later-developed concept of time preference. [Time Value of Money, Wikipedia Link](#)
16. An airdrop is an unsolicited distribution of a cryptocurrency token or coin, usually for free, to numerous wallet addresses. [Airdrop \(Cryptocurrency\), Wikipedia Link](#)
17. Ethereum, which was conceived in 2013 and launched in 2015 (Wood 2014; Tapscott & Tapscott 2016; Dannen 2017), provided a remarkable innovation in terms of making blockchain based systems Turing complete (or theoretically being able to do what any computer can do: Sipser 2006).
- (a) Ethereum is a decentralized, open-source blockchain with smart contract functionality. Ether (Abbreviation: ETH) is the native cryptocurrency of the platform. Among cryptocurrencies, ether is second only to bitcoin in market capitalization. [Ethereum, Wikipedia Link](#)
 - (b) In computability theory, a system of data-manipulation rules (such as a computer's instruction set, a programming language, or a cellular automaton) is said to be Turing-complete or computationally universal if it can be used to simulate any Turing machine. [Turing Completeness, Wikipedia Link](#)
A Turing machine is a mathematical model of computation describing an abstract machine that manipulates symbols on a strip of tape according to a table of rules. Despite the model's simplicity, it is capable of implementing any computer algorithm. [Turing Machine, Wikipedia Link](#)
18. Socially responsible investing (SRI), social investment, sustainable socially conscious, "green" or ethical investing, is any investment strategy which seeks to consider both financial return and social/environmental good to bring about social change regarded as positive by proponents. [Socially Responsible Investing, Wikipedia Link](#)
- (a) Environmental, social, and corporate governance (ESG) is a framework designed to be embedded into an organization's strategy that considers the needs and ways in which to generate value for all of organizational stakeholders (such as employees, customers and suppliers and financiers). [Environmental, Social and Corporate Governance, Wikipedia Link](#)

(b) The areas of concern recognized by the SRI practitioners are sometimes summarized under the heading of ESG issues: environment, social justice, and corporate governance.

19. The recent LUNA / UST episode on the Terra network, from May 8 to May 13 2022 and beyond, is a demonstration of the risk of holding concentrated portfolios (Lee et al., 2022; Briola et al. , 2023).

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