Economic Principles of PoPCoin,
a Democratic Time-based Cryptocurrency

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Abstract. While democracy is founded on the principle of equal opportunity to manage our lives and pursue our fortunes, the forms of money we have inherited from millenia of evolution has brought us to an unsustainable dead-end of exploding inequality. PoPCoin proposes to leverage the unique historical opportunities that digital cryptocurrencies present for a "clean-slate" redesign of money, in particular around long-term equitability and sustainability, rather than solely stability, as our primary goals. We develop and analyze a monetary policy for PoPCoin that embodies these equitability goals in two basic rules that may be summarized as supporting equal opportunity in "space" and "time": the first by regularly distributing new money equally to all participants much like a basic income, the second by holding the aggregate value of these distributions to a constant and non-diminishing portion of total money supply through demurrage. Through preliminary economic analysis, we find that these rules in combination yield a unique form of money with numerous intriguing and promising properties, such as a quantifiable and provable upper bound on monetary inequality, a natural "early adopter's reward" that could incentivize rapid growth while tapering off as participation saturates, resistance to the risk of deflationary spirals, and migration incentives opposite those created by conventional basic incomes.

1 Introduction
A well-functioning free market rewards the providers of valuable products and services, encourages innovation through competition, and limits waste by financially starving ventures that fail to produce value. But today’s free markets embody at least two long-term sustainability problems: they allow uncontrolled increase in inequality [67], and they cannot function without constant growth [43,41]. For centuries, philosophers and economists have proposed ways in which the concept and function of money might be improved or redesigned to be more stable, equitable, and sustainable [29,45,40]. Permissionless cryptocurrencies, however, offer us the unprecedented opportunity not only to envision on paper a "clean-slate" redesign of money, relatively unconstrained by either the economic status-quo or risk-averse governments, but also to implement alternative monetary designs and experiment with them circulating in real-world communities.

PoPCoin is a cryptocurrency project aiming to prototype and eventually launch a more democratic, equitable, and sustainable form of money. Today’s
“democratic” societies and organizations typically attempt to satisfy the democratic principle of equality only in terms of governance, via “one person, one vote” in decision-making. PoPCoin, in contrast, pursues democratic equality in three dimensions: governance, operation, and economics. Governance equality means “one person, one vote” in decision-making, as usual. Operational equality in PoPCoin means “one person, one unit of stake” in securing consensus and maintaining a shared history or blockchain. Finally, economic equality in PoPCoin means ensuring all participants equality of opportunity to employ money – and the community resources it represents – towards personal and collective goods. This paper focuses on the third objective of economic equality: the others, while equally important challenging, we leave for other work to address.

Motivated by supporting sustainable and equitable economic opportunity while retaining capitalistic rewards for valued work and innovation, PoPCoin regularly mints and distributes new money to all real human participants. The basic goal of PoPCoin’s monetary policy is to ensure that these “basic income” distributions provide all participants a baseline of economic opportunity that is equitable, continuous, and unvarying in both space and time. Equality over “space” – i.e., population – means guaranteeing each participant an equal share in each distribution of new money. Equality over time means the value of each basic income distribution represents an equal and constant proportion of the community’s total monetary resources. Most critically, the basic income’s proportionate value and utility must not diminish from one month, year, or generation to the next.

This paper’s first main contribution is a preliminary “long view” economic model and analysis of what a sustainable, democratically egalitarian form of money might look like, if it were eventually to become widely-adopted as the predominant currency within a community of sufficient critical mass. Our analysis adapts existing tools from economic theory to develop PoPCoin’s monetary policy and identify several interesting properties. First, in line with pre-cryptocurrency ideas such as Gesell’s freigeld and universal basic incomes, PoPCoin decouples broad economic growth from debt by giving all participants a regular supply of debt-free money. Second, PoPCoin’s design imposes a readily-calculate upper bound on inequality in the distribution of PoPCoin among participants after each minting, thereby ensuring a form of sustainability in terms of basic financial inclusion, contrasting with classic currencies where inequality can increase without bound. Third, while increased real growth can create monetary deflation by increasing demand, PoPCoin appears to mitigate the classic risk of “deflationary spirals” – where high demand yields higher real interest rates and hence borrowing costs, making money even more scarce in a positive feedback loop. Because PoPCoin’s basic income is not debt-based, higher demand on PoPCoin raises the basic income’s real value without affecting its broad avail-

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1 Many organizations that are often loosely labeled “democratic” fail even in this, including permissionless proof-of-work and proof-of-stake cryptocurrencies, and open-source communities whose governance is dominated by a few core committers.
ability to participants, and may counteract deflation by giving all participants both opportunity and purchasing power to spend or invest.

While this long view is promising, real currencies are not isolated but inhabit a larger economic ecosystem. This paper’s second main contribution is a preliminary exploration of several intriguing properties we may expect of a permissionless cryptocurrency embodying PoPCoin’s monetary policy. First, a preliminary exchange rate analysis suggests that we may expect PoPCoin to increase gradually in value over time with respect to an inflationary fiat currency like USD, assuming that both the size and spending behavior of the PoPCoin community is stable in certain respects. We don’t actually expect either of these factors to be stable in practice, however, especially while a PoPCoin community is small and rapidly-evolving, leading to a second key observation. Because basic income represents a fixed fraction of total PoPCoin supply divided by participant population in that minting, earlier participants in a growing community receive a larger fraction of total supply in earlier mintings. This effect might serve as a natural “early adopter’s reward” – and an incentive for participants to promote PoPCoin and grow the community – that automatically tapers off as participation saturates and stabilizes. Third, while we may expect speculative trading and “HODLing” of PoPCoin to yield wild exchange-rate swings as with other cryptocurrencies, PoPCoin continually “taxes” speculative holdings and redistributes value to participants’ basic incomes, which may both disincentivize too much speculative holding and reward participants for weathering speculative storms. Nevertheless, we prove that a rational participant may save some of his income to increase his future utility, and the rich would pay more demurrage fee than the poor, even though they are subject to the same mechanism and global demurrage rate. Fourth, because PoPCoin represents a permissionless and borderless community, its basic income floats to some single global value versus other currencies, rather than being defined by policy within a jurisdiction as in a conventional basic income. PoPCoin’s basic income will therefore buy more and feel more useful in poor countries with low cost-of-living than in rich ones, it will gradually redistribute wealth from the latter to the former, and any “migration incentive” it creates will be from rich countries to poor: opposite the poor-to-rich migration incentives that a conventional UBI would contribute to.

This initial development of PoPCoin has many limitations, of course. It focuses only on monetary policy, leaving operational and governance issues out of scope. Our preliminary economic analysis, detailed in the appendices, makes many simplifying assumptions that may prove unrealistic, and our formal model currently covers only a subset of the interesting properties of PoPCoin that we identify and explore intuitively. Further, because PoPCoin as developed here effectively “taxes” only money and not non-monetary wealth such as real estate and investments, it inherently incentivizes spending over holding. This may be desirable to stimulate economic activity as Gesell proposed [29] – but it may also make other currencies and non-monetary wealth more attractive as investments, limiting the total value we can expect PoPCoin to acquire, and similarly limiting its potential to address inequality in general across all forms of wealth.
Indeed we expect, and accept, that PoPCoin may not appeal much to economically “greedy” users, but mainly to those motivated more by social, political, or sustainability goals.\footnote{Such goals may of course be considered economically rational in terms of “enlightened self-interest” as opposed to greed.} We leave these limitations to be addressed in future work.

2 Monetary Principles and Design of PoPCoin

2.1 Democracy, Money, and the Principle of Equal Opportunity

Democracy, or literally \textit{rule by the people} \cite{26}, has no single definition but embodies widely-held principles. The Council of Europe boils democracy down to two key principles: \textit{individual autonomy} – that “People should be able to control their own lives (within reason)” – and \textit{equality} – that “everyone should have the same opportunity to influence the decisions that affect people in society” \cite{17}. Political philosopher Robert Dahl defines criteria essential to democracy, among them equal opportunity to obtain “enlightened understanding” of the issues, to control the agenda, to participate in discussions, and to vote on decisions \cite{18}. We normally interpret “equality” only as \textit{political equality} in self-governance.

Among the “decisions that affect people in society”, however, classical economics carves out a huge swath – namely, almost all decisions on allocating society’s resources – in which \textit{inequality} rules. We have mostly exempted money from the democratic principle of equality: those with more money can spend proportionally more on what they like, hire more labor to help them, invest more in ventures they support, etc. With inequality exploding \cite{67}, leaving 90\% of incomes stagnant as $2.5$ trillion was transferred to the top 1\% since 1975 \cite{69}, current trends toward \textit{unlimited inequality} represent a clearly unsustainable path.

Furthermore, economics and governance are inseparable in practice: “money is power.” More money buys more influence \cite{30} – whether via advertising, lobbying, or online bot farming \cite{10}. For the growing global “precariat” \cite{73} struggling to survive on stagnant incomes from multiple uncertain sources, finding the time even just to vote – let alone fulfill Dahl’s democratic criteria of “effective participation” and “control of the agenda” based on “enlightened understanding” – feels increasingly like a distant luxury only the rich can afford. In numerous ways, economic inequality corrodes political equality and undermines democracy.

Irving Fisher noted the unsustainability of uncontrolled economic inequality, and its corrosion of political equality, after the conclusion of World War I in his 1919 annual address as president of the American Economic Association:

\begin{quote}
Our society will always remain an unstable and explosive compound as long as political power is vested in the masses and economic power in the classes. In the end one of these powers will rule. Either the plutocracy will buy up the democracy or the democracy will vote away the plutocracy. In the meantime the corrupt politician will thrive as a concealed broker between the two. \textsuperscript{24}
\end{quote}
Political and economic philosophers alike often support the principles of inclusion and equal opportunity. Even capitalist economics generally presumes that participants compete on a fair and “level playing field” even if outcomes may – and arguably should – be highly unequal. Among the opportunities most people want are the opportunities to earn economic rewards for hard work, innovation, or wise investment. For these purposes, we cannot realistically pretend that everyone is equal in either abilities or motivation. But if we accept that allowing (equal) opportunity to earn rewards necessitates allowing inequality in economic outcomes, this does not mean we must or should accept unlimited inequality.

Classical monetary policy is driven primarily by stability concerns: particularly stable prices, to protect money’s functions as a unit of account and a store of value, and a stable money supply to drive commerce. Even at this modest goal of maintaining a stable “status quo,” however, classical economics fails miserably, yielding frequent “boom-and-bust” cycles that show no signs of abating. But as Bitcoin and the countless cryptocurrencies it inspired have underlined, money is not only a social good but a technology that can be designed, and some designs will serve us better than others. We now have the opportunity not only to rethink but also to implement and deploy new forms of money without anyone’s permission. Money can now be created electronically by ordinary individuals, not just by banks. And even wildly-unstable digital currencies can capture tremendous interest and enter widespread use.

The central idea motivating PoPCoin is the radical question of whether in focusing single-mindedly on stability, classical economics got its basic priorities wrong? Stability is great when we can get it, but a stable march towards global economic (and environmental) destruction is eventually just as disastrous as an unstable march to the same end. Could we design, implement, and deploy a form of money that instead pursues sustainability and equal opportunity as its primary goals, with stability as a still-desirable but subsidiary objective?

2.2 Towards Sustainable Equal Opportunity in Space and Time

The design space of cryptocurrencies and monetary policies is clearly rich and infinite, so we cannot expect to find any unique or best “Answer” to the above challenge. But could we find some relatively simple monetary policy that plausibly achieves these goals under arguably-realistic assumptions – ideally a policy we can encode into a few simple rules that a cryptocurrency can enforce automatically? Classical economic theory calls for constant guidance from central banks to maintain a semblance of economic stability. Could we find a “hands-free” rule-set with the potential to avoid at least the most destructive instabilities – namely positive feedback loops such as overheating or deflation spirals – while ensuring equal opportunity in some formally definable fashion? In PoPCoin we develop two simple rules that appear particularly promising in combination.

The first rule is that all participants regularly receive an equal supply of newly-minted money as a baseline foundation for economic opportunity, which we refer to as equal opportunity in “space”. This rule relates closely to the increasingly-popular idea of basic income, but expressed in monetary
rather than a purely social policy – a distinction that yields important differences we explore later in section 4. The philosophical grounds for an equal supply of basic income is clearly to support equal opportunity, a justification often de-batably ascribed to John Locke [54,48,60]. Our justification for a regular supply is to ensure that support for equal opportunity remains inclusively available for life in the face of personal losses from risk-taking, accidents, disasters, etc., as discussed further in appendix A.2.

The second and less-precedented rule underlying PoPCoin is that the portion of total money supply distributed equally to all participants must be constant at each distribution, in particular not diminishing with time, summarized as equal opportunity in “time”. Basic income proposals typically rely on a policy decision to choose some “appropriate” value that somehow balances standard-of-living expectations against fiscal budgeting constraints. But the “right” balance between expectations and affordability is infinitely debatable and subject to change frequently with public and government mood. Moreover, any chosen value denominated in an inflationary fiat currency will diminish in real value and effectiveness in time, just as minimum wage protections have eroded [16]. PoPCoin introduces the more radical proposition that we simply peg the value of each distribution to a constant fraction of total money supply, chosen and justified on some less-fluid basis, such as the lifetime an average person has to enjoy or re-invest rewards, as discussed in appendix A.3.

These rules work together toward ensuring that the economic opportunity offered by regular distributions of new money is egalitarian in both “space and time”: i.e., individually between the participants in any given distribution, and collectively between earlier and later distributions. Instead of attempting to support some particular standard of living, PoPCoin attempts to ensure that all money distributions are fair and proportionate: both individually among the participants in today’s distribution, and collectively with respect to the portion of monetary wealth similarly distributed in prior months, years, or generations.

This combination of rules supports economic sustainability in two respects. First, PoPCoin’s first rule ensures that all participants have an equal and inalienable source of debt-free income, which could break the economy’s reliance on constant growth to achieve broad-based increases in living standards as discussed in appendix A.1. Second, PoPCoin’s second rule ensures that one’s opportunities today are not dominated by economic wins and losses of the past, and that inequality cannot increase without bound as we explore later in appendix C. While PoPCoin directly addresses only economic and not environmental sustainability as some proposals do [35], limiting growth dependance and inequality could reduce pressures that often result in environmentally unsustainable practices and policies.

2.3 Time is Money: The Semantic Meaning of a PoPCoin

A unit of fiat currency today generally represents an arbitrary unit of value, whose nominal value has no meaning except in relation to perceived real value and to other currencies as it floats through supply and demand. One dollar
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doesn’t “mean” anything. PoPCoin, in contrast, builds on an idea pioneered by time-based currencies [58,12,42]. Since money is so commonly used to trade peoples’ time in providing labor and services, why not define the a currency’s value in terms of a person’s time? Time is an inherently-stable reference point, whose advance we can quantify precisely in terms of other physical phenomena, as atomic clocks do. Time is also inclusive and democratically egalitarian, in that everyone living inherently receives a constant “supply” of time at the same rate as others – ignoring space travelers at relativistic velocities for now.

Imagine a purely-fictional world in which all people spend eight hours each day supplying services to someone else, eight hours per day consuming the services of others, and eight hours per day sleeping. Further suppose that all work consists solely of unspecialized services that anyone can perform, like sitting with someone to keep them company, so that one hour of anyone’s time is worth exactly as much as an hour of anyone else’s. Then the only need the inhabitants have for “money” is to negotiate which hours each person spends working (and for whom), consuming services (from whom), or sleeping. In this fictional world, one PoPCoin would represent exactly one hour of anyone’s time.

We make no pretence that this fictional world models reality, but treat it merely as an “ideal reference” against which we may treat complex reality as a (large) set of adjustments, the cumulative effects of which we let supply and demand reveal dynamically. Since not everyone’s time is equally valuable, for example, a specialist whose time is five times more sought-after than that of a fully-unspecialized worker would find herself able to charge five PoPCoins per hour, all other factors corresponding to the ideal reference. We similarly expect the trade value of a real PoPCoin to deviate from the ideal for myriad other reasons: e.g., people like to work only five days per week and take holidays; participation changes due to people adopting or leaving PoPCoin; people also use other currencies competing with PoPCoin; investors artificially increase PoPCoin scarcity by HODLing it and thereby keeping it out of commercial circulation; usage changes and shocks in other economically-linked currencies affect PoPCoin indirectly; ad infinitum.

While accepting that reality is fluid and far too complex to analyze all the factors, nevertheless the ambition is that one PoPCoin should always conceptually “mean” something with respect to peoples’ time, should do so equitably, and should mean the same thing in a decade or a century as it does today.

2.4 The PoPCoin Algorithm for Monetary Policy

We can now specify the PoPCoin monetary policy concisely in terms of the pseudocode in algorithm 1. This algorithm is concerned only with what happens at each regular minting, and assumes that wallets and normal trading between

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3 Some time-based currencies ask participants to trade and bank units of time literally, at a fixed “exchange rate” regardless of the service. This approach has unsurprisingly proven most successful in service areas such as child- and elderly-care, where trust and community spirit may readily be seen as more important than specialized skills.
Algorithm 1: Pseudocode representation of PoPCoin monetary policy

| input: $B$, the number of PoPCoins issued to each participant per minting |
| input: $\alpha$, the fraction of total PoPCoin supply redistributed per minting |

$N_0 \leftarrow$ initial number of participants at launch

for $t = 1$ to $\infty$  // one minting per time period

| $N_t \leftarrow$ number of participants at time $t$  // take new participation census |
| scale wallet balances by $N_t/N_{t-1}$  // adjust for participation changes |
| scale wallet balances by $1 - \alpha$  // apply demurrage to existing coins |

| issue each participant $B$ PoPCoins  // distribute new basic income |

end

mintings are handled by standard (e.g., Bitcoin-like) transaction processing. In brief, at each minting the algorithm (a) determines the new number of participants at time $t$, (b) redenominates the currency to account for participation changes, (c) applies demurrage to current balances to keep total supply constant, and (d) issues a constant $B$ new PoPCoins to each participant. We briefly unpack and informally justify each step below.

Because we want one PoPCoin to represent one hour of unspecialized work in the ideal reference world above, and each of the $N_t$ participants at time $t$ have an inherent supply of $B$ work-hours of time per minting period, total PoPCoin supply must depend on – and be proportional to – participation. To account for participation being non-constant in a real permissionless cryptocurrency, algorithm 1 effectively redenominates the currency in step (b) whenever participation changes. That is, the algorithm simply scales all existing wallet balances by the factor $N_t/N_{t-1}$ to convert the last time period’s currency – appropriate for $N_{t-1}$ participants – into a “new currency” appropriate for $N_t$ participants.

To ensure that algorithm 1 can issue each participant a fixed number $B$ of new PoPCoins per minting in step (d), while also ensuring that the total value of all newly-minted currency represents a fixed fraction $\alpha$ of the currency’s total supply as discussed in section 2.2, we must demurrage all existing wallet balances in step (c) by the factor of $1 - \alpha$. This demurrage ensures that total PoPCoin supply at time $t$ asymptotically approaches but never exceeds $BN_t/\alpha$.

Redenominating a conventional currency with printed banknotes is of course an expensive process typically done only rarely after periods of inflation [61]. Demurrage is similarly nontrivial with printed banknotes – a purpose for which Gesell [29] invented the clever idea of stamp scrip, where the holder of a banknote must purchase and periodically affix stamps weekly in order to keep the banknote valid [25,14]. Redenomination and demurrage are straightforward in principle for a Bitcoin-like cryptocurrency, however, where all wallet balances reside on a shared ledger. We may worry that currency users may be confused and concerned on seeing their nominal wallet balances change periodically – but this already happens with conventional bank accounts when maintenance fees are charged, interest is deposited, etc. Further, the implementation-efficiency issue of regularly updating all wallet balances is readily addressed by internally
denominating wallet balances in an inflationary and participation-independent “hidden currency” like PoPlets as discussed in appendix G.

Simplistically assuming one minting per year, we would set $B = 365.25 \times 8 = 2922$ to reflect the ideal reference model above in which one PoPCoin represents eight hours of unspecialized work per day. The fraction of total supply demurred and redistributed at each minting, $\alpha$, is similarly somewhat arbitrary but might reasonably be set to 2%, giving PoPCoin a 50-year “tenure” corresponding to around a modern human working lifespan as discussed in appendix A.3.

### 3 A Basic Model for PoPCoin with Three Principles

We now introduce an economic model built on methods typically used in monetary policy by central banks and other cryptocurrencies. We then express the principles of PoPCoin in this model: fixed basic income, equality over population and equality over total supply. Finally, we derive PoPCoin’s monetary policy from these principles alone and argue that PoPCoin’s monetary policy is both necessary and sufficient to fulfill them.

#### 3.1 Economic Modeling Assumptions

Monetary policies, whether directed by central banks or encoded in cryptocurrency code, are generally built on two methods to control the money supply: adjusting interest rates and directly distributing money. Our economic model incorporates both of these methods. Table 3.1 summarizes the notation we use subsequently throughout this paper.

| Symbol | Meaning |
|--------|---------|
| $M$    | Money supply. |
| $R$ or $r$ | Interest rate. |
| $B$ or $b$ | Basic income expressed in amount of PoPCoin given to each participant. |
| $D_t$ | Amount of total basic income distributed in period of $t$. |
| $x_i$ | Account balance of person $i$, expressed in PoPCoin. |
| $N$ | Population size. |
| $\alpha$ | The ratio of newly issued PoPCoin to total supply. |

Table 1. Notation. The uppercase letters represent macroeconomic variables, whereas the lowercase ones represent microeconomic variables.

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4 More frequent mintings, likely more practical, just require adjusting the constants.

5 Interest-rate driven monetary policy used to be the most effective standard tool used by central banks. As interest rates plummeted to zero, however, central banks have had to adjust money supply more directly, either through quantitative easing or by directly handing “helicopter money” to spenders[19]. Cryptocurrencies like Bitcoin and Ethereum, in contrast, generally do not have the concept of an interest rate: They solely rely on block rewards as their mechanism to inject money and increase the money supply.
On a Micro Level we assume a world with \( N_t \) participants during a time period \( t \), where \( t \in \mathbb{N} \). We denote by \( x^i_t \) the balance at the end of period \( t \) for any participant \( i \), \( i = 1, 2, \ldots, N_t \). Naturally, \( x^i_t \) carries into the next period \( t + 1 \), as savings that potentially yield interest. Our model assumes the interest on savings as part of the income of any participant during each period of time. We further denote by \( r^i_t \) the interest rate on savings of participant \( i \) from period \( t - 1 \).

In addition, a participant \( i \) also generates the following two types of income at the beginning of any time period \( t \): (a) the basic income \( b^i_t \) distributed to each participant, and (b) the earned income, denoted by \( in^i_t \). Participant \( i \)'s balance may accumulate over time, i.e.

\[
x^i_t = x^i_{t-1}(1 + r^i_t) + b^i_t + in^i_t - out^i_t,
\]

where \( out^i_t \) denotes the expenditure of participant \( i \) in period \( t \).

On a Macro Level we assume that both basic income and positive interest income are freshly-minted, i.e. created by the monetary system purely numerically – instead of relying on any social entity such as a government or philanthropist, or by compelling one into debt. These are the only two methods to mint new coins. Similarly, we assume that the negative interest simply “disappears”, which leads to a reduction of the total currency supply. Therefore, the net change of the total supply becomes the sum of all participants’ basic income and interest in the currency:

\[
\sum_{i=1}^{N_t} x^i_t - \sum_{i=1}^{N_t} x^i_{t-1} = \sum_{i=1}^{N_t} x^i_{t-1}r^i_t + \sum_{i=1}^{N_t} b^i_t,
\]

or – on a macro level – we write:

\[
M_t - M_{t-1} = R_t M_{t-1} + D_t,
\]

where \( M_t \) denotes the total supply at the end of period \( t \), and \( D_t \) denotes the sum of total basic income distributed in period \( t \). The aggregate interest rate for all participants, unique in any period \( t \), we denote by \( R_t \).

3.2 The Principles of PoPCoin

The principles of achieving equal opportunity in both “space and time” from section 2.2 define the key policy constraints defining PoPCoin. We therefore abstract these principles into the following three mathematical equations representing PoPCoin’s fundamental principles:

\(^6\) The interest rate can be zero, i.e. no interest; positive, i.e. a currency holder can earn positive capital income from his saving; or negative, i.e. a currency holder needs to pay for keeping his saving. Although it is common to assume for a positive interest rate, a zero or negative rate is not unseen. At the time of writing the central banks of Japan, Denmark, and Switzerland are implementing negative interest rates\([13]\).
(I) The Principle of Fixed Basic Income. Because PoPCoin is a time-based currency, each participant periodically receives the fixed nominal amount $B$ of basic income as introduced in Section 2.4 above,

$$B^i := B^i_{t-1} = B^i_t,$$

where $B^i$ denotes the basic income of participant $i$.

(II) The Principle of Equality over Population. Because basic income is intended to support equal opportunity in PoPCoin, its amount must be the same across all participants. We denote this universal amount as $B$, i.e.,

$$B := B^i = B^j,$$

where $i$ and $j$ denotes two different participants. We therefore obtain the total amount of newly issued PoPCoins as:

$$D_t = N_t B.$$  (3a)

(III) The Principle of Equality over Total Supply. PoPCoin achieves equality across time and generations by setting the total amount of newly issued PoPCoin to be a fixed proportion of the existing PoPCoin supply, i.e.,

$$\frac{D_t}{M_t} = \alpha.$$  (3b)

with $\alpha$ a constant system parameter. Appendix A.3 discusses how we might choose the value of $\alpha$.

3.3 Deriving the PoPCoin Monetary Policy From Its Principles

Adopting all Principles (I)∼(III) uniquely determines the monetary mechanism of PoPCoin; any change to the mechanism would refute at least one of its principles. In the following, we derive the mechanism of PoPCoin step by step from a strawman case with a constant population size and money injected through basic income, but no interest rate, to a simplified scenario that allows for interest rate, and finally to a general situation with varying population size.

Strawman: Fixed Population, Basic Income and Zero Interest. With a fixed number of participants, Principles (I) and (II) set the total basic income distributed in each period to a constant, according to eq. (3a). Under a zero interest rate setting over all time periods like Bitcoin and Ethereum, the total amount of PoPCoins would grow linearly:

$$M_{t-1} + D_t = M_t.$$

This would violate Principle (III), however, in that the issue-to-supply ratio (eq. (3b)) would decrease over time as a result.
Simple Case: PoPCoin with Fixed Population. By this reasoning, with constant participation, Principle (III) can be maintained only under a negative interest rate, i.e. $R_t = -\alpha$.

We substitute $D_t$ in eq. (2) by its form in eq. (3b). Under the negative interest rate $-\alpha$, the total currency supply over time becomes:

$$M_t = M_{t-1}(1 - \alpha) + D_t.$$  

(4)

A negative interest rate or demurrage devalues existing coins gradually over time [50]. In this case, the demurrage rate is exactly $\alpha$.

General Case: PoPCoin with Population Changes. Now consider the general case with population changes. We denote by $n_t$ the population growth rate in period $t$, such that $N_t = (1 + n_t)N_{t-1}$. By eq. (3a), the total amount of newly issued PoPCoin, or $D_t$, grows at the same rate:

$$D_t = D_{t-1}(1 + n_t).$$  

(5)

Solving the system of eq. (2), eq. (3b) and eq. (5) for the interest rate, we obtain $R_t = (1 + n_t)(1 - \alpha) - 1$. Total currency supply now takes the following form:

$$M_t = M_{t-1}(1 + n_t)(1 - \alpha) + D_t.$$  

(6)

This matches our algorithm 1 that existing PoPCoins scaled by the factor of $(1 + n_t)(1 - \alpha)$ with new basic income distributed to every participant.

PoPCoin Supply Grows Proportionally to the Population Size We denote $\mu_t$ as the growth rate of PoPCoin, we have:

$$\mu_t = n_t.$$  

(7)

This equation can be clearly presented from the relationship between the currency supply and the population size, implied by the combination of eq. (3a) and eq. (3b), i.e.,

$$M_t = \frac{1}{\alpha}BN_t,$$  

(8)

and it is not hard to verify that it is consistent with PoPCoin’s monetary policy shown in eq. (6).

4 Preliminary Economic Analysis of PoPCoin

Preliminary analysis of the above model leads us to a number of interesting observations about PoPCoin, as detailed in the appendices and summarized here. These analyses of course make many simplifying assumptions and cannot hope to model all the complex factors relevant in reality, but they allow us to tease apart some broad effects and trends.
**Bounded Inequality.** PoPCoin’s most important property from a sustainability perspective is that it establishes an upper bound on inequality, at least in terms of monetary wealth denominated in PoPCoin. Appendix C shows that after each basic income minting, PoPCoin ensures an upper bound in three inequality metrics: Gini coefficient, variance across all participants’ balances, and ratio between any two balances. Limiting inequality in monetary wealth alone this way would not, of course, necessarily bound inequality in general across all forms of wealth, even in a hypothetical population that used only PoPCoin as money. Nevertheless, to the degree that having access to money with which to engage in commerce and seek to improve one’s fortune is a key element of economic opportunity in practice, PoPCoin might ensure that this social good and driver of opportunity at least cannot become too unevenly divided over time.

**Adoption Incentives.** When participation grows more quickly than the demurrage rate of \( \alpha \), PoPCoin’s monetary policy offers a natural “reward” to early adopters – along with an incentive for early adopters to promote PoPCoin and further increase adoption. Suppose the number of participants doubles in some period \( t \), for example, so \( N_t = 2N_{t-1} \). Then the basic income \( B \) that an early adopter received at time \( t - 1 \) will, after redenomination for the population change in algorithm 1, have a nominal value of \( 2B \) at time \( t \) before demurrage. The early adopter’s saved basic income from time \( t - 1 \), therefore, is effectively worth almost two basic incomes at time \( t \). This does not mean that the real value of these savings necessarily doubles correspondingly, of course. But if the new adopters put the currency in active use and circulation similarly to the existing users, thereby growing the real PoPCoin economy roughly proportionally as well, then the early-adoption reward will also be meaningful in real value.

These effects will naturally create speculation incentives while population and/or currency usage is rapidly evolving. Rational investors who correctly predict at time \( t - 1 \) that participation will double by \( t \), for example, may be willing to buy PoPCoin from other participants at \( t - 1 \) for close to twice what they expect it to be worth at \( t \), precisely to take advantage of the early adopter’s reward. Speculation may well create wild swings in PoPCoin’s trade value, just as with other cryptocurrencies. But recall that PoPCoin’s primary goal is long-term fairness and equitability, with stability only a subsidiary goal, as discussed in section 2.1. As PoPCoin gradually saturates some population of receptive users, the early-adoption reward tapers off and disappears as participation stabilizes, leaving demurrage as an incentive to spend rather than hold PoPCoin. We leave the mathematical definition in appendix B.

**Exchange Rate Analysis.** A preliminary exchange rate analysis in appendix D, both long-run and short-run, indicates that PoPCoin would gradually appreciate with respect to inflationary fiat currencies assuming other factors remain stable. For the long-run analysis, we assume that price is flexible and **Purchasing Power Parity** holds [1]. The short-run analysis yields a similar conclusion, together with the expected **exchange rate overshooting** phenomenon [23], under the assump-
tion that prices are sticky and *Uncovered Interest Parity* holds [39]. In summary, the fact that PoPCoin’s money supply is constant – though continually-renewing via basic income distributions and demurrage – should keep PoPCoin ultimately “anchored” in its relation to time as discussed in section 2.3, as fiat currencies gradually drift via inflation.

**Purchasing Power Analysis.** Appendix E employs classical inflation theory [23] to analyze the purchasing power of PoPCoin. We find that PoPCoin’s purchasing power may be expected to increase in the long run, resulting in deflation, whenever real economic growth exceeds population growth. While deflation is deadly in classical economics, this is because of the dependency of economies on debt-based money creation. Monetary scarcity increases the real interest rates, which disincentivizes borrowing and spending, which makes money even more scarce. We argue in appendix E that because new PoPCoin is created via debt-free basic income rather than loans, deflationary spirals are unlikely to occur PoPCoin even in the presence of deflation.

Our exchange rate and purchasing power analyses are currently based on the assumption that PoPCoin has saturated a fairly large community. We do not expect this assumption to hold in a rapid-growth early phase development of PoPCoin, however. We speculate that as users adopt PoPCoin so that more and more goods and services can be purchased with PoPCoin, its exchange rate and purchasing power with respect to other currencies would increase. We have not yet modeled this scenario, however, a task we leave to future work.

**Speculation and Saving Analysis.** Appendix F analyzes how a rational individual would behave with respect to saving or speculative HODLing of PoPCoin versus spending for productive use. Due to the early adoption reward mechanism discussed above, speculation on PoPCoin is likely to happen in early stages, potentially making the currency unstable but also attracting more users. However, after PoPCoin has successfully saturated its potential user base, speculation is subject to tax via demurrage and therefore is disincentivized. Nevertheless, we find that the rich might still save income to improve utility – thereby paying higher tax rates than the poor – even though a consistent global demurrage rate is applied to everyone. Thus, we by no means expect speculation or savings to disappear even once participation in PoPCoin stabilizes. To the extent it continues, however, all participants are effectively compensated for any resulting instability via the tax-and-redistribution effect of demurrage and basic income.

**Stability versus Equitability.** A central bank’s primary mission is to maintain price stability, traditionally by monitoring real economic indicators and using a variety of policy levers to target about 2% inflation [22,64]. Stablecoins [53,59] are cryptocurrencies that similarly pursue stability, typically by pegging their value to that of a traditional currency – and hence indirectly relying on that currency’s underlying central bank. All of these (direct and indirect) stabiliza-
tion techniques depend on complex economic monitoring and adjustment mechanisms, none of which have yet proven stable in fact over historical periods [70]. PoPCoin follows Bitcoin’s audacity of adopting an “automatic monetary policy based solely in nominal data” [6]. This choice makes PoPCoin’s policy attractively simple, while carrying the immediate implication that – like Bitcoin – we cannot expect PoPCoin to exhibit price stability with respect to real economic activity in the way that central banks and stablecoins aim to.

The dynamic controls that would be necessary for conventional price stability, in fact, appear incompatible with PoPCoin’s mandate of equitability in space and time, at least as modeled above in section 3.2. Adjusting the demurrage rate $\alpha$ to track economic indicators would mean that the aggregate basic incomes distributed at some times must represent a different proportion of total monetary wealth than the aggregate basic incomes distributed at other times, hence potentially eroding one generation’s economic opportunity versus another.

Thus, the choice between price stability and equitability as a currency’s “prime directive” may represent a fundamental and in some sense irreconcilable difference. Nevertheless, an intriguing question for future exploration is whether a currency like PoPCoin might achieve a different form of stability in the long run: e.g., if its user population grows sufficiently large, if that population’s demand for PoPCoin (e.g., the average “basket of goods”) becomes sufficiently stable in a human behavioral sense, and if demurrage limits inequality and dis-incentivizes speculation sufficiently to ensure that PoPCoin’s long-run real value mostly reflects relatively-stable aggregate human behavior of the population and not the speculative sentiments of commercial banks and rich investors. We leave this fascinating question of what “stability” really means for future exploration.

**Migration Incentives.** Finally, while so far only based on informal analysis, we observe certain striking differences between the borderless, permissionless basic income in PoPCoin and a conventional basic income proposal implemented as a fiscal policy in some government jurisdiction. Conventional basic income proposals not only require making difficult choices about what level of basic income is “affordable” balancing standard-of-living expectations against budget constraints, but also can create resistance from the fact that they incentivize to “inward migration” towards jurisdictions that have (larger) basic incomes, potentially exacerbating already-inflamed divisions and “fortress” mentalities. The basic income embodied in PoPCoin, in contrast, promises only equitability rather than any particular standard of living – but also ensures that its reward for participation is borderless and available anywhere PoPCoin can be adopted. Further, because PoPCoin’s basic income will trade at the same value against other currencies anywhere, its purchasing power will be greater in poorer regions with lower cost-of-living. If PoPCoin creates any migration incentives at all, therefore, they will be from richer to poorer jurisdictions, thereby potentially addressing one significant perceptual roadblock to UBI adoption.
5 Related Work

PoPCoin may be considered a digital community currency [50,71], intended as an experimental tool to support commerce and economic empowerment among users who voluntarily opt into using it. Gesell’s demurrage ideas [29] inspired the Wära and Wörgl community currencies during the Great Depression [75, chapter 13] – as well as the WIR in Switzerland [53], which still exists as a commercial barter network. Community currencies in the Wära and Wörgl tradition, inter-enterprise currencies like WIR, and cryptocurrencies like Bitcoin all fit under the broad umbrella of complementary currencies [57], as does PoPCoin as a new democratically-motivated hybrid design point in this space.

Many have observed that time itself can serve as a currency. Time banking was first introduced in Japan by Teruko Mizushima [58], then followed by many time-based currencies globally. While some time currencies such as Time Dollars [12] ask users to trade or bank one hour of anyone’s time at a fixed 1-to-1 “exchange rate”, other time currencies such as Ithaca HOURS account for expertise by explicitly permitting specialists to charge several time-currency HOURS per real hour of their time [31,36,42]. PoPCoin builds on time as an ultimate foundation for semantic meaning and value in a complementary currency, while taking the pragmatism of Ithaca HOURS further by accepting that the trade value of one PoPCoin may freely “float” based not only on specialization but innumerable other adjustment factors as discussed in section 2.3.

Bitcoin inspired many new approaches for implementing digital complementary currencies usable globally via decentralized architectures. Nimes [63,47] attempts to create a decentralized time-based cryptocurrency, for example. Encoiner [9] and GoodDollar [3] are recent cryptocurrencies incorporating UBI principles. Researchers have also analyzed various monetary aspects of cryptocurrencies, such as the implications of Bitcoin [6,51], Proof-of-Stake systems [77,11], stablecoins [53,59], and Central Bank Digital Currencies or CBDCs [28,51,46]. To our knowledge, PoPCoin is the first attempt at designing and economically analyzing a permissionless cryptocurrency motivated foremost around supporting the democratic principle of equal opportunity, overriding even the traditional primary goal of monetary price stability.

Other work has focused on the important challenge of implementing Proof-of-Personhood [7,72]: i.e., a one-per-person notion of stake in a decentralized setting. A key challenge here is addressing the false identity or Sybil attack problem [21]. PoPCoin builds on physical-world pseudonym parties [27], while other approaches build on social trust networks [68], biometrics [32], or government-issued identifiers [55]. While security implementing decentralized proof-of-personhood without compromising privacy remains a critical unsolved problem, it is orthogonal to and out of the scope of this paper.

6 Conclusion

PoPCoin is a cryptocurrency that aims to prototype a more democratic, equitable, and sustainable form of money. PoPCoin introduces three principles
Economic Principles of PoPcoin, a Democratic Time-based Cryptocurrency

to achieve its goals: fixed basic income, equality over population, and equality over total supply. Through regular distribution of freshly-minted coins as basic income to every participant, PoPcoin bounds inequality across the population. Through a small demurrage rate of 2-5% that slowly devalues each coin, PoPcoin controls the money supply and limits the lifetime of money, bounding inequality across generations. Using established economic models, our analyses on inequality, exchange rate, purchasing power, speculation and saving show the potential effectiveness and sustainability of PoPcoin’s monetary policy.

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A Discussion of Design Principles and Justifications

This section discusses further issues and considerations justifying PoPCoin’s design principles, which were omitted from the main paper due to lack of space.

A.1 Debt, economic growth addiction, and free money

It has been said that “gold is the only financial asset that is not someone else’s liability” [20]. In our current banking system based on fiat money, both central and commercial banks can create money by issuing debt. Fiat money thus always represents a liability to someone in the economy. When a central bank expands its balance sheet by purchasing assets such as government bonds or private debts, the resulting money is the central bank’s liability. Commercial banks also create money “out of thin air” by issuing loans [79]. When a commercial bank lends money to a borrower, the bank creates assets and liabilities simultaneously, thereby creating new money, which is a liability of the commercial bank.

Fiat money therefore consists essentially of “IOU’s:” any debt-based dollar existing in the economy implies that someone will have to pay back this dollar, generally with interest, sometime in the future. Because the money needed to pay the compound interest on each loan has not (yet) been created at the time the loan is issued, however, we collectively face a “grow or die” problem: the economy must perpetually grow in order for enough debt-based money to exist in the future for all borrowers to have any chance of paying off all the interest on loans issued now. If the economy fails to grow rapidly enough to cover the compound interest demanded on all existing loans, then some of those loans must default – and in a major financial crisis this often means many loans default [70,34].

At its launch, Bitcoin [62] appeared to create a remarkable new exception to the above rule. “Anyone” could mine new Bitcoin – akin to mining gold – without incurring debt or creating a liability for anyone. It is unclear to what degree this exception to the money-is-debt rule still holds, now that mining is economically infeasible for anyone without access to cheap power and the latest mining hardware, and neither are readily available to newcomers without incurring debt or another form of liability [78]. Nevertheless, Bitcoin was merely the most recent demonstration that it is possible to create debt-free money without incurring a liability on anyone, as Gesell’s “free money” theory had predicted [29] and as partly confirmed in subsequent experiments and analysis [25,38]. Although both Gesell’s stamp scrip and Bitcoin arose from other motivations, breaking the unsustainable cycle of economic “growth addiction” from debt-based money may be one of the most important potentials they demonstrate in principle.

A.2 Why regular distributions instead of one-time “endowments”?

Why should distributions of money to support equal opportunity be regular, and not special “one-time” events for example? As an alternative, Condorcet [15] and Paine [65] proposed in the 1790s a one-time basic endowment at birth or
maturity. Further, real governments have occasionally even implemented one-time, “more-or-less” equal distributions to “more-or-less” all citizens: e.g., in the voucher privatization programs following the collapse of the USSR [8], and more recently in emergency response to COVID-19 [44].

But steady-state economic reality is populated by a mix of people of all ages. People are continually born, coming of age, and dying; people are continually achieving wins and suffering failures and losses. Real innovation requires risk-taking – people need the opportunity to try something, fail, and start over. One-time distributions can be lost through bad investments, personal disasters such as addictions or other medical conditions, displacement and losses from to war or natural disasters, etc. In general, one-time distributions cannot guarantee people, throughout their lives, the power to start over with the same opportunities they had before a loss. This observation leads us to the conclusion that baseline support must be a relatively continuous – or at least periodic – supply made available to all individuals while still living and potentially able to take advantage of it.

A.3 On what basis to choose a reasonable demurrage rate?

An important question is how we might choose the demurrage rate $\alpha$ in PoP-Coin. We might approach this question on either a philosophical basis or one of pragmatic historical experience.

We can find philosophical and moral foundations for demurrage in the fact that many – perhaps most – forms of property ownership throughout history have been time-limited rather than indefinite. Most physical goods and capital have inherent time limits on ownership by virtue of being perishable or wearing out: food, materials, equipment, buildings, even land used unsustainably. Counteracting money’s durability advantage over other goods was a primary motivator for Gesell [29].

For thousands of years, rulers of ancient Mesopotamian civilizations including those of Sumeria, Assyria, and Babylon regularly proclaimed acts of Misharum, cancelling all debts and freeing debt-slaves empire-wide, for economic renewal and protection from encroaching aristocracy [37]. Jewish society encoded such a tradition into its most fundamental laws by requiring a “year of jubilee” every 50 years. Modern intellectual property law confers only limited-time ownership. Shareholder corporations are fairly exceptional in allowing unlimited-time ownership – but there are strong arguments that firm ownership should not be unlimited, as in proposals for stakeholder tenure [76] and other stakeholder governance models [49].

Given this ancient and modern precedent alike, it should not seem radical to view money as a social good that society grants an individual possession of for a reasonable period, but not forever. In a cryptocurrency or smart contract, we could certainly implement money that behaves like “leprechaun gold” by suddenly vanishing after a particular lifetime, though doing so would compromise its fungibility by making a coin’s real value decrease with age [2]. But observe that in a hypothetical steady-state “leprechaun gold” economy a fraction $1/L$ of
all money would vanish and have to be renewed year if each coin lasts for \( L \) years. By eliminating \( 1/L \) of the value of all coins each year via demurrage, instead of eliminating all of the value of \( 1/L \) of the coins each year, we achieve the same aggregate rate of devaluation and renewal while preserving the fungibility of coins. Since \( \alpha = 1/L \) is the demurrage rate, we can consider the reciprocal of the demurrage rate to be the effective lifetime or ownership tenure of the demurred coins, even if they “vanish” only gradually rather than instantly.

But money is a social instrument used by people to reward people for valued goods and services, and the people so rewarded have limited lifespans in which to enjoy (or further invest) those rewards. There is then reasonable grounds to tie the lifetime of such a reward to a time period something like a human generation or working lifespan: because that is the time in which rewards earned early in a person’s life may reasonably be expected to benefit \( \text{them} \) – rather than their heirs or successors – whether through further investment or spending for enjoyment. A reward that lasts significantly longer will primarily benefit the rewarder’s heirs or successors, who will generally have different aptitudes and motivations, and who may be unlikely to produce much (new) value for society from that legacy reward.

From an equal opportunity perspective, it is of course unjust for the children of poor families to have their opportunities dominated and limited by the economic losses or other hardships their ancestors faced. But it is also arguably unjust to the children of rich families to be denied ever knowing how much of whatever wealth they accumulate truly reflects \( \text{their own} \) accomplishments, to be proud of, and how much represents wealth and advantage they inherited purely by luck of birth. Thus, just as with a limited-duration intellectual property right, tying the ownership tenure of demurred money to something comparable a working human lifetime optimizes for conferring most rewards on \( \text{those who earned it} \), while allowing and expecting the descendents of both winners and losers to prove themselves on a “playing field” that is, if not completely level, at least not tilted to an unbounded and continually-growing degree either.

This is at least one philosophical basis for choosing a demurrage rate of, say, somewhere between 2% and 5% per year, corresponding to an ownership tenure period of about a 50-year modern human working lifespan or about a 20-year generation gap, respectively. Gesell’s proposed demurrage rate of 5.2%, though derived from the fact that there are 52 weeks per year, comes out at the upper end of this range. The ancient Mesopotamians, whose rulers most often declared \( \text{Misharum} \) on the ascension of each successive ruler – i.e., about once per generation – might be viewed similarly as precedent for the 5% end of this range, whereas the Jewish tradition’s 50-year jubilee cycle would be precedent for the 2% choice. (Granted, both human generations and lifespans were substantially shorter then so the correspondence is shaky and imprecise.)

The pragmatic historical basis reflects the experience of modern central banks practicing Keynesian economics, in which inflation-targeting serves a purpose closely-related to if not quite identical to Gesell’s demurrage [45]. Experience seems to be that 2% has proven a reasonably safe and effective inflation tar-
get to steer between the risk of deflationary spirals at the lower end, and risk of overheating leading to hyperinflation or bank runs at the upper end \cite{22,64}. There are also arguments for higher inflation targets of around 4\% \cite{5}. Thus, whether based on a fundamental basis of matching ownership tenure to human lifetimes, or based on the pragmatic economic experience of central banks, demurrage rates in the 2–5\% range seem likely reasonable, though there is nothing magical about any particular value.

B Long-Term Assumption and Adoption Incentive

**Long-Term Assumption on Population Changes.** We assume that in the long term, once PoPCoin is widely deployed and adopted within some user population, that population becomes relatively stable. Mathematically, that is, \( \exists \tau \in \mathbb{N}^+ \text{ for } \forall t \geq \tau, \)

\[
\left| \frac{N_t}{N_{t-1}} - 1 \right| \leq \epsilon, \quad \epsilon \approx 0. \tag{9}
\]

In reality, participation in PoPCoin will not be fixed or perhaps even stable, especially in early phases when we would hope to see rapid adoption. In the long term, however, once PoPCoin has saturated whatever population proves amenable to adopting it, we expect participation to stabilize since human population changes slowly compared with most economic effects.

**Adoption Incentive and Long Term Supply Stability.** The dynamic interest rate mechanism creates a potentially strong adoption incentive in early stages, as our previous discussions in section 2 showed that the interest rate \( R_t = (1 + n_t)(1 - \alpha) - 1 \). We illustrate this adoption incentive through an example. Suppose that the number of participants doubles in one period \((n_t = 2)\), for example. The interest rate \( R_t \) would be close to 2, if \( \alpha \) is sufficiently low, implying that the nominal savings of “early adopters” nearly double in just one period. This does not mean that real value necessarily doubles correspondingly, of course. But if the new adopters put the currency in active use and circulation similarly to the existing users, thereby growing the real PoPCoin economy roughly proportionally as well, then the early-adoption reward will also be meaningful in real value.

When PoPCoin successful saturates among all the potential users, with our long-term assumption on population size, the interest rate would drop to nearly zero, i.e., the early-adoption reward tapers off and disappears. Mathematically, a negative interest rates is equivalent to \( \epsilon < \alpha/(1 - \alpha) \) when \( t \geq \tau \).

The long-term stability of PoPCoin supply is a significant distinction from the fiat currencies’ supply, which grows exponentially over time.
C Inequality Analysis

We utilize three different metrics to analyze how the monetary policy of PoPCoin can have effects on inequality among all participants\(^7\). These metrics complement each other, in that some capture aspects overlooked by others. We emphasize that, it is one of the most significant distinct property from current fiat currencies that the design of PoPCoin itself reduces the inequality and brings a theoretical upper bound of inequality.

**Reducing Inequality through Demurrage.** When the number of participants is stable and fixed, after each devaluation of the existing PoPCoins and distribution of basic income to every participant, the inequality level reduces. We first measure inequality by both variance and the Gini coefficient. For the variance, the inequality is strictly reduced, since

\[
\text{Var}(1 - \alpha X + B) = (1 - \alpha)^2 \text{Var}(X) < \text{Var}(X). \tag{10}
\]

In economics, the Gini coefficient aims to measure the inequality level within a group of people. The Gini coefficient \(G\) is defined as half of the relative mean absolute difference of variables, \(i.e.\)

\[
G(X) = \frac{\sum_{i=1}^{N} \sum_{j=1}^{N} |x_i - x_j|}{2N^2 \bar{x}}. \tag{11}
\]

We know from eq. (8) that, when the number of participants is fixed, the PoPCoin supply is fixed as well. Therefore, after the devaluation and distribution of the new PoPCoin, the mean of the participants’ balances remains unchanged. Hence, we obtain

\[
G((1 - \alpha)X + B) = (1 - \alpha)G(X) < G(X). \tag{12}
\]

Therefore, when the population size is stable, the PoPCoin monetary policy reduces inequality measured in both variance and the Gini coefficient.

Next, we analyze the inequality level between any two participants. We use the ratio of their PoPCoin balances to measure the inequality level:

**Definition 1.** For any pair \((i, j)\), \(e_{i,j}\) is the inequality ratio between them, and

\[
e_{i,j} = \begin{cases} 
\frac{x_i}{x_j} & x_i \geq x_j \\
\frac{x_j}{x_i} & x_i < x_j 
\end{cases}
\tag{13}
\]

According to the definition, when \(e_{i,j} = 1\), the two participants have the same amount of PoPCoin balance, and a bigger \(e_{i,j}\) means a higher inequality between the two participants. Without loss of generality, we assume \(x_i \geq x_j\)

\(^7\) For all participants together, we set \(X_t = \{x_i^t\}\), for \(i = 1, 2, \ldots, N_t\).
(otherwise we can switch \( i \) and \( j \)). For any pair \((i, j)\), immediately after the demurrage and new basic income distribution, we have

\[
\frac{(1 - \alpha)x^i + B}{(1 - \alpha)x^j + B} \leq \frac{x^i}{x^j} = e_{i,j}.
\]

Therefore, the inequality ration will not increase after the event, and if \( x^i > x^j \), the inequality is strictly reduced.

**Upper Bound on Inequality.** We analyze the upper bound on inequality in terms of the variance across all participants’ balances, the Gini coefficient, and ratio between any two balances. To have a fixed sample size, we continue to assume the number of participants is stable and fixed. Because we investigate the worst situation, \( X \) can be arbitrary with condition \( x^i > 0 \) for any \( i \) and \( \sum_{i=1}^{n} x^i = M = \frac{1}{\alpha} BN \).

For any distribution of \( X \) satisfying the conditions, the upper bound of variance is

\[
\sup_X \text{Var}((1 - \alpha)X + B) = \left( \frac{1 - \alpha}{\alpha} B \right)^2 (N - 1).
\]

(14)

(Proof in appendix C.1)

A Gini coefficient of one indicates maximal inequality. For large and finite size of participants, where only one person has all the PoPCoins, and all others have none, the Gini coefficient will be nearly one. When the number of participants tends to be infinite, the Gini coefficient will be one. In our case, after the demurrage and distribution event, the Gini coefficient will be very close to \( 1 - \alpha \). Specifically, we have

\[
\lim_{N \to \infty} \sup_X \text{G}((1 - \alpha)X + B) = 1 - \alpha.
\]

(15)

(Proof in appendix C.2)

For the inequality ratio between any two participants, after a devaluation and basic income distribution, we have

\[
\sup_{1 \leq i,j \leq N} e'_{i,j} = \sup_{1 \leq i,j \leq N} \frac{(1 - \alpha)x^i + B}{(1 - \alpha)x^j + B} = \frac{1 - \alpha}{\alpha} N + 1.
\]

(Proof in appendix C.3)
C.1 Proof of Variance Upper Bound

The optimization problem can be written as

\[
\begin{align*}
\text{maximize}_X & \quad \text{Var}((1 - \alpha)X + B) \\
\text{s.t.} & \quad x^i \geq 0, \forall i \in [N] \\
& \quad \sum_{i=1}^N x^i = \frac{1}{\alpha}BN,
\end{align*}
\]

By applying properties of variance, we have

\[
\text{Var}((1 - \alpha)X + B) = (1 - \alpha)^2 \text{Var}(X)
\]

\[
\text{Var}(X) = \frac{1}{N} \sum_{i=1}^N (x^i)^2 - \left( \frac{1}{N} \sum_{i=1}^N x^i \right)^2 = \frac{1}{N} \sum_{i=1}^N (x^i)^2 - \left( \frac{1}{\alpha}B \right)^2
\]

Therefore, the optimization problem is equivalent to

\[
\begin{align*}
\text{maximize}_X & \quad \sum_{i=1}^N (x^i)^2 \\
\text{s.t.} & \quad x^i \geq 0, \forall i \in [N] \\
& \quad \sum_{i=1}^N x^i = \frac{1}{\alpha}BN,
\end{align*}
\]

Since \( \sum_{i=1}^N (x^i)^2 \leq \left( \sum_{i=1}^N x^i \right)^2 = \left( \frac{1}{\alpha}BN \right)^2 \) and the equality is achieved when \( x^i = \frac{1}{\alpha}BN, i \in N \) and \( x^j = 0, \) for all \( j \in N \) and \( j \neq i. \) Substituting the results, we obtain the upper bound is \( \left( \frac{1 - \alpha}{\alpha}B \right)^2 (N - 1). \)

C.2 Proof of Gini Coefficient Upper Bound

We first prove the upper bound with fixed \( N. \) The optimization problem can be written as

\[
\begin{align*}
\text{maximize}_X & \quad \frac{(1 - \alpha) \sum_{i=1}^N \sum_{j=1}^N |x^i - x^j|}{2N^2x} \\
\text{s.t.} & \quad x^i \geq 0, \forall i \in [N] \\
& \quad \sum_{i=1}^N x^i = \frac{1}{\alpha}BN.
\end{align*}
\]
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The denominator is constant with a fixed \( N \) and \( \sum_{i=1}^{N} x^i = \frac{1}{\alpha}BN \). Let us assume that \( x^1 \geq x^2 \geq ... \geq x^{N-1} \geq x^N \), we have

\[
\sum_{i=1}^{N} \sum_{j=1}^{N} |x^i - x^j| \leq 2 \sum_{i=1}^{N} \sum_{j=i+1}^{N} x^i \leq 2(N-1) \sum_{i=1}^{N} x^i = \frac{2(N-1)}{\alpha}BN.
\]

The equality is achieved when \( x^1 = \frac{1}{\alpha}BN \) and \( x^i = 0, 2 \leq i \leq N \). Substituting the results, we obtain the upper bound is \((1 - \alpha)\frac{N-1}{N}BN\). When \( N \) tends to infinity

\[
\lim_{N \to \infty} (1 - \alpha)\frac{N-1}{N} = 1 - \alpha.
\]

C.3 Proof of Ratio Upper Bound

For \( N \geq 2 \), let us assume that \( x^1 \geq x^2 \geq ... \geq x^{N-1} \geq x^N \), we have

\[
\sup_{X, 1 \leq i, j \leq N} \frac{(1 - \alpha)x^i + B}{(1 - \alpha)x^j + B} = \sup_{X} \frac{(1 - \alpha)x^i + B}{(1 - \alpha)x^N + B} \leq \frac{(1 - \alpha)(\frac{1}{\alpha}BN) + B}{B} = \frac{1 - \alpha}{\alpha}N + 1.
\]

The equality is achieved when \( x^1 = \frac{1}{\alpha}BN \) and \( x^i = 0, 2 \leq i \leq N \).

D Exchange Rate Analysis

D.1 Long-run Analysis

First, we focus on formulating the long-term exchange rate of PoPCoin to other fiat currencies. For this purpose, we assume that (a) PoPCoin has successfully saturated a sufficiently large community for general transactions, (b) price is flexible in the long run, and (c) that Purchasing Power Parity (PPP) holds in the long run. We adopt the PPP theory \([1]\) to model PoPCoin’s long-term exchange rate.\(^8\) The PPP theory argues that two currencies are in equilibrium when a basket of goods is priced the same in both currency area, taking into account the exchange rates. Mathematically, the exchange rate can be formulated as a function of several important economic indicators, \(i.e.,\)

\[
E_{p/s} = \frac{P_p}{P_s} = \frac{M_p/M_s}{L_pY_p/L_sY_s}, \quad (18)
\]

\(^8\) Empirical evidence \([23]\) indicates that the exchange rates of several currencies against U.S. dollars have reached their equilibrium, exactly as the PPP theory has predicted.
where $M$, $P$, $Y$ and $L$ denote the currency quantity, the price level, the real income and the liquidity demand of the currency, respectively. The subscript $p$ denotes PoPCoin and $\$\$ denotes the compared fiat currency. $E_{p/\$}$ is the exchange rate between the two currencies. Here we further assume a fixed liquidity demand in the long run analysis and re-denote it by $\bar{L}$.

Money supply for a fiat currency does not have a single “correct” measure. Instead, it has several definitions for various purposes, for different countries or under their accounting rules. This section uses M2 as the supply of fiat currency, including cash, demand deposits, and saving deposits in banks. M2 is usually the key economic indicator forecasting inflation [33].

By contrast, cryptocurrency generally has a clear definition of money supply. Anyone can easily compute the total supply of Bitcoin at any time, for example, based on the block number. In PoPCoin, anyone can trivially calculate the total PoPCoin supply based on eq. (8). The ongoing development of decentralized finance (DeFi) will likely lead to other various definitions of money supply in the future. In any case, cryptocurrency and fiat money have fundamental differences: the cryptocurrency deposit in banks will never be like the cryptocurrency recorded in the decentralized blockchain since there is no central bank or government to bail out the banks.

The trend of money supply for fiat currencies has always been increasing so far. The plot of the USD M2 money stock provided by Federal Reserve Economic Data (FRED), for example, clearly shows this trend. On the other hand, cryptocurrency generally has a clear policy for its supply, maintained by machines enforcing software-encoded rules. It is therefore easy to forecast the future supply of cryptocurrency. This is an important feature as it reduces complexity in predicting the exchange rate of cryptocurrencies relative to a fiat currency.

The PoPCoin exchange rate relative to fiat currencies is formulated as below by transforming eq. (18) into its relative form

$$d_{p/\$,t} = (\mu_{p,t} - \mu_{\$,t}) - (g_{p,t} - g_{\$,t}),$$

where $\mu$ is the growth rate of currency supply, and $g$ is the real income growth rate. This equation formulates the change of the exchange rate $d$ as the difference of currency growth and real income growth in both currency areas. If we assume that both currency areas have the same real income growth, the exchange rate is completely determined by the difference of currency growth.

Recall that eq. (8) states that the only factor dominating the supply of PoPCoin, other than time, is the number of participants or population size. Thus, the growth rate of PoPCoin is the same as population growth rate. If we further assume that the change of population is limited and relatively slow, the supply of PoPCoin will be similarly constant and stable. With the assumption that growth rate is stable in the long run, eq. (19) takes this reduced form:

$$n_{p,t} - \mu_{\$,t} = d_{p/\$,t}$$

[9] https://fred.stlouisfed.org/series/M2
The end result is simple: as long as the population size is stable and the fiat currency supply expands as usual, the long-term level of the exchange rate of PoPCoin relative to inflationary fiat money will always increase over time.

D.2 Short-run Analysis

In this subsection, we briefly demonstrate a model for short-run analysis. We adopt an asset approach to explain the exchange rates in the short run [23]. In this approach, we consider all currencies to be assets, and therefore currency holders could have capital gains on their currencies by participating in a lending market. For PoPCoin, its nominal interest rate depends on two factors: (a) the interest rate from the PoPCoin mechanism and (b) the interest rate from lending. At the end of this subsection, the short-run analysis gives us a guideline on how to reduce fluctuation of the short-run exchange rate.

The short-run analysis relies on the long-run analysis and its assumptions. We further assume that (a) the exchange rate predicted by the long-run analysis is the expected future exchange rate, (b) the price level in the short run is sticky, (c) there is a sound lending market, and (d) the nominal interest rate is flexible and Uncovered Interest Parity (UIP) holds in the short run.

The UIP theory states that the exchange market is in equilibrium when the expected rates of return on each type of currency investment are equal. Mathematically, this can be formulated as

$$i_p = i_s + \frac{E_{p/t}^e - E_{p/t}}{E_{p/t}},$$

(20)

where $i$ denotes the nominal interest rate of the currency, and the superscript $e$ means the expected value in the future. Based on our assumption, the expected exchange rate is from our long-run analysis or

$$E_{p/t}^e = \frac{P_{p/t}^e}{P_{t}^e} = \frac{M_{p}^e/M_{t}^e}{L_{p}^e Y_{p}^e/L_{t}^e Y_{e}^e}.$$  

(21)

In contrast to the long-run analysis, in which we assume that the price level is flexible and prices adjust to bring the market to equilibrium, in the short run we assume price is sticky, and it is the adjustment of nominal interest rates in each currency zone that brings the money supply and money demand into equilibrium. Hence, unlike in the long run, we assume that $L$ is a decreasing function of the nominal interest rate of $i$. Mathematically, for a currency, we have

$$\frac{M}{P} = L(i)Y.$$  

(22)

We now have all the building blocks to predict the exchange rate of PoPCoin in the short run. When PoPCoin has successfully saturated in a community with a stable population size, implying its supply is stable and predictable, with all else equal, a permanent issuance of the compared currency would influence the
exchange rate in both the long run and short run. In the long run, we know that an increase of $M^e_c$ caused by the increase of the currency $c$ leads to the expected exchange rate $E^e_{p/s}$ decreasing. In the short run, as the price level is fixed, according to the eq. (22), its nominal interest rate will decrease. Both effects would lower the spot exchange rate according to the eq. (20).

Denoting the new spot exchange rate as $E^\prime_{p/s}$, it is not hard to prove that $E^\prime_{p/s} < E^e_{p/s}$, a phenomenon that economists refer to as exchange rate overshooting. The analysis tells us that when there is a tendency for more permanent monetary policy shocks, then there will be a tendency for a more volatile exchange rate [23]. This suggests that having a fixed monetary policy as in PoPCoin could potentially help to reduce volatility of the exchange rate.

E Purchasing Power Analysis

We analyze PoPCoin’s purchasing power by formulating its inflation rate. Inflation reduces a currency’s purchasing power as the prices of goods and services increase. This is a long-run analysis based on the assumption made in appendix D.1, and is not necessarily applicable in the short run.

We begin our analysis with the quantity theory inflation equation [23], i.e.,

$$\pi_t = \mu_t - g_t,$$

where $\pi$ is the inflation rate, $\mu$ is the growth rate of the currency supply, and $g$ is the real income growth rate in its currency zone. As we stated earlier, PoPCoin’s nominal growth rate is equal to the growth rate of the population in its currency area. Therefore, we may apply the equation to PoPCoin as

$$\pi_t = n_t - g_t,$$

where $n$ is the population growth rate, $n_t = N_t/N_{t-1} - 1$. This equation simply tells us that, if the population is relatively stable in the long run ($n_t$ is 0 or very close to 0) and the real growth rate is positive, PoPCoin will deflate rather than inflate. With little or no real income growth, the price level denominated in PoPCoin will be stable.

Thus, in contrast with the mainstream tradition of central banks targeting a mild inflation rate [22,64], PoPCoin is deflationary in the long run whenever the economy’s real growth rate exceeds population growth rate. Is this a bug or a feature? In classical economics it would definitely be a bug, due to the risk of deflationary spirals. But would the same risk apply to a PoPCoin economy?

The risk of deflationary spirals. We argue that a classic deflationary spiral is unlikely to occur in PoPCoin, and hence that deflation is not necessarily bad for PoPCoin, because of the way it creates money via basic income rather than debt. This conclusion may be true as well for other cryptocurrencies whose issuance does not rely on debt, such as Bitcoin’s early period before mining became power- and capital-intensive [78].
To understand why, we have to examine how today’s fiat money is “printed”. As we stated earlier in this section, there are many different measures of the currency supply. Why there are so many? One of the reasons is that not only central banks can “print” money, but also commercial banks can “print” money [79,56]. More specifically, monetary base (MB) is created or directly controlled by the central bank, while M2 includes the money created by commercial banks.

How is money created and distributed? In cryptocurrency, this creation is simply written in its code. For instance, Bitcoin is created whenever a new block is mined, and the newly issued bitcoins are distributed to the miner of the block, while PoPCoins are created regularly and distributed to every participant equally. In the fiat money system, no one solves mathematical puzzles, nor does everyone receive an equal portion of newly created currency. How does it work in fiat currency? A simple and infeasible solution is to give the newly created money to the government directly. However, this power is so easy to be abused and nowadays the majority of countries have more or less independent central banks making sure that newly created currency will not directly put into the government’s account.

The real “secret” is that today’s fiat money is based on credit. Money is created whenever an entity borrows money from commercial banks or central banks. This entity could be a government that wants to fund its deficit, an individual who takes a mortgage, or even a bank (including the central bank) itself which creates money from the thin air by borrowing money to itself to fund its purchase. Meanwhile, when the borrower repays, the principal of loans is destroyed [52]. This implies that the key distinction from cryptocurrency is that cryptocurrency lending does not create new money in general.

How does the mechanism of fiat money creation relate to deflation? Here we adopt an analysis by Fisher in 1911 [4] to illustrate the deflationary spiral and to argue why PoPCoin and cryptocurrency do not suffer from it. We begin the spiral by a fall of the price level or deflation. This causes the rise of the real interest rate, increasing the cost of borrowing. This urges borrowers to reduce their demand for loans, causing the money supply to fall. All else being equal, reduced currency supply means price level will decrease even further, and therefore a deflationary spiral has formed.

In contrast to fiat money, however, PoPCoin is not based on credit. A fall in the price level does not influence the PoPCoin supply, because new money is injected constantly via debt-free basic income rather than through loans. Although deflationary spirals are a major risk for fiat currencies, therefore, we have substantial reason to believe that PoPCoin and other non-debt-based currencies could substantially mitigate this risk.

F Speculation and Saving Analysis

As with other cryptocurrencies, speculative investment is likely to happen in PoPCoin. This may cause unpredictable exchange rate swings in the short run, as in today’s market for unpegged cryptocurrencies. Is this a bug or a feature?
We reiterate that in PoPCoin, price stability is not the primary goal but only a secondary goal subsidiary to long-term fairness and equity, as discussed in section 2.1. Thus, while stability would be nice to have if and when we can get it, we are willing to live with some instability – especially short-term instability – if doing so helps us reach the currency’s long-term monetary policy objectives.

To analyze susceptibility to speculation, it is useful to distinguish between three situations that might prevail with respect to the participating user population: rapid growth, stability, or rapid degrowth.

**Early-adoption rewards dominant during rapid growth.** First consider the situation in which participation in PoPCoin is growing rapidly, as might occur in an early phase if it achieves a critical mass of interest to drive rapid adoption as happened to Bitcoin in its early years. In such a phase, speculative investment is encouraged by PoPCoin’s “early-adopter’s” reward mechanism as described in appendix B. With belief that more participants will adopt PoPCoin scheme in the future, current participants can expect a positive reward and gain more PoPCoin from HODLing than spending it. With this adoption incentive, people may be more willing to adopt PoPCoin, and to convince others to adopt it as well, which may be exactly what is desired in such an early phase. Because the early-adopter’s reward tapers off to nothing as participation growth slows or eventually stops, however, this reward mechanism – and the speculative swings and bubbles it might contribute to – should be temporary and self-limiting.

**HODLing tax during periods of population stability.** Once an early rapid-growth phase stabilizes and PoPCoin has saturated whatever community is amenable to adopting it, we expect PoPCoin’s demurrage to take over eventually and disincentivize too much speculation by effectively “taxing” it.

We utilize the model and assumptions in appendix D.2 to illustrate the influence of speculative investment in the short run on its exchange rate to other currencies. We model the HODLing consequence as a temporary shock of reducing the PoPCoin supply, assuming all other exogenous variables remain unchanged and fixed. As eq. (22) showed, the nominal interest rate would increase caused by the temporary shock to PoPCoin. As the expected future PoPCoin supply remains fixed, eq. (20) shows that the spot exchange rate of $E_{p/s}$ decreases, leading to the appreciation of PoPCoin.

While the appreciation of PoPCoin benefits the PoPCoin community members who purchase goods and services denominated in other currencies, speculators need to pay the tax – i.e., the demurrage fee – under the assumption that the population size of the PoPCoin community is reasonably stable. Therefore, speculating on PoPCoin is discouraged after a rapid-growth phase stabilizes. However, if we consider the utility of a rational participant, we obtain a different result: A rational participant might be willing to pay a demurrage fee for keeping his PoPCoin to maximize his utility as a whole.
Rational Saving and Proportional Tax. A rational participant with prefect foresight may save his PoPCoin for the future, even though PoPCoins are subject to lose their value by demurrage mechanism. We prove that the PoPCoin mechanism can automatically distinguish rich and poor and apply different proportional tax rates of their saving, even though everyone is subject to the same global interest rate.

A rational participant may save some of his income by reducing the consumption today to increase the consumption in the future, even when the saving is subject to lose some of its value by demurrage. Let us consider a simple world, where agents with prefect foresight who can only live for two periods, of which he is young in the first period and old in the second period. The agents are able to have earned income apart from basic income $B$ when young, and only basic income when old. We use $in^i_t$ to denote the earned income of the agent $i$ at period $t$ and $out^i_t$ to represent his expenditure at period of $t$. Therefore, at the end of period 1, his balance is

$$x^i_1 = B + in^i_1 - out^i_1.$$  \hspace{1cm} (23)

His balance in period is subject to change by a factor of $R_2$ (the global interest rate at period 2) due to the mechanisms of demurrage and early adoption reward. Hence, at the end of period 2, his balance is

$$x^i_2 = x^i_1 (1 + R_2) + B - out^i_2.$$  \hspace{1cm} (24)

Because the agent knows that he can only live for two periods, it is rational for him to spend all his PoPCoin before the end of period two. Therefore, we have

$$x^i_2 = 0.$$  \hspace{1cm} (25)

By combining eq. (23), eq. (24) and eq. (25), we can derive his budget constraint as

$$out^i_1 = (B + in^i_1 - out^i_1)(1 + R_2) + B.$$  \hspace{1cm} (26)

The problem he is facing is to maximize utility of consumption in real term. Suppose that the utility is give by $\left(\frac{out^i_1}{P_1}\right)^{1/2} + \left(\frac{out^i_2}{P_2}\right)^{1/2}$, we can find the utility as the following function of $out^i_1$:

$$\left(\frac{out^i_1}{P_1}\right)^{1/2} + \left(\frac{(B + in^i_1 - out^i_1)(1 + R_2) + B}{P_2}\right)^{1/2}.$$  \hspace{1cm} (27)

We can find the maximum value by differentiating this function with respect to $out^i_1$, and set the derivative equal to zero. The utility function achieves maximum value when

$$out^i_1 = \frac{(1 + R_2)(B + in^i_1) + B}{(1 + R_2)^2 \frac{P_1}{P_2} + (1 + R_2)}.$$  \hspace{1cm} (28)
In order to better understand this formula, let us consider some special cases. For simplicity, we assume that $P_1 = P_2$. For an agent with zero earned income, his consumption is equal to $B/(1 + R_2)$ in the first period. When $R_2 = 0$, his consumption is equal to his basic income i.e. he will consume all of his income in the first period. If $R_2 > 0$, he can improve his utility by consuming less than his basic income in the first period, so that he can receive the extra reward in the second period. If $R_2 < 0$, the best option for him is to consume more than his income. However, if borrowing is not possible for him, the best decision is to consume all his basic income.

Now, let us consider the opposite situation. This time, we assume an agent belonging to the high-income group, in which they are able to have super high earned income in the first period i.e. $\Delta i_1 \gg B$. From eq. (28), his first period consumption is approximate equal to $\Delta i_1/(2 + R_2)$. When $R_2 = 0$, he is about to save half of his income, and when $R_2 > 0$, he is going to save even more to enjoy the reward. If $R_2 < 0$, although his saving is decreased, it is still rational for him to save a significant amount of PoPCoin, so that he can improve his consumption in the second period, even if the savings are subject to lose some of their value.

Therefore, if we consider utility, a participant may rationally save some of his income so that he can increase his utility as a whole. Hence, the rich pay higher tax rates than the poor, even they are subject to the same global demurrage rate. PoPCoin therefore automatically distinguishes the rich and poor and charges different tax rates according to their income level.

The risk of rapid degrowth. We may worry that there is a risk that if participation in PoPCoin ever starts decreasing, this could lead to a different form of positive feedback loop or “death spiral” due to the effect opposite that of the early adopter’s reward above. That is, if participation is decreasing, a basic income acquired at time $t-1$ will tend to be worth less if it is saved until time $t$. Would this trigger more participants to leave the system, increasing the rate of participation degrowth, and so on? While this is an issue worth considering, it seems unlikely to be a major problem for one simple reason: basic income is free to all participants. So even if participation drops for whatever reason and the remaining participants suffer an “early adopter’s penalty”, all those remaining participants, if rational, still gain more by continuing to participate than by dropping out and giving up their basic income. For this reason, the main risk we perceive to PoPCoin collapsing is not through a participation death spiral but through other reasons, such as because interest and economic activity using PoPCoin becomes too weak and people stop using it simply because it is not useful or valuable enough to be worth the effort to participate.
Algorithm 2: Pseudocode implementation of PoPCoin with PoPlet

| input: $B$, the number of PoPCoins issued to each participant per minting |
| input: $\alpha$, the fraction of total PoPCoin supply redistributed per minting |
| $N_0 \leftarrow$ initial number of participants at launch |
| $E \leftarrow$ a constant // initialize the exchange rate |
| for $t = 1$ to $\infty$ // one minting per time period |
| $N_t \leftarrow$ number of participants at time $t$ // take new participation census |
| $E \leftarrow E(1 - \alpha)N_t/N_{t-1}$ // update the exchange rate |
| issue each participant $B/E$ PoPlets // distribute new basic income |

G PoPlets: an Internal Microcurrency to Avoid Wallet Redenomination

PoPCoin’s definition and monetary policy as defined by algorithm 1 has the technical drawback that all wallet balances on the ledger – not just the one wallet per participant that receives new basic income – must be adjusted for participation changes and demurrage in each period.

For implementation convenience and efficiency, we may prefer an alternative method of enforcing PoPCoin’s monetary policy without affecting the nominal values of all wallet balances at each minting. We can achieve this goal by introducing a closely-related currency we will call PoPlet, which has a time-varying exchange rate with PoPCoin. The exchange rate is maintained by software, so PoPCoin’s users do not need to be aware of the existence of PoPlets.

In Bitcoin, the Satoshi represents the smallest atomic unit of Bitcoin that can be transferred. Similar to the Satoshi, the PoPlet is the indivisible atomic unit in PoPCoin. Unlike Bitcoin, whose “exchange rate” between Satoshi and Bitcoin is constant, we adopt a time-varying exchange rate between PoPlet and PoPCoin, so that we do not need to update wallet balances at mintings. The re-basing mechanism is achieved by changing the exchange rate between PoPlet and PoPCoin, as demonstrated in algorithm 2. In short, PoPlet is an inflationary but participation-independent currency, which can always be converted to or from PoPCoin by adjusting for current participation and inflation incurred thus far.