The Compto Open Money Protocol (COMP)

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Abstract - Money is a database for transporting value across time and space. Like any technology, the arc of history shows a march towards more efficient systems of money – new replaces old as value transport efficiency rises. Today, the modern global world strains against the limitations of the nationally issued fiat system, which has given rise to a great menagerie of cryptocurrencies. Cryptocurrencies remain a mockery of economists, as their deep disregard for the other utility requirements of a currency overshadows their decentralization advantage. This paper presents the first digital currency capable of replacing fiat issued currency. A foundational cross-examination of economics and physics reveals computation to be the critical missing link. A Compto credit's value derives from the universal value of energy through computation. Further, a novel economic control system is presented which engineers superior price stability. A byproduct of the control system is the first credibly global monetary universal basic income. This paper presents the economic engineering of the Compto Open Money Protocol.

Contents

1. Motivation

In 1914, Britain joined WWI, funded by an initial round of £350 million in war bonds on a banking system which held less than £38 million in gold reserves. News reports celebrated the British patriotism for the oversubscribed war bonds [1]. Only in the past few years, researchers discovered that the war bonds were not the huge success that was reported. Instead, the Bank of England had fraudulently bankrolled the bonds itself, covering it up by extension of credit to its chief and deputy cashiers and mislabeling the debt. A secret letter by John Maynard Keynes, written in 1915 and uncovered over a century later in 2017, commended the central bankers for the move, calling it "a masterly manipulation" [2]. While some remnants of the gold standard remained for decades, fraudulent debasement during WWI was the beginning of the end. In the time between when his words were written and when they were made public Keynes' ideas swelled into Keynesian Economics, the basis for modern economic policy of every major government on Earth. Without the burden of a hard asset peg like gold, governments became free to engineer money at scale.

Tyranny is prevented and society flourishes when a government (the institution with monopoly on violence) properly fears its citizens and must answer to them for its actions. Fiat money breaks that link between spending and accountability that was normally filled through taxes and loans. A government can spend trillions fighting a perpetual war in the Middle East with minimal political repercussions. A government can ravage its neighbor with war, all while deferring the cost (and the ensuing protests) until long after the killing has run its course. The funding of war must stop not when the treasury vaults run dry, but rather only when the nation has hyperinflated its currency, having exhausted the entire liquid wealth of its citizens without the need to levy a penny in taxes. Even the most malevolent dictator who is required to fund his wars with taxes or debt is limited by his ability to coerce cooperation from his citizens to collect, or market his ability to repay to lenders. The power retained by governments over the supply of money carries grave danger to peace on earth.

And yet… to date, government issued fiat is still the best money ever created in human history. Central banks have leveraged their money-printing power to react to market forces and manufacture a semblance of price stability while simultaneously providing the monetary room for incredible economic growth. This is genuinely a great benefit to society!

Currency is an engineering problem as much as it is a social construct. We have iterated on money from shells to coins to gold backed paper to paper and digital fiat, each improving on the last. Today, an industry of cryptocurrency builders have promised the next evolution in money. Yet on the basis of what gives a currency its fundamental utility value… on the basis of what made fiat a better money than gold, and gold better than shells, none so far have presented even a remotely viable alternative. This paper hopes to present the first cryptocurrency worthy of succeeding fiat.

2. Introduction

We start by building a baseline definition for money from first principles. We derive some fundamental qualitative metrics, which we establish as the basic structure for analysis. We then examine the state-of-the-art of money systems across the three existing major categories: fiat, commodity, and cryptocurrencies. Finally, we propose Compto as a new money system which draws from the advantages of all three. We provide details on its critical functional mechanisms and its potential to outperform the existing systems along the fundamental metrics defined.

2.1 Currency Fundamentals

Mainstream economic doctrine typically describes money as serving three utilities: a medium of exchange, a unit of account, and a store of value; sometimes a fourth utility as a standard of deferred payment is added [3]. However, we view these categories as merely more tangible expressions of the more fundamental utility of value transportation. Like goods loaded on a truck, value is transferred from one medium into money for the purposes of transport and eventual unloading into some other medium. Money is a database for the transportation of value across time and space. The goal of a money system is to preserve as much of the original value through this multistep process as possible.

Goods and services are sold at one location and bought at another; they are purchased one day and sold the next. Like all other forms of transportation, nonzero cost is incurred in the form of efficiency losses. Similar to losses suffered by physical vehicles (air resistance, rolling resistance, engine efficiency), the total transportation cost of money is a sum of many factors that can only approach zero asymptotically. To maximize efficiency, the sum total of a money system's costs must be minimized.

Consider the universe of all possible transactions, which span diverse origin and destination locations (and implicitly their disparate jurisdictions) and variety of timescales. For any given transaction there exists a best currency which incurs the lowest transportation cost from one time and place to another. More realistically, an acquired currency must satisfy a statistical distribution of possible future destination times, places, and quantities that is unknowable at time of acquisition. We will give a brief overview of the kinds of losses currencies may incur, using the typical Econ 101 textbook utilities as categories.

2.1.1 Medium of exchange

A currency may be easier to counterfeit or clip, like gold, causing greater breakage on average. Transfer fees can dominate the exchange cost for a currency like bitcoin due to its limited transaction bandwidth. Cash must be carried and counted by hand, which takes time and effort. Transactions have settling times. Fees are paid to credit card companies and other payment processors. Exchange of electronic USD requires a bank which must pay staff to maintain compliance with volumes of regulation.

Any currency without wide adoption also suffers from a huge discovery cost for exchange. This is because a buyer cannot rely on a rare currency since the difficulty of finding a seller who accepts said currency is so great. In the market for a particular good, the subset of sellers who accept the rare currency are unlikely to have the best price compared to the superset of all sellers. Considering this dynamic, widely adopted currencies benefit from a network effect relative to less adopted currencies.

2.1.2 Unit of account

When the value of the currency changes, merchants incur menu costs for repricing their goods/services according to the new currency value. This can take the form of physically reprinting menus, or less obvious social costs that come when an employee must demand a pay raise or renegotiate a contract. In addition to the tangible economic costs, society suffers when people incur a mental burden to relearn their intuition of how much a dollar is worth. Our collective available mental cycles are precious and finite, and their dedication towards recalibration of our mental model of what things "should cost" is a tragic waste. While everyone suffers, the least literate and most vulnerable in society suffer disproportionately from these shifts. As nominal values drift, comparisons across time become more complicated, as they require continuous adjustment from "nominal" to "real" currency values. And those "real" currency numbers cannot themselves be unchanging. (An

American today would find difficulty understanding the implications of “real” value calculations that are based on, say, 1960 dollars).

As with exchange, accounting costs fall as currency adoption rises. Menus priced in a certain currency only pay dividends to the merchant from customers who use that currency as a basis for a purchase decision. Financial records denominated in an uncommon currency will constantly face currency conversion issues. Consumers also need years of regular usage to develop a working intuition around a currency’s value. The most efficient currency should not change in value over time, to avoid repricing costs.

2.1.3 Store of value.

We consider currency’s role as a store of value and its role as a standard of deferred payment to be two sides of the same coin, which is value transportation across time. Just as value is transported forward through time by holding currency, value can be transported backward through time in the form of currency denominated debt. Because the ability to take on debt is critical in an economy, efficient transportation of value across time is just as important in reverse through time as it is forward. A currency with persistent price inflation fails to effectively transport forward, as the future money can purchase less real goods than the present money. But also a currency with a fixed supply, which deflates in the face of a growing economy, fails to efficiently transport value backward in time as the debt becomes more massive. Both represent a cost, driving high inefficiency and low utility. A volatile currency causes both holders and debtors to suffer losses unpredictably, which undermines a money system’s performance against the metric of value preservation. To efficiently store both positive and negative value, the value of currency must remain stable across time.

The efficiency of a currency’s three utilities derives from its transactability and its value stability. These are the criteria against which we can evaluate disparate money system designs.

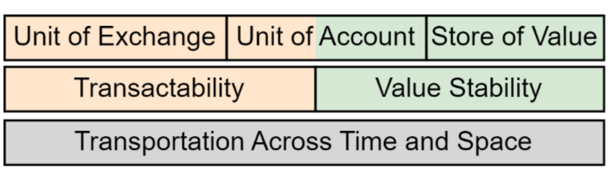

Figure 1. The layers of currency utility

3. The Case Against the Status Quo

Economists and historians have written thousands of pages covering the many historical and societal factors that have influenced the evolution of money. Any attempt to capture those nuances sits well beyond the scope of this paper. We instead use the first-principles of money as a benchmark to examine the practical design of currencies. Primary focus will be on the gold standard as a surrogate for metallist currencies, USD as representative of fiat, and bitcoin as the primary cryptocurrency.

In ancient times "functional goods", like flint, spears, cowry shells, salt... became widely used as currency because they were easier than goods like cattle or barley to exchange – their value density provided convenience in transactability, and their practical utility provided confidence in value stability [4]. As society grows and progresses in complexity, the original utility value of any one or a few commodity goods becomes comparatively irrelevant, overshadowed by its utility as a currency. And any increase in the variety of goods used as currencies would constitute a digression towards a barter system. As a currency, the uniform quantifiability of gold, silver, and other metals as stamped coins served as a basis for reliable accounting, improving transactability. Their rust-free durability did retain value, but metal coinage also suffered from debasement. Thanks to these advantages, metallism dominated for thousands of years [5]. Metallism fractured during WWI [6], and finally broke under the Nixon Shock August 15th, 1971 [7]. Despite its thousands of years track record, modern economic consensus denounces metallism (such as the gold standard) as categorically inferior to pure fiat money. Gold simply could not be pulled from the ground in enough quantities to supply an ever-growing global economy [8]. We agree with the consensus conclusion but believe gold’s failure is best understood using classical control theory, which will be discussed later.

3.1 Fiat and the Distribution Problem

A growing economy demands an ever-increasing supply of currency. It is necessary that this new currency has a pathway for entrance into an economy. Historically this was not orchestrated by grand design, instead the practical realities of how new currency was created naturally flowed into its distribution. In a precious metal based system, the miners who bore the extraction cost earned claim over any expansion of the supply. Whereas in a fiat system, the issuing government distributes new currency as it sees fit. The government either funds its own operation through debt monetization, or effectively distributes new money to banks through interest payments, asset purchases, and by allowing banks to hold partial reserves. We observe fatal problems with these distribution strategies.

3.1.1 Interest Rate Manipulation

Keynesian economics dominates today’s monetary establishment for good reason. Because fiat money is not burdened by any connection to physical goods, issuing central banks may exert unilateral control over their currency. The core Keynesian principle used by central banks is one of stimulating or suppressing aggregate demand. They use this typically with the worthy goals of price stability and maximum employment. Citizens benefit massively when central banks intervene to engineer price stability. This reduces the time transportation losses and therefore improves currency efficiency and directly addresses one of our core tenets of an efficient currency. Sadly, central banks intentionally compromise optimality along this metric by targeting an above zero inflation rate. They do this to preserve their ability to also influence employment [9]. During times of economic disruption, rather than let the free markets organically reallocate labor, central banks act to speed up the process with demand-inducing policies.

Central banks distort the time value of money higher to suppress aggregate demand. The central bank offered interest rate acts as a hurdle rate which new investments must clear. This necessarily, and by design, crowds out investments that would have otherwise happened. The investments most affected are those that produce assets which are highly durable, with a highly predictable but comparatively low rate of return. Infrastructure and home building are examples which are disproportionately impacted. Over the long term, the societal benefits of increased investment in these areas are undeniable, and yet increased investment is rendered unprofitable due to the central bank's distortion. Real returns for non-investment crowd out those investments which generate real returns as a consequence of successfully providing real value to society. When distorted returns on currency crowds out real-life investment, society suffers.

When central banks want to stimulate demand, they artificially suppress the time value of money. This is accomplished through negative real interest rates and is the reason for inflation targeting policy. The central bank punishes the risk averse by erosion of their purchasing power. offering 0% interest while the currency devalues. By degrading the currencies usefulness as a long-term saving device, the central bank induces investment. The US Health Savings Account system provides an example that lays bare these deficiencies. Despite savings being its explicit purpose, it has transformed into a Frankenstein part savings account, part 401k-style investment account [11].

If long-term savings were viable, they could act as important shock absorbers for a stable economy. In today's system, where savings are investments, an expectation of recession lowers expectations of profit, which in turn lowers asset prices. When these asset prices are effectively the basis of savings, the saver is caught off guard. The safety net that they had counted on vanished. This shock is damaging to the psyche but economically it manifests as a reduction of consumption that becomes a self-fulfilling recessionary cycle. Because of the cost to hold uninvested cash, only large insurers like Berkshire Hathaway can afford to keep money on the sideline waiting for an opportunistic buying opportunity. This dynamic is self-defeating. It acts against the very economic stability that the fiat system was designed to induce. When currency is incapable of transportation far into the future, society suffers.

The Keynesian system relies on economic rationality. It relies on people rapidly changing their behavior in response to its manipulation. Bankers, employers, and other sophisticated actors adapt and thrive. Those who fail to adapt are economically punished. Inevitably, it is the least financially sophisticated in society who fail to adapt and suffer the punishment under Keynesian currency manipulation.

3.1.2 Bank Runs

Central banks also allow private banks to increase the money supply. Banks accomplish this by loaning out more money than are held as deposits, creating new money in the process. (A fact that is likely to horrify the average person but is routine for economists and bankers). This fundamentally introduces the risk of bank runs, which has in turn given rise to an evolving mosaic of rules, hefty regulatory oversight burden, and corresponding enforcement. These are immensely costly, prone to failure, and even when fully functional only serve to minimize, not eliminate, the bank-run risk. Governments insure some deposits to mitigate the risk, but they cannot fully insure all deposits, or even most, (and indeed no government does) because of the moral hazard it creates for bankers to take outsized risk. When new money is created by private banks, bank runs become an ever-present danger, and regulations become an ever-present cost.

3.1.3 Debt Monetization

When governments use new money to fund their operating expenses, they do so in lieu of collecting taxes or attracting creditors for sovereign debt. The fiat system allows governments to bypass the critical stabilizing effect provided by these latter two methods. The risk of default on debt becomes irrelevant because the government may simply choose to grant itself the currency required to extinguish all debt. Typically, governments prefer instead to use their central bank to purchase their own debt and manipulate its interest rates. The addition of a central bank with its separate balance sheet provides a level of indirection which adds a sense of legitimacy. But central banks are arms of the state. They are not and cannot be truly independent. Analysis which accounts for the impossibility of a truly independent central bank shows debt monetization as identical to direct currency grants. Central banks transfer default risk from the government's balance sheet and transform it into inflation risk for the currency it manages. In doing so, the existential risk is deferred. The national currency acts like a natural resource that can be drawn upon in times of need, such as during a recession or war. Indeed in a perfect world with wise allocation that fuels economic growth, the natural resource could be drawn upon in moderation indefinitely.

A default on sovereign debt would certainly destroy the country's credit rating and cause meaningful economic disruption. A lack of credit would force government outlays to stay within the bounds of tax receipts which would force spending reductions. The consequences of default, however, pale to insignificance relative to the devastating effects of hyperinflation [12].

The failure mode for fiat currency is the joint loss of public confidence and of the government's ability to control its currency value and interest rates. This manifests in the currency as hyperinflation. Public confidence exhibits strong bank-run-like positive feedback dynamics. The person left holding currency or treasuries in a hyperinflationary environment loses everything. The securities and currency become worthless. Early escape is rewarded. It is a well-documented engineering phenomena that positive feedback systems are inherently unstable and unpredictable [13]. Because positive feedback loops are so unpredictable, the near-term benefit of government funding through money supply expansion therefore carries a longer-term economic cost that is unknowable and unquantifiable… like drawing down a well of unknown depth.

3.1.4 Social Power Dynamics

This dynamic is exacerbated by the fundamental social dynamics of government. The institution of government as the canonical social power structure inherently exhibits competitive dynamics. Power is limited, so naturally people and factions jockey and compete for that power. Because no man rules alone, power is delegated into hierarchical social structures [14]. The loyalty of key supporters must be won, rewarded, and maintained by those in power who depend on them. Furthermore, in the struggle for power competition rewards the resourceful. Those who fail to use every possible resource to purchase loyalty from key constituents will find their support, and their accompanying power, usurped by those that do not share the same reservations. By definition, the most successful will wield the greatest power.

These are fundamental laws of competition. The actions of competitors can be generalized as inputs to a reward optimization function for power. Consider two groups: those willing to draw down the well to optimize their power, and those who are unwilling. The set of all actions available to the former is a superset of the latter. The superset is guaranteed to contain the subset's most optimal actions, but the extra degree of freedom presents new possible actions that could (and are likely to) produce a solution that is unbeatable by the subset. Any one individual may be unlikely to exploit this option. But over many competitors, many years, and many iterations, the person or group more willing to exploit fiat currency creation for political gain will be victors, elevated to the greatest positions of power.

Today's Keynesian economic system is an instance of the resource curse (paradox of plenty). Governments and politicians are waking up to the fact that they can fund operations and reward their supporters not through taxes, but through monetized debt. The nation's future currency stability is traded away for an upper hand in today's political battle. As discovered by Hungary, Zimbabwe, Venezuela, and countless other countries eventually the point of no return is hit and the well runs dry, leading to hyperinflation and utter economic collapse [15]. In the hands of a government which possesses complete restraint against abuse of absolute monetary power, fiat money could be the perfect currency. Because no democracy or dictatorship on planet Earth has Satoshi Nakamoto level restraint, the fiat system's existence is unstable in the long term.

3.1.5 Geopolitical Risk

Since the beginning of international trade, the world has had a "reserve currency" that dominates and facilitates that trade… the Florentine Florin, The Dutch Guilder, the Pound Sterling, etc., now the US Dollar [16]. This should not be surprising since international trade suffers from the same incidence-of-wants problem as local trade. A system in which every country trades with their own currency is just a larger scale barter system. And the barter system is unworkable, so a reserve currency emerges. This requires governments and international traders to hold a currency that is managed by a foreign government. The currency inherently carries a myriad of risks which stem from foreign government control. The currency holder or their country may fall out of favor with said government for any number of reasons. They may be excommunicated from the rails of international trade or find their assets to be frozen or seized. The foreign government may also simply choose to devalue the international currency to further their national objectives. These are real risks that have materialized time and again through history and that reduce the utility of a fiat currency.

3.2 Commodities and the Feedback Loop Problem

A growing global economy collectively demands greater quantities of currency. So over time, the total value of currency must also grow to accommodate the new demand. Since each unit of currency should not change in value, but the total value must grow, it is the number of units of currency that must increase. To keep prices stable, (and thus currency's value transportation efficiency high), the money supply must grow a goldilocks amount to meet global demand, not too much and not too little.

A naïve algorithm might specify increases the money supply at a fixed percentage or fixed quantity per year, perhaps tied to historical global GDP growth rates. Unfortunately, the global economy does not always grow at a reliable fixed rate. So such a solution fails to accommodate a booming economy and devalues itself in a stagnant or shrinking economy. Errors compound and dislocation between money demand and supply can become severe over time, causing price instability and loss of currency effectiveness. Because economic activity cannot be forecasted with any reasonable accuracy any effective currency therefore requires a feedback system. Some system must exist which ties money supply quantities in some way to the broader economy. Effective currencies need dynamic feedback-based control.

A feedback controls system, also called a closed-loop control system, consists of: (1) A dynamical system. (2) An observable process variable. (3) An actuating element capable of influencing the dynamical system. (4) An entity which measures the difference between the process variable and some set point, then (5) reacts with the actuating element with intent to reduce the difference between the measured process variable and the set point. (6) The measurement and resulting action occurs repeatedly. If the action tends to reduce the error, the result is a stabilizing negative feedback loop. If the action reinforces the error, the result is a positive feedback loop which is unstable.

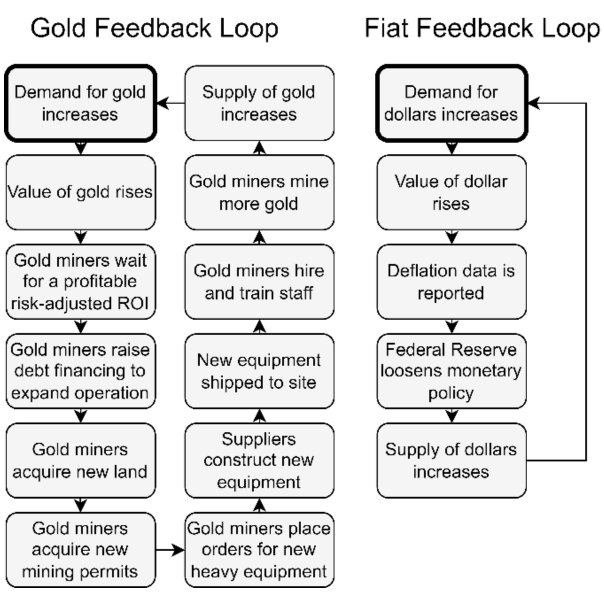

Figure 2. Comparison of the market response mechanisms of gold and government issued fiat.

Both gold and fiat are economic implementations of closed loop control systems. The United States Government measures inflation and employment and acts on the US dollar via the Federal Reserve balance sheet, and gold mining firms observe the price of gold and act on the supply of gold via mining equipment. Consider the two feedback loops in Fig. 2:

3.3 Gold (and other commodities)

Gold as a currency suffers from many issues (counterfeiting, theft, debasement, clipping, transportation, and storage to name a few). These are significant issues primarily surrounding transactability which are well documented and will not be fully explored here. Rather we focus on a key issue regarding money supply and price stability.

Gold supply expansion relies on the ability for the mining industry to react to market dynamics by scaling up or down heavy mining activities. Gold mining operations are complicated. Huge initial fixed-cost capital investment is combined with a significant lagging time cost. (It takes 5-10 years minimum to bring new production online [17]). These factors compound so that miners require a very high expected return-on-investment. Gold prices must rise and stay elevated *high enough for long enough* to justify investment. Initial steps towards capacity expansion can begin only after this hurdle is cleared. In contrast to gold, the feedback loop of the US dollar relies on the Federal Reserve's ability to enact monetary policy in response to market research, which can operate on the order of months.

The massive time gap between when the price of gold rises and when gold from new production capacity begins to hit the market is the control system's loop delay. Gold's years long loop delay imposes hard limits on the maximum performance of its closed loop transfer function. In classic PID control terms, loop delay directly impedes the proportional "P" component's ability to react instantly to the system error. The ideal proportional response is instantaneous, but in real-world systems the proportional response is divided over the lag time. The lag time is the sum of practical limitations of the measurement system (measurement channel delay) and practical limitations on the speed of the actuation system (actuation channel delay). This lag bleeds the proportional component into the integrating component as the final actuation effect is gradually achieved over a length of time. This causes a near-integrating PID response which gives minimal internal feedback. The time delay causes a lag dominant response characterized by larger, higher amplitude oscillations [18]. By definition, no reactive dampening can occur faster than the loop delay. Some amount of measurement channel delay affects the Federal Reserve's response as they wait to act on market data. However, a massive multi-year actuation channel delay dominates the gold industry's market driven response.

This limitation on gold's money supply expansion likely worsened and spread the Great Depression across the world [19]. A central bank's power to rapidly adjust the money supply at-will tightens the feedback loop approximately two orders of magnitude from many years to a couple months. The volatility reduction predicted by this control system model is observed in Fig. 3. It shows 130 years of commodity currency with 0% average inflation but high volatility (6.2% std. dev.), compared to the last 50 years of fiat currency with 4% average inflation and less than half the volatility (2.9% std. dev.). Inflation notwithstanding, the practical societal benefits of such a large reduction in currency volatility cannot be understated.

Furthermore, because competition pushes marginal commodity profits towards zero, the value of new money is roughly equivalent to the size of the mining industry. The economy's incremental cost for one unit of money supply expansion is approximately one unit. This is extremely costly, especially when compared to fiat whose cost to produce an incremental unit of money is close to zero. Before an economy can benefit from the expanded supply, it must first bear the expense of its production. This is incredibly expensive and starves the economy of the currency growth it needs. Gold (and all metallism in general) suffers fundamentally from weak and slow control mechanisms, causing poor performance on the critical metric of price stability.

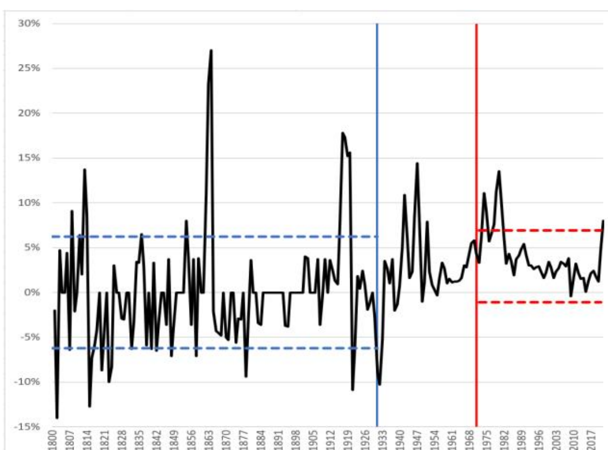

Figure 3. U.S. Annual Consumer Price Inflation, 1800 to 2022. Comparison of gold-standard vs fiat. [20]

3.4 Cryptocurrencies

Where gold and fiat have fallen short, many have turned to cryptocurrencies as the solution. Thousands of projects exist, but none so far offer stable value, or transactability that supports a global throughput – our two cornerstones of what makes a currency valuable. Now consider the feedback loop of bitcoin.

No mechanism exists to separate the speculation about the future of the currency as a whole from the individual unit value of a bitcoin. This leads to complete failure in price stability. Any cryptocurrency that fails to provide a feedback mechanism for stable value also fails to provide a competitive utility as money. A currency with a stabilization mechanism is the only viable currency. Unfortunately today's assortment of misnamed "stablecoins" also fail by this metric.

The first question for a stablecoin is… stable to what? Almost all stablecoins are pegged one-to-one to an existing fiat currency. Thus the stablecoins are only "stable" because they are compared to the gross volatility of the broader cryptocurrency ecosystem. They piggyback off the stabilizing actions of the central banks, but fail to offer any advantage or protection from price instability in the fiat system. When political leaders print money in excess of the market demand and cause inflation, stablecoin holders foot their share of the bill. Algorithmic stablecoins suffer from death spirals. Collateralized stablecoins become undercollateralized when the market outgrows the value of the collateral, which puts hard limits on scalability. Stablecoins attempting to target a basket of goods like the CPI-U must rely on manipulatable and error prone reporting by institutions with no guarantee of surviving in perpetuity, a shaky foundation for a global currency. To date, stablecoins exist in name only.

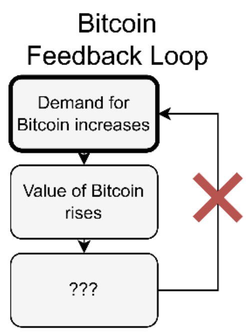

Figure 4. Bitcoin has no mechanism to respond to market disturbances.

4. A More Perfect Money System

So we begin to construct the foundational elements of our new currency by examining perhaps the most core element of currency – value. Value is an amorphous concept, one which does not lend itself naturally or inherently to abstraction and tokenization. And yet, the perfect currency must tokenize this abstract concept of value into something tangible, something real. It is therefore necessary to begin with a thesis for value, for how it is derived, and how it is conferred upon objects, so that a proper abstraction can be built.

The concept of value has been notoriously elusive for economists and philosophers to nail down. As an example of the challenge, consider a deli that can produce a sandwich for $5 then sell it for $10. The customers love the sandwich so much that they would have willingly paid $20. What was the value of the sandwich? The $5 it cost to produce, the $10 market price, the $20 customer benefit, or something else? Karl Marx famously attempted to tackle this problem by distinguishing between a measurable exchange-value and an unmeasurable use-value of goods [21]. Michael Heinrich criticized Marx and emphasized instead a monetary theory of value [22]. Physiocrats believe value is derived from land [23]. In contrast there is the classical labor theory of value [24], there is Léon Walras's marginalism [25], Nitzan and Bichler's power theory of value [26], etc. For practical purposes, most economists simply collapse the concept down to simply exchange price, as other definitions of value do not lend themselves to quantifiability.

It is our view that all these theories make a similar mistake. Value should instead be thought of as a many dimensional vector space, with each dimension corresponding to a unique human's subjective judgement of worth. Many factors feed a unique human's judgement of worth, including their social and physical environment, their life experiences, brain chemistry, etc. Such a model tackles the above deli problem by describing the sandwich as having not one value or even a handful of values but as many different values as there are people to value it. And these values are subject to change with each passing moment as people and their environments change. Consider the classic diamond-water paradox [27]. Such a model of value allows that the glass of water simultaneously possesses a very small value for most people who have abundance and incredible value to the desert islander who needs it for survival. Similarly, the diamond is valued highly by the nobility who otherwise have their basic needs met and is simultaneously worthless to the desert islander. Debate arises only by first misunderstanding the irreducibly high dimensionality of value.

This high dimensionality cannot be reduced because one cannot possibly model the uncountable complexity of unique human experiences, environments, and histories. Creators of models like those mentioned above develop, iterate, and argue over models which attempt to simplify value… which attempt to reduce value to a singular dimension. Like the projection of a 3-dimensional surface onto two dimensions, the result is inevitably distorted. When economists argue over whose distortion is superior it is akin to mapmakers arguing whether the Earth is best represented with a stereographic or a Mercator projection. 2D projections have their place, but all are inferior distortions relative to a 3-dimensional globe.

In addition to the dimensionality, our irreducible vector space model rejects the idea that value is native to, or derivable from, our physical environment. The consequence is that, while physical quantities such as length or mass and can be easily defined and measured with arbitrary unit vectors, no such arbitrary unit vector for value exists. Put another way, there exists no object in the universe which can be measured and found to have a defined quantity of value that transcends time and exists outside the subjectivity of human emotion.

4.1 Currency: The Information Bridge

Yet, humans cannot think or communicate using many dimensional vector spaces, so the need to abstract, the need to collapse to a single unit value, persists. Despite their flaws, many such systems have served this need to varying degrees of success, which we discussed above. An object of arbitrary value can serve as a basis by which trades are conducted. But those who have the object cannot have so much of it that it becomes worthless. Likewise if supply were exhausted such that most people have none, its utility as a currency is diminished and a new object to facilitate trade must replace it. The ability for the object to facilitate trade is therefore only accomplished through a delicate balance of scarcity and abundance.

The collapse of the vector space is accomplished not through the presence of some ideal currency, rather through the act of trade itself. The trade, which depends on currency, causes a redistribution of all types of goods away from those who value them disproportionately little to those who value them highly. While the value vector space persists, the allocation of goods normalizes across a more shared singular vector of prices. Currency can therefore be thought of as an information layer, which collapses the high dimensionality of value. Currency bridges the information world of values and the physical world of goods and services.

4.2 Energy: The Physical Bridge

> *"In this cosmically uniform, common energy-value system for all humanity, costing will be expressed in kilowatt-hours, watt-hours, and wattseconds of work."*
> - R. Buckminster Fuller, "The Critcal Path" (1982)

Just as currency is an information layer that links economic value to the real world, there exists a parallel fundamental physical layer spanning economics and the physical universe – Energy. Energy is wealth. We become richer as our ability to produce and consume energy grows. With enough energy, humanity is capable of literally turning dirt into gold. But our streets are not paved with gold because we have better ways to improve our lives with that energy. That energy powers air conditioners, planes, washing machines, microwaves, cellphones, data centers, smelting plants. Bicycles become motorcycles become sedans become jets become spaceships – each consuming more energy than the last.

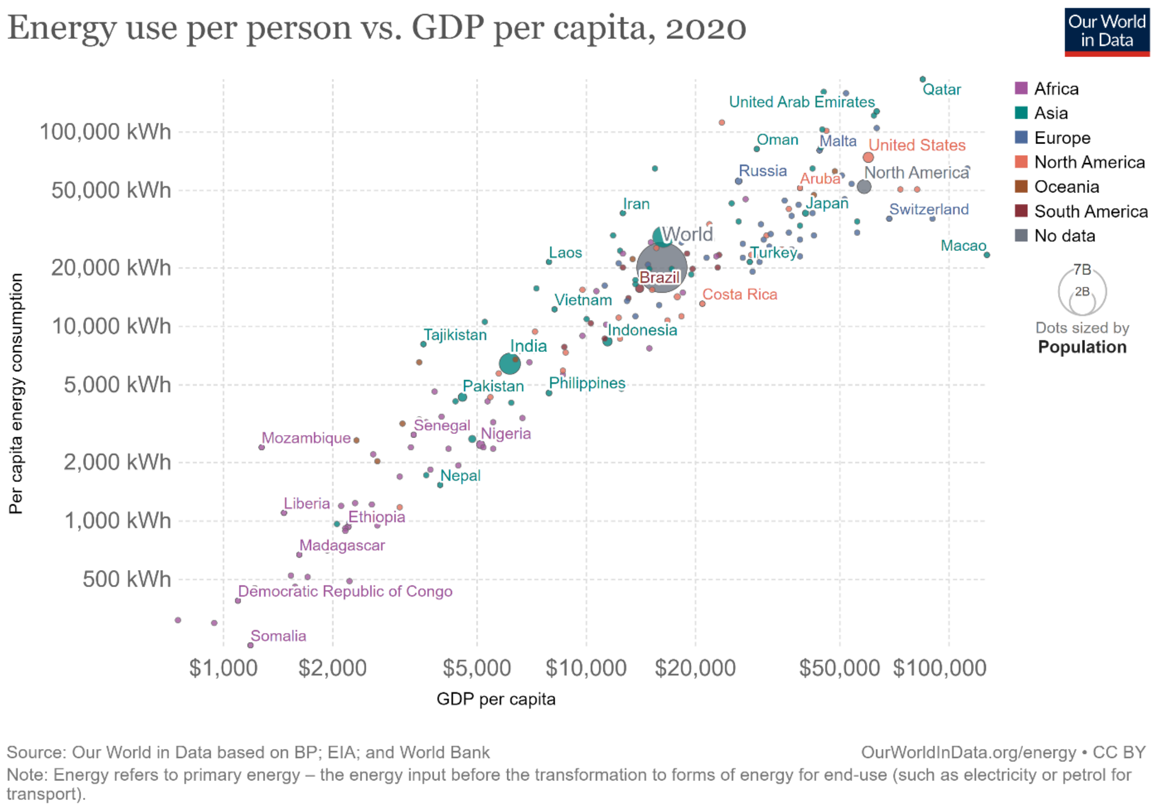

Figure 5. Energy use growth proportional to GDP growth.

One cannot pave a dirt road unless one can supply the 11.4 Terajoules that are needed [28]. Whether energy consumption produces wealth, or wealth produces energy consumption is a question left to the reader. Fig. 5 shows the undeniable link.

The idea of a currency based on energy is not new. Henry Ford proposed an energy currency system in a 1921 New-York Tribune article “Ford Would Replace Gold With Energy Currency and Stop Wars” [29]. Many others have mused on the concept, but to date no complete, viable implementation has yet been proposed.

In a world with energy as currency, one could imagine using batteries as wallets. Unfortunately, a cellphone battery contains ~15 watt-hours, an amount of energy worth less than $0.01 USD. Sadly, physically transported energy currency in the form of battery wallets is infeasible. Several systems have been proposed in which an institution could regulate the world's energy [30][31]. The global institution could distribute kilowatt-hour vouchers and require electric power generators accept the vouchers. Unfortunately, the complexity of the regulatory burden and spatial and temporal electricity price volatility make this solution equally infeasible. Any attempt to universally regulate and meter a phenomenon as fundamental to our universe as energy generation and consumption is certainly a foolhardy endeavor. Any functional energy currency must instead be as decentralized and as fundamentally grounded in physics as energy itself.

4.3 Computation: The Missing Link

The above two bridges even when taken together are useless. Currency cannot serve its information theoretic purpose without physical instantiation, and energy itself is not a usable currency. The final bridge is computation. A non-zero amount of energy must be consumed for any computation. This is shown empirically and also theoretically according to Landauer’s principle [32]. Additionally, irreducible computation produces output in the form of information. Computation therefore transforms energy into information. But not all information produced is viable as currency. Through careful selection of the algorithm and its inputs, the computation’s resultant information can meet the necessary criteria for use as a unit of currency. In doing so, the bridge is completed not just between energy and information but between economic value and the real world.

It is the act of computing that allows energy to become usable as currency. The delicate balance of scarcity and abundance is accomplished. Scarcity arises through the ubiquitous value of energy, through the uncountably many alternative ways a unit of energy may improve our lives. Abundance arises through the fundamentality of energy in the universe. Wherever the sun shines, wherever there is nuclear bonds, there is energy also.

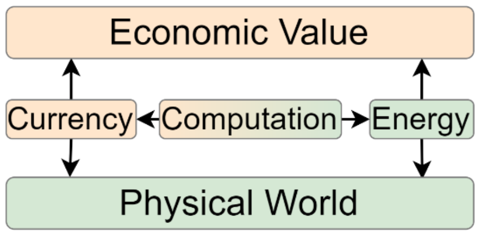

Figure 6. The three bridges.

4.4 Implementation

This paper proposes an algorithm which defines a computation of irreducible complexity, whose input includes a public key uniquely identifying the owner and an ephemeral value. The algorithm must output a solution that is verifiable, unpredictable, and collision resistant. These factors ensure that each unique solution in existence identifies a corresponding unique completed run of the algorithm (and therefore expenditure of energy). The algorithm must be difficult enough to cause consumption of a meaningful amount of energy over the course of the computation. Because the algorithm takes unique identification as input and is collision resistant, each solution is sufficiently unique and attributable to a unique identity.

A set of protocols are then defined to:

(1) Record and report newly minted currency.
(2) Multiply and distribute new currency.
(3) safely record transactions and transfer currency from one identity to another.

The group of mining and transfer protocols are collectively called Compto Open Money Protocol (COMP).

5 Control System Design

New currency is produced when energy is consumed in computation. The value of each unit of currency is tied to the cost required to produce a new unit of currency. Unique solutions derive their value from the guaranteed real cost required to compute a new equivalent unique solution.

With this mechanism those who wish to gain currency are presented with a choice. They may buy currency from existing owners at the market price, or they may mine new currency by performing the necessary computation. This choice serves as the foundation for a market-driven price stability mechanism. At scale, market participants will buy incremental currency if the spot price is below their mining cost (driven primarily by electricity prices), and they will mine new currency as long as it remains profitable.

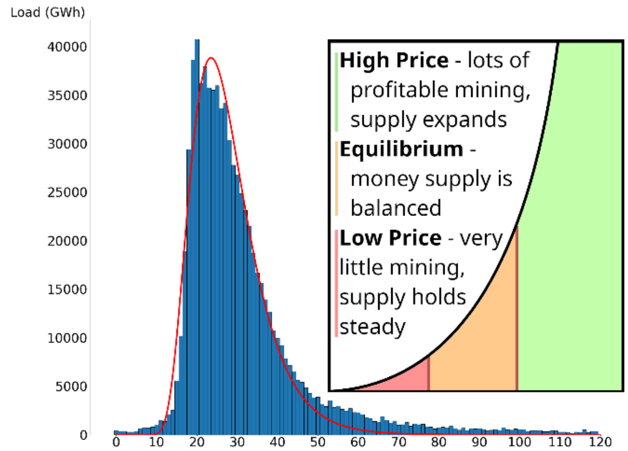

Figure 7. scaled lognormal distribution overlaid on PJM 2018 wholesale electricity prices. [33]

As economic growth causes demand for currency to outstrip the current supply, deflationary pressure pushes energy prices down and mining profitability up. We find the quantity of electricity produced for a given wholesale price to approximate a steep lognormal distribution (Fig. 7), so small movement in the spot price of energy translates to massive swings in the quantity of energy available for profitable mining. The spot price climbs the curve, causing more mining and more currency to enter the economy, pushing the price back down. The reverse is also true that falling currency value can place the spot price of energy low enough that an insignificant portion of energy can be profitably mined, effectively fixing the currency supply. The combination of supply expansion during deflation and stagnant supply during inflation completes the first component of the feedback cycle.

5.1 Solving Control Problems

Unfortunately, the mere existence of a negative feedback control system does not guarantee that the process will be controlled. The above approach can reduce loop delay but by itself suffers from control action saturation and a system natural frequency that is too low. The market mechanism instead serves as the foundation.

5.1.1 Control Action Saturation

Control elements of closed loop systems exert a control action on the process variable to reduce error. Undersized control elements can fail to overcome a growing error, leading to runaway instability and system failure. Real world limits exist on the speed and scale at which energy can be turned into currency. For estimation, we assume that the global energy industry costs $4.5T USD/year [34], total money supply of all currencies is $82T USD [35], global GDP increases 2-4%/year avg [36], and money supply grows at a similar rate. At global scale this implies $1.6T-3.3T USD worth of yearly global money growth. Assuming 1$ of energy spent yields 1$

money supply expansion, this would constitute 36%-73% of global energy production. Such an expense is both infeasible and wasteful. Just like the gold industry before it, the control element of energy would be grossly undersized compared to the world's currency needs. Changes to the algorithm difficulty to produce more units of currency per kWh spent would only serve to lower the market spot price while leaving the control problem unchanged. An alternate mechanism of distribution is also required.

5.1.2 Natural Frequency

A purely proportional money multiplier through alternate distribution (new money not awarded to miners) could prevent saturation of the control action. But a proportional multiplier also fails to react strongly enough to changes in demand, resulting in unacceptably low price stability. This effect can primarily be attributed to the fact that the mining control action acts upon the rate of new supply production, rather than the total money supply. Total supply instead is the result of integrating the rate of new supply production over time.

Compto's new currency distribution is instead based on the derivative of the mining rate over time. With distribution being the primary contributor of new currency, the integrating process described above and this new differentiating process cancel each other out. The result is total Compto credit *supply* proportionally approximates the Compto mining *rate*.

Because distributed currency cannot be clawed back (in cases of falling mining rates), a high-water-mark for mining rate is established. The high-water-mark sets a hurdle that, when crossed, triggers distribution of new money above and beyond what is introduced by mining alone. This distribution corresponds with a resetting of the high-water-mark equal to the new higher mining rate.

Because differentiation acts as a high-pass filter, the system is susceptible to high-frequency noise amplification. Single points of high mining rate could distort supply higher than desired. To solve for this, a form on low pass filter is applied, which places a limit on the amount of new supply that may be distributed on a given day. The practical implementation is discussed in section 6.1.

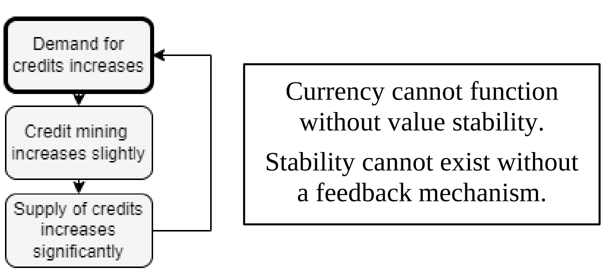

Figure 8. Compto improves responsiveness.

5.1.3 Control Loop Delay

As discussed in section 3.2, loop delays kill feedback mechanisms as the intended response is instead integrated over the delay period. Central Banks were able to tighten the price stability feedback loop delay from years to months, which improved price stability compared to precious metal commodities. Compto energy credits retain the commodity price fundamentals of a precious metal system, while simultaneously further shrinking control loop delay to just 24 hours.

5.2 Control System Modeling

We modeled both the naïve proportional based system and the improved derivative based distribution system (Fig. 9). Any such model of course cannot hope to capture the complexity of the global economic system. This model intends to demonstrate the strength of the derivative-based control system for money supply expansion. The following is a non-exhaustive list of various assumptions and simplifications used in the model:

(1) A homogeneous miner set is defined, who all share a common profit maximization function.
(2) Miners' energy cost distribution is proportional to the lognormal energy price distribution (Fig. 7).
(3) Miners expand operations instantly when profits exceed their IRR hurdle rate.
(4) Miners IRR hurdle rate is defined by 18% required annual return over 10 years on an initial capital investment equal to 2 years of future revenues, and an operating cost equal to energy consumption.
(5) Miners halt operations when their operating cost exceeds revenue.
(6) The rate of currency value change is according to effective supply (that is: currency value times quantity) divided by (a set quantity of) currency demand, divided over 30 days.
(7) Currency value is also disturbed by a daily random walk within +/-0.1%

As demonstrated in the model, when mining is below the high-water-mark, the derivative distribution model prevents significant money supply growth. And when mining climbs above the high-water-mark, supply expands significantly. The combination of these effects results in a strong feedback-driven clamp which holds prices steady in both high and low/no growth scenarios. In contrast, proportional distribution tends towards equilibrium, but weakly, and in a way that is inflexible towards different conditions. Derivative distribution experienced a ~5% variance in price peak to trough between the no-growth and very-high-growth scenarios. In contrast, proportional distribution swung from a +15% price increase over the initial condition to a drop of over 20%, failing each of the tests.

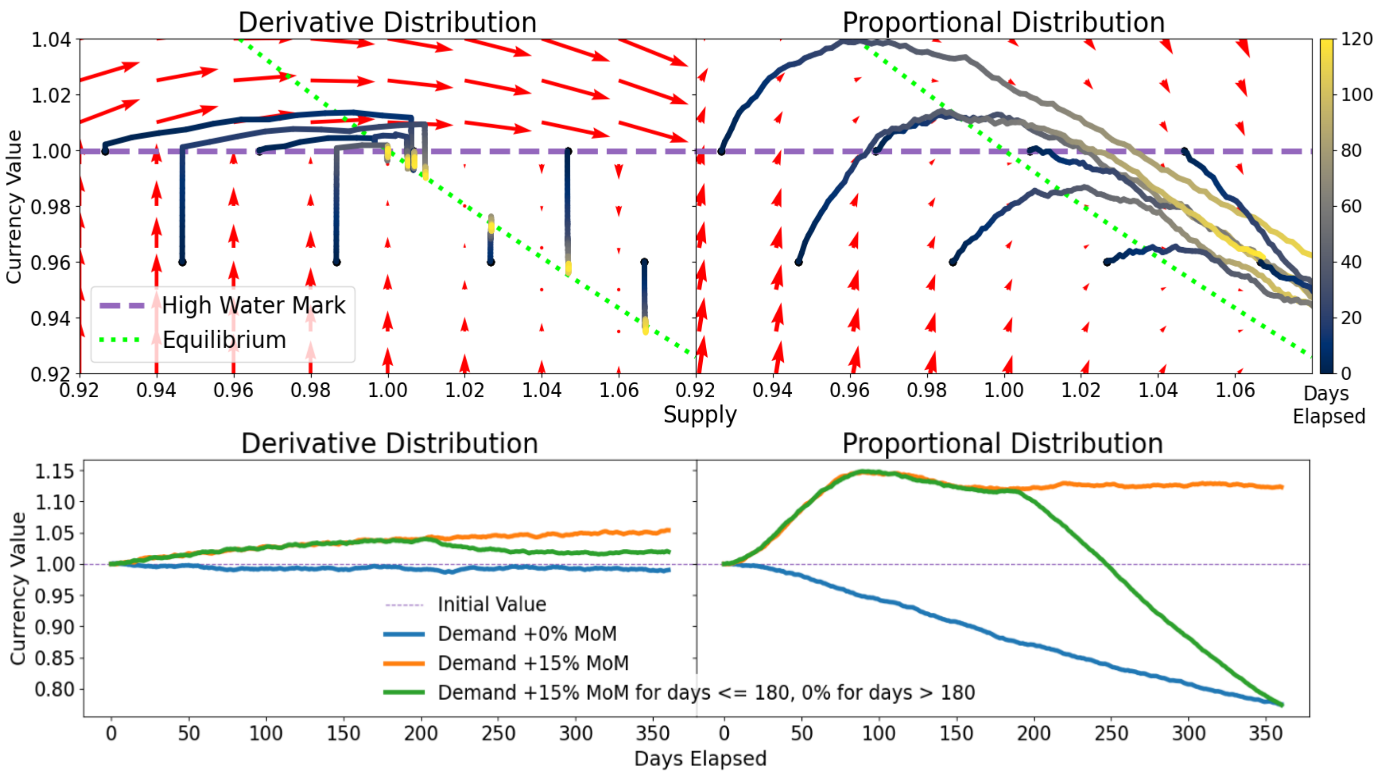

Figure 9. (top) vector field and several computed paths towards equilibrium across currency value and supply vector space. (bottom) currency value movement over 1 year with in static and high-growth demand scenarios.

6. Compto Energy Credits in the Real World

The energy and computational foundation of Compto, when taken alone, could be considered a moderate improvement over other commodity currencies. However, this algorithmic control system layer augments the proposed system, imbuing it with stability and scalability. Together, the transformed system becomes a powerful currency, one which is worthy of competing for adoption, one which is free of political and geopolitical meddling, one which can facilitate the prosperity of all nations and unite all economies.

6.1 Distribution

Currency that is produced but not awarded to miners must find an alternative route into the economy. The traditional fiat method of government control results in corruption, abuse, and power centralization. The traditional commodity method of miner rewards is woefully undersized for the modern economy, the traditional cryptocurrency method is self-serving and Ponzi-like. A new method of distribution must be defined, one which divides as fairly and as broadly as possible.

According to classical economic doctrine, economic growth derives from land, labor, and capital. One could then imagine a perfect system which distributes new currency across each of these factors according to their precise relative economic contributions. Such a perfect system is not implementable. Compto's practical distribution model excludes both land and non-currency capital as a factor of production, deeming it infeasible to quantify land and physical capital productivity and ownership on a global scale.

New currency is instead distributed evenly between currency and labor. Currency which is distributed evenly according to existing currency functions as, and indeed can be likened to interest payments, a familiar financial construct. Half of all distributed currency takes the form of these interest payments, despite the fact that currency itself certainly contributes less than half of total factor productivity. The relative overweighting of currency as a factor of production serves to counteract any inflationary forces of expected incremental computational efficiency gains.

The other half is evenly distributed among all living humans. In doing so, labor is properly respected as a core pillar of value creation. As such, it is more fairly compensated for its contribution to improvements in the overall economic prosperity that demands greater quantities of currency. This is now possible thanks to the proof-of-unique-human infrastructure developed by WorldCoin [37]. These distributions, as a path for money supply growth, constitute the first ever credible implementation of global universal basic income. We acknowledge that not all humans contribute equally to economic growth, but contend that a distribution mechanism equally weighted for all humans is both practical, and likely to achieve more prosperous outcomes at global scale than existing fiat distribution.

The exact quantity of distribution necessary is a balancing act. The existing state-of-the-art for control system engineering still often resembles trial-and-error, which is not feasible on an economic scale. Instead, we must select a multiplier appropriately scales the mining industry in a hypothetical "One Global Currency" outcome. The industry must be sufficiently small so as not to crowd out other productive electricity usage, while also sufficiently large that it can effectively translate global economic forces into a price signal for money.

We consider 5% of the energy industry as the maximum upper bound for mining activities. We then calculate an absolute upper bound for the Compto mining industry and total Compto energy credit supply. We simplify the assumptions by focusing only distribution, which far exceeds currency production from direct mining activity. This simplification guarantees that the estimate will overestimate mining activity, which pairs nicely with the upper bound target above.

In today's $USD we estimate a total world money supply to be ~$80T, with an yearly energy industry of ~$4T. Combined with the 5% above, we get two factors of 20, and a factor of 365 to scale mining activity from a yearly to a daily level (to coincide with the daily rate at which Compto distribution is calculated). This results in Compto's distribution factor of 146,000.

A danger of derivative based control systems is noise amplification, this could result in single day outlier datapoints having an outsized impact on Compto's distribution. As such, we place a limit on the distribution (and therefore high-water-mark growth) for any given day according to an exponential decay function

$$hwm_{max} = (S - M)^{-\alpha} + E$$

hwm_{max} is the proportion of current supply allowable to be distributed for that day. S represents the current supply of Compto energy credits. M is the minimum supply for which the exponential decay kicks in. α is the decay factor, and E is the end state allowable daily percentage increase. Reasonable values for M, α, and E were found to be 10,00,000, 0.3, and 0.00061 respectively. This asymptotically approaches an end state that allows for an upper bound growth rate of ~25% annually. This is intended to provide plenty of room for intense economic growth while effectively rejecting outliers on a day-to-day basis.

6.2 Computation and Energy Efficiency

There will be a period of mining efficiency gains as technology is optimized for the mining use-case. The good news is the work algorithm used for Compto mining is the same as bitcoin, SHA256 [38]. Compto therefore benefits from over a decade of industry maturity in mining efficiency advancements. As the semiconductor industry continues to mature, computational efficiency gains become increasingly incremental, and will plateau (Landauer's principle guarantees this). In the interim, Compto's market price equilibrium can be expected to be persistently above what headline ASIC efficiency numbers might imply. This is because the distribution of miner input costs can be seen as a convolution of the distributions of energy prices and computational efficiencies (that is, not everyone has the most efficient ASICs and not everyone has the cheapest energy). Miners can offset computation efficiency disadvantages with energy price advantages and vice versa.

A similar concern could also be raised that improvements in energy generation will increase energy abundance and thus erode Compto's value. In section 4.2 we discussed that energy is wealth, so a greater abundance of energy carries with it a greater propensity to produce and consume – greater wealth. Greater energy abundance therefore carries with it a need for greater quantities of currency, so that the real value of one unit of currency remains largely unchanged. Instead, we suggest the most dangerous scenario is one in which the riches of energy abundance are held back by a money supply that is indifferent to its changes.

6.3 Impact on Energy Markets

Several second-order effects should be considered. In the proposed system, nations rich with energy do not gain undue influence. From air-conditioning to exports to heavy industry, every nation already monetizes their energy resources to the best of their ability. Any energy spent mining currency is forgone by one of a myriad of other value producing industries. The opportunity cost means energy rich nations have minimal undue influence to gain in an energy-based currency environment.

A major issue in global transition to renewable energy is grid volatility [39]. Classically: the wind doesn't always blow, and the sun doesn't always shine. As the generation mix shifts, grid operators face growing challenges in maintaining balance of supply and demand. Grid operators are thus often forced to rely on natural gas peaker plants or battery banks (which come with a massive economic and natural resource cost) to mediate volatility [40]. In times of too high production, solar panels, as an example, may be disconnected from the grid during peak sunlight hours to prevent grid overvoltage. Because of this, the economics of solar panels break down as a greater proportion of the grid becomes renewable. Lifetime panel cost is then divided over a shrinking base of lifetime useful electricity production [41].

An energy-based currency allows for a greater renewable energy mix in the electricity grids that miners operate. Miners are incentivized to consume energy during peak generating hours when electricity input prices are low, and to shut down machines during periods of peak demand, when electricity prices are high. Flexible consumption directly improves grid stability and the economics of renewable energy installations.

7. Conclusion

Currencies can be judged on their efficiency in providing utility as unit of account, medium of exchange, and store of value. And currency price stability over time is found to be a fundamental prerequisite of an efficient currency. Because the economy is a complex dynamical system, a feedback loop is necessary to maintain stability. The Compto Open Money Protocol is proposed as an improvement in stability to the existing currency systems. This is achieved by allowing the creation of new money through the expenditure of energy via computation. Markets find an equilibrium price at which the money supply is only expanded in times of high demand. It is further augmented with a distribution mechanism that improves price stability, offsets inflation, and combats poverty for all of planet Earth. Compto incorporates this advantage with the other fundamental advantages of cryptocurrencies; it is a decentralized, digitally native, global currency. See compto.com/opensource for a technical implementation of the Compto Open Money Protocol.

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