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Original Paper

The Money Paradox

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Abstract

Money has two key properties—accumulation (value) and liquidity (exchange), which results in what we define as "The Money Paradox". In the language of Physics, money can be in either static (value, potential energy) or dynamic (exchange, kinetic energy) state, however the same money can't be both static and dynamic at the same time because the states are mutually exclusive. In our paper we discuss the conditions under which money changes its state and how such transformations impact continuity (stability) of economics. Our goal is to identify the measures of continuity and thus sustainability of economic activity, as well as to help determine a point in time when new money must be infused into a financial system in order to maintain a continuous production and exchange of goods and services within an economic system without interruption, i.e., a financial crisis.

Keywords

money paradox, financial crisis, economic continuity, quantitative easing, monetary policy, money creation

1. Introduction

All objects in the universe have a tendency towards lower levels of energy. Scientists call this a high level of entropy. According to this principle, all objects tend to occupy the lowest energy level possible with time.

As shown in the research paper "Statistical mechanics of money" by Dragulescu A. A. and Yakovenko V. M., money follows exponential distribution as the entropy growth of the economic system first increases rapidly and then gradually stabilizes:

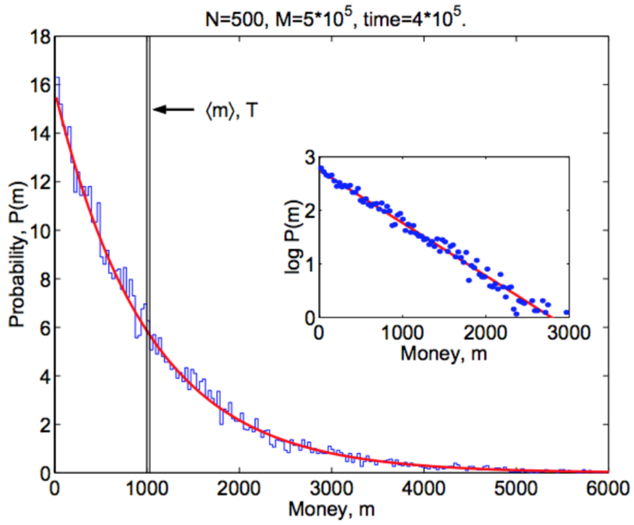

Figure 1. Histogram and Points: Stationary probability distribution of money *P(m)*. Solid Curves: fit to the Boltzmann-Gibbs Law *P(m)* ∝ *exp (-m/T)*. Vertical Lines: The initial distribution of money

As the distribution of money changes from its initial state, the system's entropy begins to grow, as shown on the next graph:

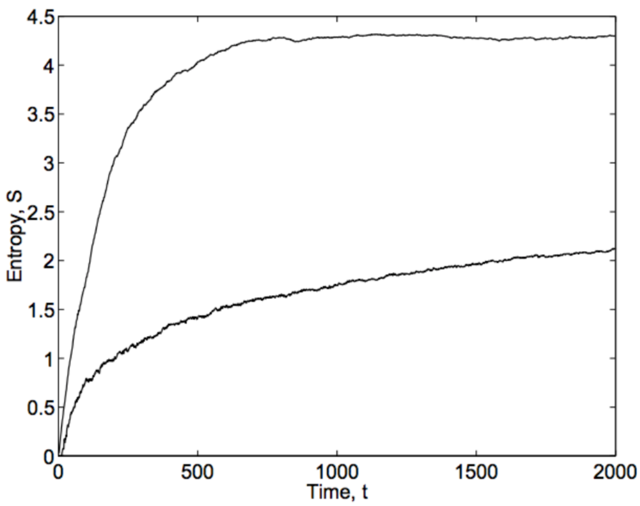

Figure 2. Time Evolution of Entropy. Top Curve: For the Exchange of Random Factor of the Average Money in the System, m = M/N

As stabilization of rate of growth of entropy coincides with the distribution of money approaching an exponential function, we believe this to be a universal pattern for reduction of the economic system's "kinetic energy" as a precursor of its eventual freeze, as follows from the Boltzmann equation, which describes the time evolution of the distribution function P(m) due to pairwise interactions:

$$\frac{dP(m)}{dt} = \iint \{-w[m, m'] \dashrightarrow [m - \triangle, m' + \triangle]P(m)P(m') + w\,[m - \triangle, m' + \triangle]$$

$$\dashrightarrow [m, m']P(m - \triangle)P(m' + \triangle)\} dm' d\,\triangle.$$

Here w[m,m']→[m−Δ,m'+Δ] is the rate of transferring money from an agent with money m to an agent with money m'.

In order to avoid the freeze and retain their level of kinetic activity (speed, or rate, of economics), economic objects require additional energy (e.g., inflow of new money) in order to decrease entropy. Otherwise such a system would inevitably stall because any further continuity of the money flow would be impossible due to its freeze.

We believe this pattern of events is caused by what we define as "The Money Paradox": money's two key features, value and exchange, are mutually exclusive. Speaking in physics' terms, the money can be either static (accumulated potential energy) or dynamic (exchanged kinetic energy), however the same money can't be both static and dynamic simultaneously.

A very simple example of how this principle works in a real physical world is what's defined as a Time Constant in electrical circuits, which is what physicists use to measure the time interval required for a system to change from one state to another.

In this example, a capacitor discharges at a declining exponential rate. It produces the higher levels of exchanged energy, while dissipating most of its charge with both voltage and accumulated charge dropping rapidly until the time constant is reached where the capacitor's voltage and remaining charge fall considerably from their initial levels and then continue to fade away at a much slower rate as shown in Figure 3 below:

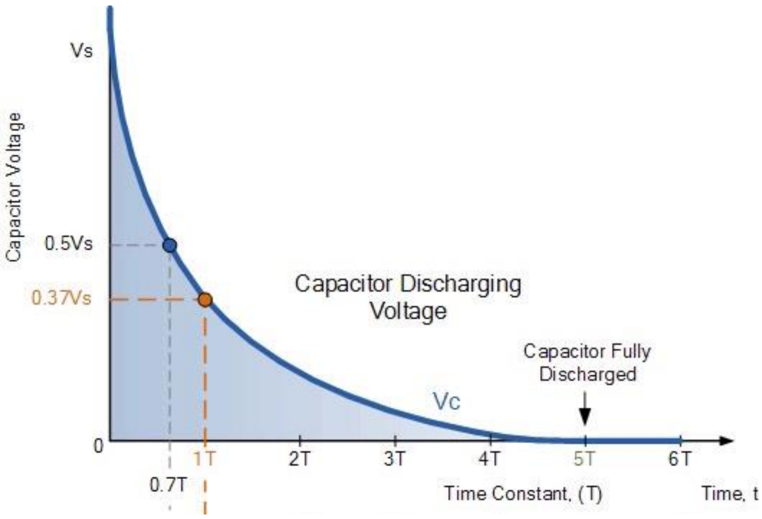

Figure 3. Voltage of a discharging capacitor vs Time, in terms of the Time Constant. As the capacitor discharges, it loses its charge at a declining rate

The slope of the curve represents current, or the flow of charge (exchanged energy), which decreases with time as accumulated potential energy of the stored charge transforms into energy of the electric current, eventually bringing the overall system to a higher level of entropy - a low energy state.

Similar to this example, it is impossible for static money (at its lowest level of kinetic energy) to do any work without a transformation, which liquefies and expends that energy. Transformation of money from static to dynamic state (potential to kinetic energy) is possible only if there's sufficient potential energy to begin with, which cannot be true, if the system is already at the highest level of entropy (i.e., the low energy state).

2. Method

Value (accumulation) - a static state of money before or after a transaction of exchange takes place. Exchange (liquidity) - a dynamic state of money coincidental with a transaction of exchange taking place.

Value and Exchange are temporally distinct because the same money can either be statically valuable or serve as means of exchange. In this way, money is a pre-requisite of an exchange.

When a value item of goods or services is produced, such item's value will be recorded as a part of Gross Domestic Product (GDP) only upon its initial exchange with money. The same is true for non-production items, e.g., land. Whether this exchange occurs or not will depend on availability of a willing buyer with enough purchasing power (potential energy of money) to execute a deal, and a willing seller who will get something else of value in return, or just keep the money as value equivalent.

Labor and resources, the key drivers of economics, are recognized via money exchange, because the money represents a universal value as a legal tender of exchange. However, if there is no new value created, e.g., economic activity stops growing, money making becomes harder and harder, which initially results in a slowdown of the economy and later in its freeze.

The more goods and services are produced, the more valuable (in-demand) money becomes, which in turn undermines its liquidity. In other words, as the system continues to produce, it increases the value of money because money, unless the speed of its circulation also increases, becomes a commodity in short supply, and therefore loses required liquidity to maintain the status quo.

This problem is currently solved by the world central banks via infusion of new money into a financial system, frequently referred to as "quantitative easing" through acquisition by central banks of treasury bonds, mortgage backed securities and other financial instruments, all linked to economic performance. However the mechanism of new money infusion attracted a great deal of criticism for its contribution towards growing income inequality and inflation concerns.

The mathematical solution of The Money Paradox would be via conversion of exponential distribution into a normalized distribution, thus contributing to a reduction of the system's entropy, where the latter ensures a more stable flow of money and thus continuity of economic activity.

Assuming the amount of money within the system—its value (potential energy) plus liquidity (kinetic energy) is conserved, economics can be thought of as a closed system. The total energy of such a system is constant:

$$\text{Potential energy} + \text{Kinetic energy} = \text{Total energy}$$

However the cumulative distribution of money is not constant. On the contrary, as was demonstrated in the aforementioned work "Statistical Mechanics of Money", it is the flow, or time evolution of the money distribution between the agents, which eventually achieves an exponential distribution after T transactions of exchange.

One kind of energy (potential) converts into another kind (kinetic) and the conversion is irreversible due to the law of entropy (*S*), or the second law of thermodynamics.

Mathematically, entropy is defined as:

$$S = \ln \Omega(T)$$

Where $\Omega(T)$ is the number of distinct states of money distribution within an economic system after T transactions of exchange and $\Omega(T) \propto T$. S is a monotonically increasing function, meaning entropy can only grow with time (and new transactions T); it is also not limited from above and can grow to infinity.

Rate of change of entropy is the first derivative of S:

$$S' = 1/\Omega(T)$$

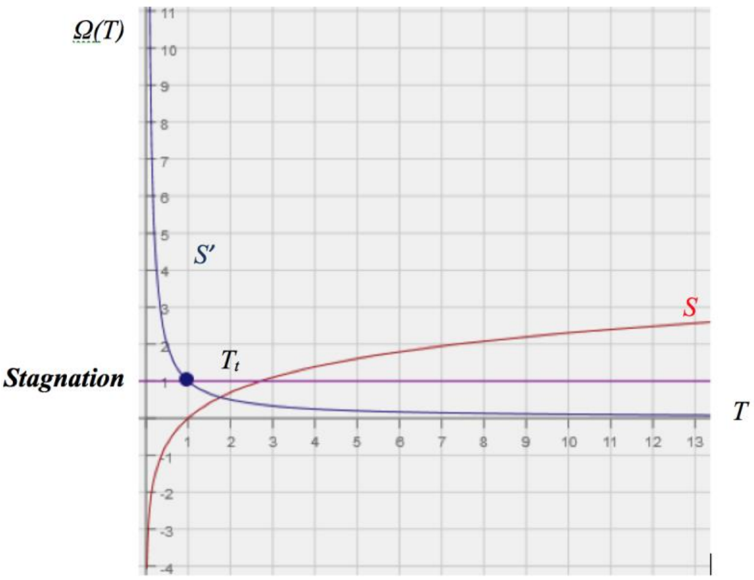

Figure 4. Red: *S = ln(Ω(T))*; Blue: *S' = 1/Ω(T)*. Stagnation level reached at *T = Tt*

3. Result

Much like the voltage of a discharging capacitor in Figure 3, *S'* is monotonically decreasing and asymptotically approaching 0 at infinity. Therefore its value can be a measure of the health of the economic system. First of all, its range is always bounded by 0 from below and, once a certain point *Ω(Tt)* is reached after *Tt* transactions, *S'* permanently drops below a threshold level of 1, which then bounds it from above. From that point onward the rate of change of entropy is guaranteed to have a negligibly small (and decreasing) positive value. Entropy is then so high that, while it continues to grow, it no longer grows appreciably and stagnation follows. Thus, once we reach a certain point *Tt*, the economic system will have lost most of its potential energy and will be unable to sustain more economic activity:

$$S' < 1$$

At the outset, *S'* has a high magnitude and falls rapidly until it equals 1 (the point *Tt* on the graph in Figure 4) and from that point on it falls much slower and becomes exceedingly small, approaching 0. The point *Tt* can be thought of as the point where quick, dynamic growth of an up-and-coming economic system is replaced by the stagnation of a mature one.

It is important to note that the energy produced by the system during the money exchange (its liquidity) equals to GDP of that system. This means that the amount of energy produced is inherently limited by the initial amount of energy M (money) within the system.

4. Conclusion

In order for a given economic system to continue functioning and not stall, its economic activity should, on the one hand, continuously create value items and, on the other, continuously maintain a sustainable distribution level of the money within the system. This approach will keep the system's entropy rate of change above 1 (S' > 1) and prevent a negative scenario that would require new money to be infused in order to keep the economic activity robust and avoid stagnation.

Infinite supply of new money is necessary for continuous growth of the economy in order to keep its entropy at a lower level, and the point at which new money must be considered for infusion into the system is when its first derivative is less than or equal to one ($S' \leq 1$).

Addressing this problem by converting effectively unlimited supply of money (unlimited potential energy) into productive work is still a big challenge for the economists. Quantitative easing and its methods of liquidity infusion are still debated among the world's best financiers and economists today. Nevertheless the mechanisms of new money infusion must be thought through in more detail. As "The Money Paradox" dictates, residual cash accumulated from past work solidifies as its value doesn't go back into the system, but rather creates an upward pressure, causing exponential distribution of money within the system in the long term.

4.1 Marginal Cost of New Money Is Zero

It costs nothing to introduce any amount of new money into a financial system (marginal cost of new money is zero), yet such system's economic participants must earn this new money by performing work. The time period between infusion of new money and work performance is effectively how much time this new money buys to continue economic status quo. As follows from our earlier discussion, this time is shortened with every single GDP transaction up to the point *Tt*.

4.2 Cryptocurrencies (e.g., Bitcoin, Ethereum, etc.) Do Not Solve "The Money Paradox"

Total quantity of known cryptocurrencies is limited at the starting point. Unlike conventional money, where new money is not limited, cryptocurrencies can be divided into 1/1000 of a coin or 1/1000000 of a coin, etc., however the mechanism of "division" past a certain point in the future is not defined. Therefore our conclusion on "The Money Paradox" holds for all cryptocurrencies in the same way as with conventional money.

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