A Thermodynamic Theory of Money

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ABSTRACT

The paper postulates a *thermodynamic theory of money* and describes both quantitavely and qualitatively its mechanics that unify economic production and finance in a sustainability framework. The theory will examine various economic issues, such as, full employment, economic growth, economic development, economic justice, the role of financial institutions, technology transitions and sustainable natural resource use, and be contrasted with the dominant money theory. It is claimed that as the current practice lacks any objective natural limit, it artificially violates the 2nd Thermodynamic Law, creating all the conditions for the transformation of a financial crisis to economic and eventually to an environmental one. Finally, the paper proposes a necessary biophysical re-design of the global financial architecture based on the theory's ideas for overcoming the current financial, economic and environmental crisis. The theory begins from Gessell's ideas on a *natural money system* and is further expanded to include Roegen's ideas as well; thus providing the wide range of the theory's consistencies with Ecological Economics. Primarily, money must imprint accurately thermodynamic resource depreciation; which means that it must accurately reflect the total entropy increase from natural resource transformation into economic goods. Considering ecosystem entropy as a kind of *benchmark entropy*, natural resource transformation into products will only increase total entropy in the system; being in accordance to the 2nd Law ($dS/dt \geq 0$). Furthermore, products are also subject to thermodynamic depreciation. This effect should also be reflected in the value of money across time, via a respective *purchasing power loss* and *negative interest rates*. Generally, as money comprises a social covenant on the accepted means of human economic exchanges, its purchasing power must primarily follow the thermodynamic depreciation of the economy's material base. This will eventually give motivation for the economy's perpetual quantitative regeneration and all investments to be oriented solely on the real economy -as all new money can be created only through this process- which makes extreme inflation and involuntary unemployment also absent. Contrarily, when via positive interest rates the money's purchasing power is artificially not subject to the 2nd Law -although the economy's material base may be diminishing- it favors the accumulation of non-productive money or *lazy money* of excessive –but only virtual- purchasing power. Although at the initial stages of the economy's growth there is a surplus of capacity for real economy investments this may not be quite visible, the economy eventually turns its preference to non-productive financial activities (i.e. financial derivatives) that multiply money at a faster rate and with less risk, instead of re-investing it on the economy's quantitative regeneration. In turn, lazy money favors motivation for fast resource depletion in order for profits to re-enter the financial sphere and be multiplied. From this vicious circle derive long-term economic and ecological distortions that impact negatively on overall human welfare; such as investment deficits, inflation, involuntary unemployment, extreme income inequalities, resource depletion and environmental degradation. As the economy has to produce new goods to regain its lost purchasing power, the theory is further expanded to deal with the problem of long-term resource sustainability. While for renewable resources the loss of purchasing power may be considered to be naturally regenerated (i.e. biomass, ecosystem carrying capacity), for non-renewable resources (i.e. fossil fuels) it should be considered permanent. This motivates *by default* the limitation of rapid additional entropy production; hence efficiency increases and resource preservation in order for the purchasing power loss to be limited as much as possible. However, as a consumed non-renewable resource cannot be recreated the continuance of its use demands additional resource pumping from the environment, which does not ensure its long-term sustainability. Hence, the compensation on non-renewable resources should consist in a qualitative form. The idea concerns *Research & Development* (R&D) as a process that aims at the economy's energy and material transitions that mitigate the long-term pressure to the ecosystem from resource pumping. As R&D embodies uncertainty, relative risk management schemes on the innovations' acceleration of expected arrival time are mathematically examined. Via a system that is designed by default to limit the production of additional entropy and feedback a perpetual technological progress, money becomes an environmental anchorage of the human economy, securing both its economic and ecological stability.

Keywords: Gessel, natural money system, Roegen, 2nd Law, benchmark entropy, thermodynamic depreciation, purchasing power loss, negative interest rates, lazy money, R&D

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Introduction

Environmental policies that do not take into consideration the dynamics of money circulation within human societies and how the latter contributes through a quite complex –and usually obscure-mechanism to the inducing of environmental crises is destined to fail. In the era where financial markets have dominated over the material production, most solutions that are suggested today concern the reform of industrial production, however completely ignoring its strong determination and dependence from the money market dynamics. At the same time there is a huge gap concerning the environmental dimension of money, so that the contemporary monetary and financial system works in a state of "environmental anarchy". However, it must be recognized that this conversation is absent so far from academic research because of lack of clear understanding of the causality relationships between the financial architecture and its potential to boost, induce -or even- create environmental crises. Indeed, to the eyes of most people, the environmental crisis connects directly to industrial production failures and inefficiencies as the last visible link; however the primary cause can very well be the financial market and the industrial production only a vehicle. As result many studies that attempt to comprehend the problem and combine sustainability with industrial production -although very thorough and with best intentions- usually fail. The paper's purpose is to shed light on the clarification of the above mechanics and suggest the principles of a sustainable monetary and financial architecture.

1. What is money and what does it reflect?

Money is nothing else but a social covenant. As people live in a society that produces economic goods for its members' survival and welfare, money is the socially agreed means of exchanging these produced economic goods. Money could take any form; it could be livestock, stones, metals, bones, food, plants and generally any kind of material object that the society has appraised to be of value according to its own specific criteria. Generally, the concept of money is evolving, reflecting the specific social needs in every era. Historically, all kinds of form of money have been tested and whereas the same forms have succeeded in some societies they have failed in others. Many could be said on the reasons of this spatio-temporal differentiation in human societies, but the resume is that where specific money types failed was due to that the generally accepted means of exchanging produced economic goods could not follow accurately the true value of the latter. In a few words the means of exchange were unable to reflect accurately the true value of the produced economic good. For instance, biologically-based money systems (livestock, crops etc.) worked very well in purely agricultural societies, where the money and the produced good were the same. As societies began to evolve and learn the extensive use of metals, livestock –and generally biological resources- were abandoned as they suffered from intense population variability (i.e. massive deaths from diseases, cropland reductions from natural disasters) so that they could not be used as a long-term means of value preservation. Hence, in many cases, primitive societies found themselves possessing abundant metals but not enough money to exchange them; thus led to the exchange of metals directly. As the minuses of biologically-based money systems were gradually understood, societies were led to the restoration of this imbalance, adopting metals as the primary means of exchange and value preservation.

2. Money and natural environment

A first connection to the thermodynamic laws can be posed at this point; as economic production is actually a transformation of raw materials extracted from the natural environment, one could set the question: "What is the relationship between money and the transformation attributes of raw materials?" As all transformation processes in nature are subject to the laws of thermodynamics (Roegen 1971), the question could take a more specific form as: "What is the relation between the money circulation dynamics and the thermodynamic attributes of the produced economic goods that are supposed to be the objective base for the money creation?"

In ancient societies the environmental dimension of money was much clearer. Each society could produce as much money as its natural limitations allowed. Specifically, money supply was perfectly depended on the availability of gold and silver deposits. Usually, societies with rich gold and silver deposits could expand their domination outside their land more easily; as gold was appraised of great value by all neighboring cultures, if the society was rich in ore deposits could expand its political influence more easily. Furthermore, as the pieces of gold or silver were marked with the government's seal, the money supply was a strong symbol of sovereignty and dominion. The availability of gold and silver deposits defined the limits of the society's economic production and political dominion. As soon as the deposits were depleted, the only way for a society to expand its dominion was through war in order to conquer new lands and new ore deposits that would mitigate its limits. In a few words societies sought more gold and silver resources to put their seals on. Wars at that time were strongly correlated to the saturation of a society's economic limits and its effort to be released by them.

With the introduction of paper and fiat money, limitations such as the above vanished. Now, the increase of money supply is based more on the society's capability to expand "credit trust" between its members, as well as with other societies (international markets), than in the availability of the raw materials used to create the money. Of course, credit trust is still quite determined by the ability of the society to produce economic goods, as well as its saturation. However, as money supply is detached from the availability of raw materials and the abundance of finance is increase with the appearance of international financial markets this relation concerns the long-term. Nowadays, the huge importance of money in modern societies is based on two of its endogenous attributes: **(a)** it can be created at almost zero cost and relative abundance and **(b)** it can impact the transformation part of the economy quite rapidly and quite significantly.

2.1 The thermodynamic axioms applied on money

We could think of analogies between money dynamics and thermodynamics. As the main reason for the existence of thermodynamic phenomena is the thermal difference between two communicating systems, the reason for money flows is the imbalances between supply and demand for a socially accepted means of exchange of economic goods. Any imbalances between two thermal systems that are both isolated to their environment[1] but communicate to each other via a "thermal gate" will tend to diminish until they become thermally equal. From this process work will be produced. At the point of balance there no further natural tension for spontaneous flows. At this point a short review of the four laws of thermodynamics and their analogies to the money dynamics is necessary.

Zeroth law of thermodynamics: *If two systems are in thermal equilibrium with a third system, they must be in thermal equilibrium with each other*. This is the axiom on which the definition of temperature is based. Temperature depends on the heat flow between communicating systems. As long as those systems are in thermal equilibrium there is no heat flow; thus the temperature remains constant. A similar pattern is suggested above with the notions of demand and supply. The analogue could be visualized with two social systems, where one possesses a surplus of money and one a deficit. The society with the money deficit will offer a motivation to the society with the surplus in order to borrow it and valuate it for economic production that will provide it with a better material base in the future. Additionally, the society with surplus has the motivation to lend its money with the deal to be paid a higher amount in the future for this service. Unless there such a motivation that creates monetary imbalances between the two systems, there cannot be a spontaneous money flow.

[1] There are three kinds of thermodynamic systems: **(a)** *Isolated* that do not exchange energy and mass with their environment **(b)** *Closed* that exchange only energy but not mass with their environment and **(c)** *Open* that exchange both energy and mass with their environment. With the term "environment" we describe the surrounding system that hierarchically includes the system under study and is the primary source of mass and energy. The term is artificial and relative to the scale of study; there is not actually an "absolute" environment as we scale-up to the universe. Isolated systems are regarded as reference systems they are the most easy to manipulate their material and energy accounting.

First law of thermodynamics: *The amount of energy in an isolated system remains constant irrespective of the change of its forms*. From this axiom derived the idea that the universe is an isolated system and energy in it remains constant. Heat and work are both forms of energy transfer; however within an isolated system with two parts in thermal imbalance their ratio will change until they reach equilibrium. Whatever the change of ratios may be the total energy of the system does not change. Generally, the increase in the internal energy of a system (*U*) equals to the heat supplied to the system (*Q*) minus the work (*W*) done by the system (U = Q – W). According to the first thermodynamic axiom in an isolated system applies U=0 as Q=W. This axiom may very well find its analogue in the monetary flow. In a few words, the axiom suggests that keeping all things constant (ceteris paribus) across exchanges, money only changes pockets but never diminishes or increases. It must be denoted that this case does not concern money lending but purely bidirectional exchanges (outflow of an amount of money and inflow of an economic good and vice versa).

Second law of thermodynamics: *The entropy of any isolated system not in thermal equilibrium either remains constant or increases*. Via this thermodynamic axiom, is introduced for the first time an asymmetry in nature –contrarily to the first axiom described above. The second thermodynamic axiom is complementary to the first as it refers to qualitative elements. This is the most crucial axiom, and it has been discussed in the scientific community much since it was first introduced. While according to the first axiom the energy of a system remains constant, the quality of this energy does not; specifically, it is degraded across flows from one system to another. Entropy is the amount of work introduced to the system. As the two parts of the isolated system equilibrate thermally, their energy remains constant but also becomes of lesser form; particularly heat that is not capable of producing more work. Isolated systems spontaneously evolve towards thermal equilibrium; the state of maximum entropy of the system (thermal equilibrium). This is the most complex axiom to conceptualize and difficult to transfer to money dynamics. However, it is the most crucial as well as it sets the dichotomy between the amount of money and its value. This is directly connected to energy and material degradation described by N.G. Roegen. As the (constant) amount of money circulates to satisfy the exchanges of goods within the economy it looses value because of the thermodynamic depreciation of the exchanged goods that occurs naturally. The loss of the money value becomes from the increase of prices; which is generally called inflation. Money is supposed to reflect the value of the economic goods that are the objective of exchanges. The thermodynamic degradation of economic goods is actually a reduction of their availability. With constant amount of money and diminishing availability of economic goods (ceteris paribus), prices increase. Increased prices mean that the purchasing power of money decreases as fewer exchanges per unit money can be implemented. The above can be better understood via Figure 1 below:

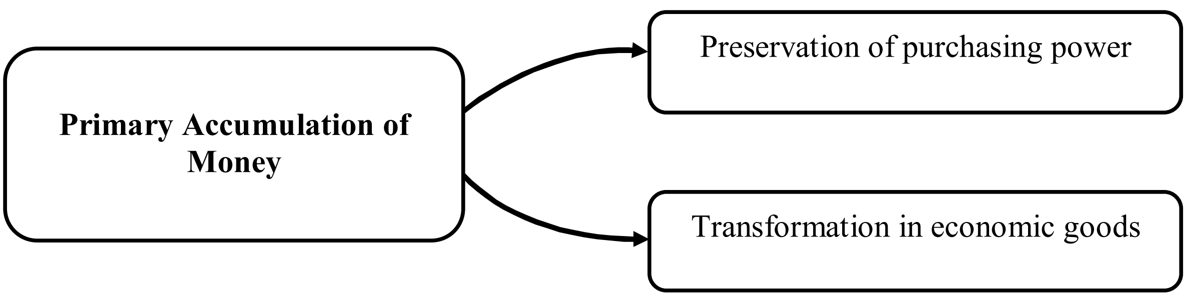

Figure 1: Primary accumulation of money and the two paths of preserving it.

Figure 1, reflects the two paths that a possessor of money can follow. The possessor can either maintain the amount of money he processes and its embodied purchasing power or sell a part of the money in exchange for some economic good. Both choices have the attribute of diminishing value because of the validity of the second thermodynamic axiom. By choosing the first option the money possessor actually maintains his ability to preserve its potential to make a purchase in the future. However, as the available economic goods are thermodynamically degraded in time, their price will increase and the processor of money will gradually loose a part of this potential. Contrarily, if he chooses to make the exchange, the possessor gives-off a part of the value loss embodied in the money but embodies directly the thermodynamic degradation of the economic good he purchases. It is obvious that from thermodynamic point of view both choices must be equivalent as money should always reflect accurately thermodynamic degradation of the economy's material base. When this does not happen (usually via the biased preservation of value in the money while economic goods are thermodynamically degraded) distortions begin to apply in the economy in favor of the money market (virtual economy) and at the expense of the transformation sector (real economy).

Third law of thermodynamics: *The entropy of a system approaches a constant value as the temperature approaches zero*. The entropy increase (dS/dt) of a system at a temperature of absolute zero (-273K) is zero. Until the system reaches this temperature, the entropy continues to increase as at temperatures above the absolute zero the molecules of substances still have kinetic energy. As the temperature falls to absolute zero, the entropy still continues to increase; however at diminishing rate ($d^2S/dt^2<0$). The third thermodynamic axiom is the least related to the money dynamics as it concerns conditions that are found at the limits of the universe (even in its outer limits temperatures like that are not naturally found; the average temperature in the universe is ~-270K) that determine the state of a system's mass and energy. This axiom is postulated more to set a lower universal limit than to explain often observed system states. Hence, it would be a quite foolish overstatement even to attempt to postulate a law for money dynamics in an energetically dead universe. Even the cases of complete social order collapse cannot simulate accurately a "financially dead universe", since as long there are people, natural energy flows and raw materials the system will tend to reorganize and materials with specific attributes will take the place of money.

3. Contemporary money architecture

At this point the mechanism of money production and the distortive character that the latter has for the economy is presented. It is considered of huge importance to be denoted that in the modern financial system only a few details make the difference. These details however create a specific tension of the system towards a specific state. This state is described by the so called "business cycles" that are actually periodical saturations between the true production of economic goods (real economy) and the money production (virtual economy). The (usually huge) gap that is observed is the "credit trust expansion" of which its base is the real economy. As the "credit trust" expands beyond a specific point, people begin to consider that what has been credited cannot be repaid via new wealth creation at an acceptable time-frame –usually not bigger than human life expectance. In a few words, the expectations that the real economy will speed-up production in order to cover a good fraction of the credit created are considered too high. From that point a reverse cycle of money destruction begins in order for the system to reduce the gap between its two sectors, usually with destructive consequences for the real economy as well. However, although the patterns of business cycles have been recognized and modeled, the deeper mechanisms of their creation remain –or are supposed to remain- still unknown. In this paper it is argued that the majority of business cycles are created because of the structure of the financial system itself. Three of its core attributes are enough to lead the system to an economic crash after a specific period of time; **(a)** Privately issued debt-based money **(b)** Fractional Reserve Banking (FRB) and **(c)** positive interest rates. The certainty of the "crash event" is not doubted at all, although the frequency of the crashes might very well be something to be discussed. Below, I discuss how these three elements may work in time towards the economic crash event and how this can further expand to an environmental crisis as well.

3.1 Privately issued debt-based money

What is historically common across all periods of human history is the exclusivity of the right to issue new money as a symbol of power and dominion. Until medieval times, this task belonged to the leaders of kingdoms and empires. In the Renaissance the Western civilization experienced a transitional period with the first introduction of paper money and the first unofficial practices of FRB concerning gold deposits. In modern times, all these rights are gathered by central banks. Central Banks are not necessarily public owned; contrarily in the majority of cases they are privately-owned organizations that have made an agreement with states for the right to issue money that is actually bought by the latter via debt. As the central banks possess the monopoly of issuing money, they actually lend it to the governments of states in order for the latter to use it for their economic transactions under the obligation of an interest payment at the end of each period. However, even if all the initially issued money returns to the central banks there still remains the interest, which cannot be repaid unless new money is issued. This begins again a new cycle of state indebt that gradually increases the public debt towards central banks. The important point - however- is that through this process, central banks begin to have increasing demands over the real economy as collateral (guarantee) for the supply of more money.

3.2 Fractional Reserve Banking (FRB)

The international practice of Fractional Reserve Banking (FRB) is actually a distortion of the natural laws as it provides money with the ability to reproduce in a way that violates (artificially) the second thermodynamic law, as it makes money able to reproduce without any objective natural limit. Fractional Reserve Banking actually works via the Money Multiplier. Central banks provide the issued money to commercial banks via a bank deposit. Commercial banks are obliged to keep only a small fraction of their total deposits as a safety amount. The rest can be lent with the purpose of profit in the future. The money multiplier is equal to $M=1/m$, with $1>m>0$, where (M) is the multiplier and (m) is the fraction that each bank is obliged to keep as least reserve. For instance, with a multiplier equal to –say- a value of 0,1 the money multiplier is 10 (!). In a few words, assuming that the first issued money by the central bank reflected the real economy's value, after a very short time of financial transactions between the banks and their customers the total money supply in the society is 10 times more than that. It will need a 1000% growth of the real economy to cover up this gap. Obviously this is impossible within an acceptable time-frame. Furthermore, if we assume that the central bank issues even more money, then the total money supply increases exponentially, contrarily to the real economy that needs much more time to grow proportionally. It is obvious that through this mechanism, credit trust expands at a rate that definitely cannot be paced by the real economy, leading with certainty at its saturation that ignites an economic crash event.

3.3 Positive interest rates and lazy money

The above elements could not work if the most crucial one did not apply; positive interest rates. Without positive interest rates there would be no motivation and need to deposit money in commercial banks. If interest rates were equal to zero then the possessors of money would seek an alternative investment, most probably in the real economy. This was Sylvio Gessel's main argument on the institutionalization of a "natural money system", where the money would be issued publicly and the interest rates would be zero or negative, following the general thermodynamic degradation of raw materials. In purely agricultural societies –almost totally depended on renewable biological resources- the interest rate could be even zero, provided that the depletion rate would not be greater than the regeneration rate. Gessel simply thought that the money would just simply conserve its value via the natural regeneration of the society's resources. If the society started consuming its resources at a faster rate, then money should follow the same source. By abstracting money from the society would simply provide the motivation either to substitute it by increasing the real economic production or just reduce the demand that would allow depletion and regeneration rates to equalize. However, modern industrial societies have an extremely strong dependency on non-renewable resources, such as fossil fuels and minerals. As the regeneration ratio of these resources is extremely low (much more that the average human life expectancy) the interest rates should follow negative course as their consumption embodies a net depletion effect. Negative interest rates would prevent people from depositing their money in banks (lazy money) or just leave it without investing it because they would simply have a net loss. Positive interest rates just lead the money at the opposite direction of its natural course. By increasing the amount of deposits –via positive interest rates- the amount of leveraged money is increased proportionally, leading the economy at a faster rate to its credit trust saturation.

Contrarily in the case of zero or negative interest rates, it is more profitable to invest it on the regeneration of the lost material base of the real economic production. These cases have clearly a connection to the second thermodynamic axiom as whether the real economy is based on renewable or non-renewable resources will define the course of entropy in the system. Considering that the total entropy in integrated socio-ecological systems is the sum of natural occurring entropy and the additional entropy produced by anthropogenic material and energy transformations, it could be said that economies that depend on renewable resources exclusively do not add entropy in the system ($dS/dt=0$), while economies that depend on non-renewable resources add an amount of entropy, equal to the thermodynamic depletion of the resources ($dS/dt>0$). It is of course understood that the majority of modern societies is a mix of these two cases, however in different analogies. In any case the majority of societies depend mostly on non-renewable resources.

3.4 The chain of crises

As the money reaches -after a point- its saturation limits, an economic crisis begins. Money is extremely abundant while at the same time economic goods are relatively scarce. A true wave of money destruction begins via the increase of prices, in order to restore a small distance between the real and the virtual economy. In most cases the proposed solution concerns the further increase of the money supply in order to boost a wave of investments that will increase the material base (real economy) of the financial system. However, this might very well lead to an environmental crisis because it will ignite a rapid pump of natural resources in order to assist the real economy to escape from its vicious cycle of diminish. The key element in these cases is the minimum required level of natural resources used to maintain the material base of the society (see Figure 2 below).

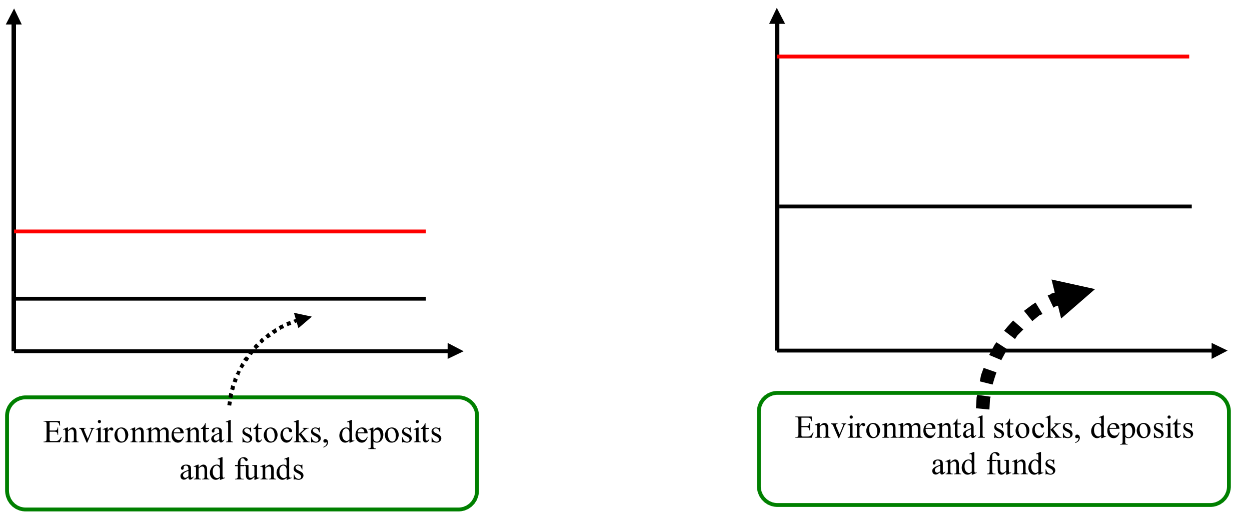

Figure 2: Two economies with the same *economic value/money supply* ratio but with different absolute values of each variable. Although the ratio is the same the second economy pumps natural resources at a faster rate in order to maintain the material base of the economy that further comprises the base for the expansion o the credit trust via money supply. The increases in money supply as a practice to overcome an economic crisis via increasing the demand may ignite or induce an environmental crisis via the overshooting of environmental limitations.

In figure 2, both of the economies have the same ratio between the value of their real economy and the total money supply circulating in them. However, they have different absolute values in each variable. The material base of the second economy is obviously much higher than the first one and demands much more natural resource pumping from the environment –per unit time- in order to sustain it. Human economies use natural resources from environmental tanks. Resources can be distinguished according to Wall (2005) to stocks deposits and funds. As said the composition of the economy is very crucial for its environmental limits. The increase of monetary circulation causes specific environmental effects. Specifically, an increase in the money supply will bring the economy much closer to its credit trust saturation limit. In order to avoid a new economic crisis, the society will seek to use this money supply to increase its material base. However, if the real economy functions at an already high level of resource pumping it is very probable that it will just transform the economic crisis to an environmental one, by facing a raw materials' availability default. Hence, although the increase of the material base is a necessary condition for the stability of an economy it is not the primary one. Generally, societies that manage to control excessive jumps in the money supply and use much of that part to build sophisticated and environmentally efficient structures tend to have a much higher survival probability.

4. Long-term sustainability: Financing transitions

As the resources are depleted via transformation for the production of economic goods in order for the money to maintain its value, significant issues of sustainability emerge. There must be introduced a thermodynamic account that will reflect accurately resource depletion and will be invested in order to maintain the ratio *resource use/resource availability* at least constant in time. Specifically, this thermodynamic depletion account will be dedicated to efficiency increases or material and energy paradigm shifts, always with the purpose of keeping a steady-state between the resource depletion ratio and the efficiency increase ratio. In a few words, this account

The Scarcity Rent (*SR*) derives immediately from the 2nd Thermodynamic Law, expressing the payment for a resource's thermodynamic depletion. This kind of opportunity cost constitutes an endogenous account, which in order to be economically effective it must be disposed exclusively in *some form* of replacement of the resource consumed in a past time. Reduced in economic values, this opportunity cost consists in *the net benefit that's lost when one unit of resource is consumed today and is not available in the future*. This concerns also renewable resources of limited quantity that have a small regeneration ratio in comparison to their consumption ratio (such as the PCC). Consequently, besides the extraction cost, the price of a resource should embody the SR as well, which is *the pure scarcity effect from a resource's consumption intensity*.

Furthermore, the SR is conceived in the model as minimum payment for natural services to human societies. While it's easy to comprehend other forms of payment -such as wages for human labor- the same is very difficult to apply for the environment's services towards human societies as the formation of raw materials in the environment does not emanate from human work. Since a consumed non-renewable fuel resource cannot be recreated (because of the 2nd Law), the SR is to be re-invested *qualitatively*; meaning in energy technology transition via R&D as *a promissory title of avoidance to need the resource in the future*. This monetary deposit is actually an investment on the mitigation of the society's dependence on the resource (or at least on its maintenance at sustainable level). Even if the resource's demand remains constant, the society's relative dependence (demand to availability ratio) on it is increasing as the resource is depleted in time. From the time that society achieves the innovation and begins to cease the use of the depleting resource, begins the *resource loan settlement* towards the natural environment. In a few words, what the SR actually does is to *enhance the transition stability*, by connecting directly energy consumption with minimum energy transition investment, primarily via the *ex ante* information provision on the resource's increasing scarcity along its use and secondarily by setting a payment framework for it.

R&D is modelled as a Poisson process. Poisson processes are discontinuous and focus on the desirable event probability within a specific time interval (Ott 1995). In this case the desirable event is the successful implementation of the R&D program (Anghion & Howitt 1998). According to the Poisson model, at some time in the future the desired R&D event time will arrive with absolute certainty at least once. The question is simply at what particular moment this will happen for the first time (the success of the R&D program needs to succeed only once in order for the new energy technology to start deploying and the substitution-transition process in the macro-scale to begin). The expression of the event's arrival probability (*P*) in the classical Poisson distribution is:

$$P = e^{-\lambda t}\text{, with } 0<P<1 \qquad (4.1)$$

Or based on the complementary probability $1 - P = 1 - e^{-\lambda t}$ (4.2)

It is obvious from eq. (3.1.1) and (3.1.2) that the model is a form of exponential decay. The classical probability (*P*) refers on the evolution of the possibility that the desirable event *does not arrive*. As (*P*) decreases by a ratio expressed by parameter (λ), this probability diminishes across time with intensity proportional to the absolute value of (λ). Contrarily, the complementary probability (*1-P*) refers to the possibility that the desirable event *arrives*. It is obvious that both views are absolutely equivalent. The parameter (λ) of the Poisson distribution refers to the average arrival frequency of a desired event within a selected time interval *t* (i.e. if the desired event arrives once within one year, then the average –say monthly- rate of arrival is 1/12=8,33%). Within this time there must have been achieved a total of ($\lambda \cdot t$) arrivals. Although the notion of the average rate has no profound practical utility, its usefulness consists in estimating the average speed of the event's arrival. This is extremely useful when attempting to increase that speed.

For very long time intervals the probability (*P*) approaches asymptotically the value *0* over time (almost absolute certainty of at least one arrival) but it never acquires precisely that value. In infinity the curves theoretically meet (see fig. 3.1, *limP=limP** as well as *lim(1-P)=lim(1-P)** when $t \to \infty$), but what matters is the distance between the curves much before that point, which is expected to be positive. As after some specific time *t*, the derivative *dP/dt* becomes extremely low – although non-zero- we are actually concerned with at what probability *P* and after, the function begins to have more output of innovation arrivals per unit time. Generally, the less is the probability value change, the more "stiff" (or inelastic to the funding increases) is the new function considered to be. Horizontal curves are more inelastic than steep curves. This is a very significant indication on the limits of manipulating R&D via purely monetary terms, in order to economize funds for other more productive means of manipulation. In a few words, R&D manipulation via monetary means does not work after a point and it should be known in advance what this point is. Generally, it could be claimed that the funding is to take place where the derivative *dP/dt* is maximized. After R&D efficiency increases exhaust monetary means, other means of increasing the average rate of innovation arrivals (i.e. administrative is to follow). A Poisson probability distribution is presented below in Figure (3.1).

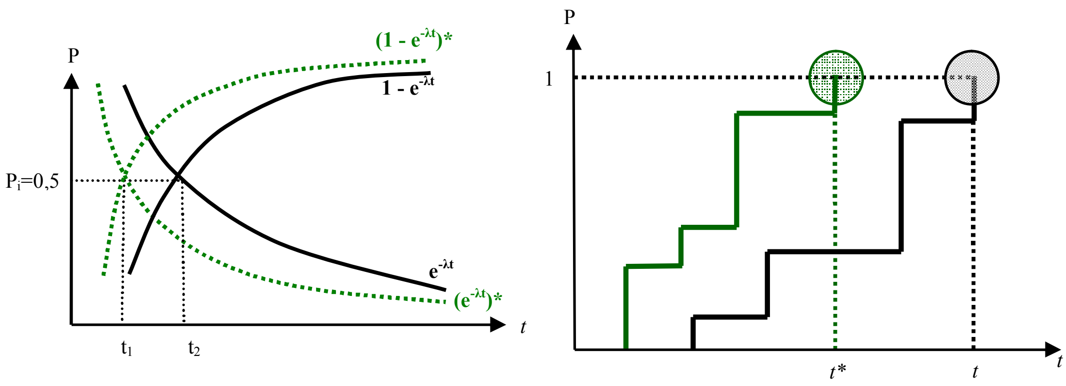

Figure 3: Probability distribution in a Poisson process: **(a)** the increase of the average rate of innovation arrivals - expressed by parameter (λ), moves the *entire* probability distribution curve (classical and complementary) to the left. A major consequence is that the whole process is accelerated. Statistically, this means that each probability corresponds to a shorter time, **(b)** internal structure of the process. Each successful step of the R&D program corresponds to a

discontinuous bigger or smaller step closer to the complementary probability (*1-P*) equal to *1*. By accelerating the process the steps are implemented at a faster rate, resulting to the probability equal to *1* sooner (at *t**) than before.

4.1 Accelerating the transition

In relation to the above, the most important parameter of the model is (λ), which essentially provides information on the R&D's temporal efficiency. Additional funding comprises a factor of technological upgrades. The (λ) correspondence in the R&D financial inputs constitutes in practice an *innovation accelerator*. This allows society to upgrade its energy technology within a shorter time interval. This measure is very useful for providing a basic orientation to societies in which innovation is difficult to be achieved because of inadequate funding. For instance, if the endogenous development of a new energy technology proves to be very expensive for the society's budget standards, the society could turn to the international R&D market. If the cost of buying the energy technology is lower than the cost of development, it could use the SR funds for purchasing it. From this particular attribute can derive a measure of the correspondence of the R&D process towards increases in available funding. We may name it as the *Financial Accelerator of Energy Technology* (*FAET*), which is the average innovations increase (λ) per additional monetary input (Z):

$$FAET = \frac{\partial|\lambda|}{\partial Z} \qquad (4.3)$$

The parameter (λ) in eq. (3.2) is considered as an absolute value (without the sign) as we are purely interested in the parameter's reaction towards funding increases without being interested on the direction of that change (we logically assume in advance that it is positive). Thus we may write the new classical Poisson probability function as:

$$P = e^{-\lambda\cdot\left(1+\frac{\partial|\lambda|}{\partial Z}\right)\cdot t} \qquad (4.4)$$

Some economies are more efficient in transforming the available funding to innovative knowledge. Differences in that efficiency concern mostly the structural attributes of a society. Hence, if we wish to be more accurate in explaining this response as a structural element, we have to calculate the response of parameter (λ) *independently* of the effects of scale and assess the *FAET Elasticity*, which is actually the percent derivative. Thus, we may write:

$$FAET_{\varepsilon} = \frac{\frac{\partial|\lambda|}{\lambda}}{\frac{\partial Z}{Z}} = \frac{\partial|\lambda|}{\partial Z}\cdot\frac{Z}{|\lambda|} \qquad (4.5)$$

According to Eq. (3.4), the elasticity removes the effects from the variables of which the scale of values differs a lot. For example, if the (λ) takes values from 0,1 to 5 and the (Z) takes values from 100.000 to 1.000.000, the *FAET* will falsely give extremely small values. This gives the false impression that a lot of money must be spent for very small increases, which is a serious underestimation. Contrarily, the elasticity gives results in percentages; which is equivalent as if the two variables had the same value scale.

Final Remarks

The paper highlights the analogues of the thermodynamic axioms to money dynamics. Within this context the idea of an ideal money system is developed, based on the original ideas of Silvio Gessel who visualized a monetary system that would follow the natural course of things. Additionally, fundamental attributes of the modern financial system were presented in order to demonstrate the level of distortion of the natural course of the economic process. Through examples it is shown that under certain circumstances the periodical financial crises –that become economic- have very good chances of becoming environmental. According to this framework of analysis, periodical crises are not considered unavoidable as they are a pure product of the structural fallacies of the monetary architecture. It is suggested that natural money system –similar to what Gessel had suggested at the previous century- should substitute the dominant financial paradigm as a way to resolve many of the world's combined financial, economic and environmental issues.

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