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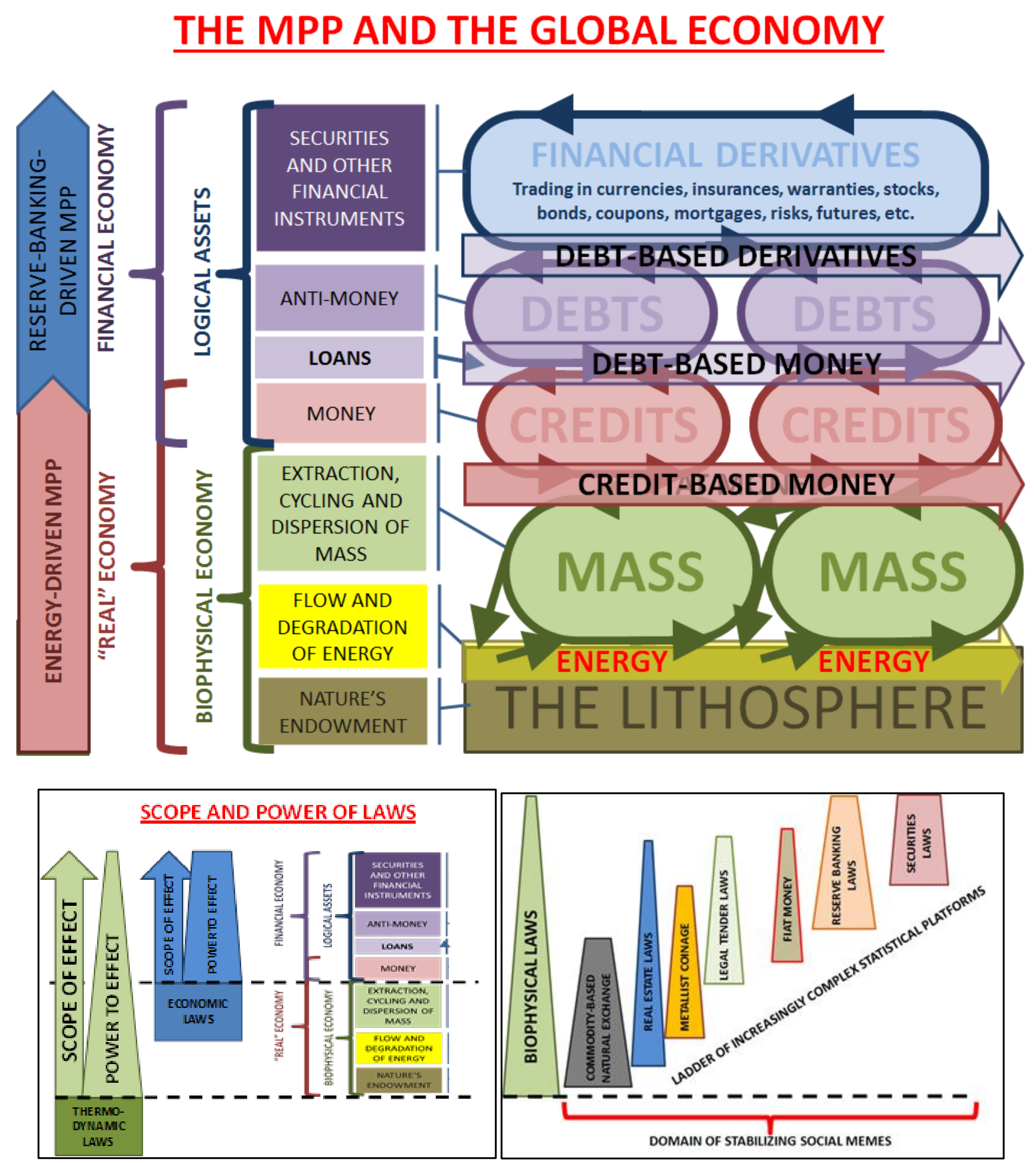
The MPP and The Global Economy

Frontispiece



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1 - References:

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B. 160218 PPR A Restatement of Odum's Maximum Power Principle R5.docx
C. 160210 NTF Critique of Restatement R5.docx
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2 - Purpose:

The purpose of this NTF is to describe how I think the maximum power principle operated to drive endless innovation and increasing complexity in the economies of the world, leading to the structure of the current global economy.

3 - Thesis:

The maximum power principle (MPP) was first described in outline by A.J. Lotka, then developed in more detail by H.T. Odum, and is now often called the Lotka/Odum MPP. When Odum talked about the MPP, his focus was on biophysical systems where the action of flows of energy clearly have a direct and dominant impact. Over the past year I have often considered how the MPP might work in systems in which energy plays a much smaller role, such as in agent-based models (ABMs) or in modern financial systems. It seems to me that these self-organizing systems are strongly driven by the MPP even though the role of energy is minimal, or, at best, indirect. So, here is my going-in thesis:

> ***The historical evolution of the modern globalized economy, and the nature of its current structure, can be explained in terms of the laws of thermodynamics, which can be expanded upon to become a set of laws of econodynamics.***

My learning process leading me to this thesis is outlined in my Economic SOAK (Sum of All (of my) knowledge), listed at Ref A.

4 - Approach

I have developed a multi-level diagram that shows what I conceive to be the dynamic structure of the modern global biophysical/financial economy. The core of this NTF is a description of each of the layers of the diagram, but before I get into that description, I need to explain several concepts that inform the description.

I intend to proceed in three steps, as follows:

- In **Section 5**, I will introduce three important sets of concepts that I need to make my main argument.
  a) I will describe the Lotka/Odum MPP as a set of falsifiable hypotheses and outline the dynamic implications of those hypotheses.
  b) I will discuss the nature and role of memes in society, and describe how memes can be embodied in real-world social institutions. I will discuss the continuum of monetary systems as a ladder of stable memes.
  c) Finally, I will discuss the interaction of the 2nd and 4th laws.
- **Section 6** is the main part of the argument wherein I will describe the development of the modern globalized economy as a series of advances from a purely biophysical world to one in which the largely logical financial economy has blossomed in size and power.
- In **Section 7** I will propose the existence of five laws of econodynamics that expand upon the laws of thermodynamics.

Section 8 will be a few final thoughts for follow-up in a later NTF.

5 - Introductory Concepts

5.1 - Assumptions About the MPP:

At Ref B I proposed a restatement of the Lotka/Odum MPP in order to produce some falsifiable hypotheses. For reference, here is the complete set of hypotheses that form the core of that restatement. It uses a lot of terminology that I have defined carefully in the Ref B document. Here are the hypotheses:

- ***MPP I** – All persistent adaptive autocatalytic physical systems are characterized by energy fluxes through persistent types of energy stores, and persistent energy pathways through which energy flows from storage type to storage type.*
- ***MPP II** – Within all persistent adaptive autocatalytic physical systems, all classes of persistent linkage events within persistent energy pathways are characterized by power-efficiency relationships for which power is maximized at some intermediate efficiency.*
- ***MPP III** – All persistent adaptive autocatalytic physical systems evolve to capture and degrade energy at a maximal possible rate consistent with available inputs. In contrast, the efficiency of the linkage events will not be maximized but will tend towards some intermediate value.*
- **MPP III-a – Co-evolution of components** – Persistent energy pathways, together with the types of energy stores and of linkage events that they comprise, must all co-evolve to achieve overall maximum power at the level of the entire system.
- **MPP III-b – Expansion of Scope and Complexity** – Any such system for which its operation is constrained by a shortage of suitable inputs, but for which alternative inputs are accessible, will tend to adapt its pathways so as to access those inputs, with the effect that energy throughput will increase.

These hypotheses are written to explain the phenomenon that Lotka first observed upon in his paper of 1922. (See Ref D.) In short, he argued that the trophic web of a persistent ecosystem can be viewed as a collection of persistent processes that capture and degrade energy (my words). Those processes can adapt to access more energy, or to access more suitable matter that is used to access and process energy. He argued that such processes compete for energy. Those that can capture the greatest share of available energy will out-compete the others, and expand their scope, and displace the less-well-adapted processes in a Darwinian-style form of natural selection. The result is that such adaptive systems will evolve to capture and degrade energy at the greatest possible rate.

There are many implications of the above hypotheses that lead to curious counter-intuitive effects, and it is those counter-intuitive effects of these hypotheses that are important for this argument. For this NTF I must assume how the MPP functions and what effects it has on a system since it would require too much space to explain it. The explanations can be found in the Ref B draft paper and the Ref C critique of that paper. It must suffice here that I merely list those assumptions without explanation.

In the following I use this terminology:

- *"system"* means a persistent autocatalytic adaptive physical, biophysical or social system upon which the MPP can operate (such as an ecosystem);

- *"process"* means a persistent energy consuming process or pathway within the persistent system (such as a trophic web or chain within an ecosystem);
- *"store"* means a sub-system that can hold energy for a while (such as an organism within and ecosystem);
- *"link"* or *"linkage"* means an event in which some portion of energy is transferred from one store to another store retaining its usefulness, while the other portion is simultaneously degraded and transformed into waste heat (such as an act of predation by one organism on another).

I will here describe how I have come to believe the MPP works in an ecosystem, with the idea in mind that they should eventually be reworded to also apply to economies. My assumptions about the operation of the Lotka/Odum MPP are:

1. **Maximum Power** – All persistent systems, at whatever scale, evolve to capture and consume energy at a maximum rate possible consistent with the quantity and form of matter and energy available to the system and flowing through the system.
2. **Antithetic Bi-Level Power effects** – The MPP maximizes power in two opposing ways at two hierarchic levels:
   a. **System-Level Power** – At the system level it maximizes the capture and degradation of energy, resulting in a maximization of the rate of entropy production by the system as a whole. This mandates the expansion of the scope and scale of the system as a whole.
   b. **Link-Level Power** – At the level of linkages within a process, that is, at the level of individual transfers or transformations of energy as it passes from store to store, the MPP maximizes the transfer of high-grade energy and minimizes the rate of degradation of energy, resulting in a minimum rate of entropy production during each transformation. This mandates the selection and preservation innovative and more effective process linkages and the suppression of old less effective process linkages within the system, enabling the process itself, and the system of which it is a component, to evolve.
3. **Evolutionary Imperative for Processes** – Just as it is an evolutionary imperative for a species to out-compete its contemporaries if it is to remain persistent, in the same way it is an evolutionary imperative for an energy-transforming process to out-compete its contemporary alternative processes within the system if it is to remain persistent. When there is a constant flow of high-grade energy through a persistent system it must self-organize and become ever more complex until some maximal level of complexity is achieved determined by the total rate of capture of high-grade energy. I am not 100% sure of what I mean by "high-grade" but an example would be the energy carried by photons coming from the Sun. Neither am I certain how I might measure the "level of complexity" but I think it has an intuitive meaning that works. My notes about EiLab partially address that issue. (See Ref. A.)
4. **System Complexity** – All autonomous changes in complexity are explained by the MPP:
   a. **Dependencies** – The maximal level of complexity of such a system is a function of the types and quantities of matter available to be taken up by the system, of the types and quantities of high-grade energy available, and of the rate at which that high-grade energy can be captured and degraded.
   b. **Sole Cause of Gains** – All autonomous increases in complexity within a system are due to the action of the MPP as it drives systems to evolve to a condition of maximum power.
   c. **Loss Due to Diminished Inputs** – All autonomous losses of complexity are due to a lack of sufficient high-grade energy sources of appropriate type, or a lack of sufficient matter

of appropriate types, to maintain the formerly achieved level of complexity. Such loss of complexity might happen at the level of the system as a whole, or at the level of one process which has lost its access to appropriate inputs.

5. **Link-Level Advantages** – Organisms exist as stores that are the elements of the system's processes, and experience competitive advantages and disadvantages through linkage events. The MPP serves to have the following selective effects. As processes compete for continued persistence, and as linkages evolve, the constituent stores experience:
   a. **Enhanced propensity to divert energy to growth and reproduction** – This enhances the probability of survival of the organism and persistence of the species, but also enhances the flow of still useful energy to the organisms downstream in the energy pathway – i.e. the offspring and the predators. This explains the profligacy with respect to energy put into reproduction.
   b. **Enhanced propensity to divert energy away from maintenance activities** – This also enhances the probability of survival of the organism, as the maintenance activities become very efficient. This explains the parsimony with respect to energy spent on foraging, homeostasis, and hygiene.

The above assumptions were specifically drafted with the trophic web of an ecosystem in mind. However, I note that, with small changes in terminology, they could easily be applied to chemical pathways within a single-celled organism, or to a supply network within an economy. Odum argued that the MPP was equally applicable in all fields.

5.2 - Economic Practices, Social Memes, and the MPP

The main argument of this NTF is essentially a non-mathematical argument. I am not an historian, and am uncertain about many historical details, but I believe that I have at least an adequate general knowledge of the history of money, of societies, and of economic and monetary theory to put together an interesting theory, and an interesting story. I find it difficult to separate my story that explains how things got to be the way they are, from my theory that explains how things function now. So I describe both at the same time. I build up an overview one piece at a time, adding each piece roughly in the order that seems to mimic historical development, but also lends to understanding of the final result.

But, there is an aspect to this approach that troubles me slightly. Most of the outstanding features of modern economic life have existed for at least two millennia, but I discuss them below as if they did not exist anywhere in the world at one time, then they sprang into being somewhere and quickly spread, then persisted until modern times. History is never that tidy, and the increases in social and economic complexity that I wish to discuss were not always recorded, and rarely locally persistent when they appeared at any time. In fact, the history of the world would tend to indicate that very few societies were persistent in the long term, and the history of advancing economic complexity is not just poorly recorded, but was in fact intermittent and often retrogressive.

At the same time, recognizing the turbulent history of economic practices, I still want to make this argument that the Lotka/Odum MPP was the most important factor in driving increasing complexity and persistence of economic practices leading up to the blossoming of today's modern globalized economy. Our economic practices are encoded in memes, or social contracts, and these memes are the objects by which, and upon which, the MPP has bestowed this increasing economic complexity.

I use the word “meme” in a sense close to that intended by the person– Richard Dawkins – who coined it as an analogue of the word “gene”. (See Ref E.) A meme is an idea, and the usefulness of that idea makes it attractive to those who hear it. The idea then spreads and becomes part of the world view of many people. Then, in similar fashion to the way genes control our biophysical functions, memes that are incorporated into our world view and our thought processes are able to control our thoughts and actions, they are able to structure our social institutions, and they can create a stable environment in which complexity can grow.

I would like to extend the meme idea to include the social contracts and physical institutions that people create under the influence of a meme. For example, trial by jury is a meme which has spread around the world and shaped the modern justice systems of many societies. That meme has determined the architecture of court houses, requiring the 12 seats for the jurors, and three benches for judge, prosecutor and defendant. Our societies have embedded this “trial by jury” meme into our laws, our understanding of fair justice, our architecture. I would argue that the MPP has been instrumental in elevating this meme to a condition of persistence.

Memes exist originally as ideas –combinations of electrical signals in the brain. But they can be physically embodied in many ways. If nobody has ever had the idea pass through their head, the meme exists only in some Platonic space where all undiscovered mathematics might also exist. Or, it may pass through the heads of many people, be regarded as a not-very-useful idea, and be discarded. We have all heard some “wrong-headed” ideas and forgotten them. But some ideas, once uttered, can gain a life of their own and stick around as opinions worth considering, or interesting explanatory information. Such ideas can transition to physical form when written down and published in many copies. Some can be encoded in moral codes preached from pulpits that encourage our restraint. Or they can be encoded in laws and regulations that require our constraint. Societies spend a lot of money and energy on legislatures, police forces, justice systems and penal systems to translate memes into laws, enforce them, and adjudicate and punish those in breach. There is even evidence that thoughts can become habit-forming, and can be hardwired into our brains due to neurological plasticity.

Memes are a critically important part of economic systems. At the most basic level, economies function because the members of a society behave in a way that allows the economy to function. There is a very long list of constraints that we place on our social behaviour that are necessary preconditions for a viable economy to function. Primarily, we must learn to respect property rights as a very high priority. Modern societies all have very complicated laws, rules and regulations related to property rights, and our jails are often full of those who are in breach of them. We must also respect the monopoly of those who make currency, so that property rights can be transferred safely to currency, and from there to others. Imagine what society would be like if, suddenly, all greed and all sense of ownership was removed. You could enter any house you pleased and live there. You could enter any grocery store and take whatever you wanted and eat it, and nobody would object. We would be like simple people living in the jungle, free of property-related constraints, living happy lives. But nature re-stocks the store for inhabitants of jungles. With seven billion inhabitants on the Earth, we need the global economy to re-stock the store. In such an idyllic society things would soon run down or run out and famine and chaos would ensue.

It can be argued that many mammals, if not most, have some sense of property. That meme is partially encoded in their genes, and partially learned from experience. Why was our species able to break free of our genes? Somehow, at some point, we learned how to encode memes more effectively via social contracts, and that sent us on our way to ecological dominance. I would guess it happened as we developed language capabilities, and learned to encode memes in words and sentences. And, did we ever break free!! It is easy to argue that a modern global economy requires the elaboration of some very sophisticated memes involving abstract concepts of risk, all encoded in mathematical formulae, in contracts, and in computer software, hardware and networks. Much of the world's higher finance goes on without much human intervention, processed by the physical embodiment of our memes, and those memes drives globalization affecting us all.

But, I think that many of the most powerful memes are encoded in our social mores and ethics. We do not steal because we believe deeply that theft is bad. Who among us would feel concern if a young thief were sent to jail leaving his family bereft? We would seriously question his moral fibre, and not the absurdity of property memes. We place property rights on a very high moral pedestal, and that is what makes our economy function well.

I understand that the earliest evidence of inter-tribal trading activity goes as far back as fifteen to twenty thousand years ago. It has been a long slow climb upwards from those primitive economic memes to the modern era. What was it that caused some memes to be preserved and spread, and others to be ignored? I contend that it was the indirect result of the MPP selecting those social processes that consume more power and cycle more matter. Those memes that more effectively encoded adaptive social behaviour, that gave some tribes survival advantages – those memes became persistent, and spread. I note that it was not always a pretty story. The MPP has no real moral sense.

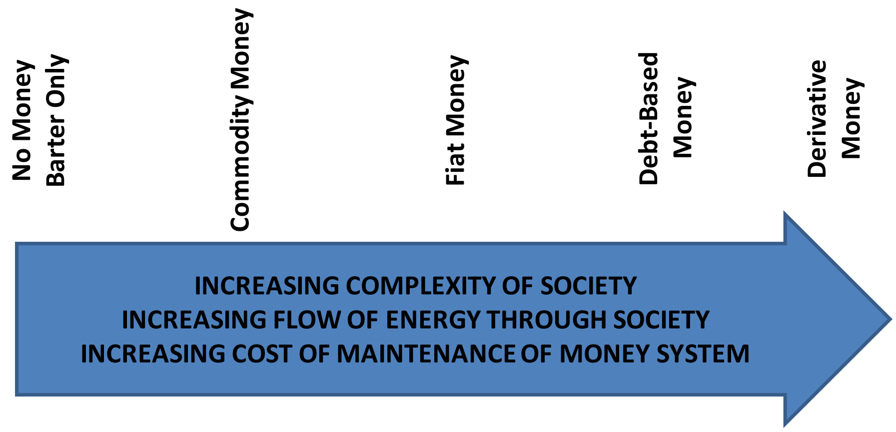
Before moving on I think there is one last point that needs to be made. The MPP is the cause of this increasing web of mores, ethics, social norms, laws, rules, and regulations, and all of that makes the society and the economy stable and persistent. But, the MPP is also responsible for taking apart such "red tape" when it no longer improves the power of the system, and becomes a drag. It suppresses moribund processes and squeezes out maintenance costs. So, this supports the idea that, sometimes, the economy needs to have some red tape – some of the social constraints – removed. But, the difficult questions are "How do you tell the difference between the good constraints and the bad constraints?" and "Good and bad for who?"

5.3 - Continuum of the Complexity/Cost of Money Systems

A theme that will be running through this NTF involves the increasing complexity of the money system and the role that plays in the economy. I think that the MPP is the driving force that causes the money systems of the world to organize themselves and then to grow in size, in scope of effect, in power, and in complexity. It is my hypothesis, herein, that the conservation of energy is somehow emulated by our social contracts around property ownership and the money used to exchange property rights. For this reason, an explanation of the connection between the MPP and money is a necessary piece in any description of a globalized economy.

On the other hand, there have been, I suppose, millions of pages written about money. And there are many ways that money has been classified (e.g. national standards for M0, M1, ...). And there are several very complicated theories about the origins and nature of money (e.g. metallism, chartallism, neochartallism, etc.). The word "money", like "energy", "entropy" or "gravity", is a noun that lots of people use and few people really understand. I offer this perspective on money, not as being necessarily more correct than others, but as one that arises from a developmental dynamic based on an understanding of fundamental statistical phenomena.

Figure 01 – The Continuum of the Complexity/Cost of Money Systems



The historical occurrences of money have been far more varied and complex than I am about to suggest, forming an overlapping ever-changing mosaic of practices. But there is a continuum between the extremes of no money on the one hand, and modern money on the other. Within that continuum I wish to identify three general interim stages of existence each of which exhibits relative stability, and stability is good for business. In the spirit of Joseph Tainter's argument (see Ref F), I suggest that the complexity of society needed to support each stage increases as we move from left to right in Figure 01. I also suggest that each step towards the right usually encapsulates and expands on the previous step, so that some measure of the function of those money systems on the left remain in place as each step is taken towards the right. It would also be my contention that each such stage in the development is more efficient at enabling the exchange of goods and services than the previous. I propose that, at each stage, there are markedly different properties, as I outline in the following tables. I cannot speak to the nature of derivative-based money, as I think that is just now emerging from the fog that envelops the developing financial economy, but I expect it is forming there, as the next rung of the ladder of economic evolution.

TABLE I – Comparison of Intermediate Stages of Money Systems

Commodity Money	Fiat Money	Debt-Based Money	
		Money (credit)	Anti-money (debt)
Based on rare items such as precious shells, stones, gems, and metals	Based on monopolized and authorized precious metals	Based on loans from merchants, first, and now bankers	

TABLE I – Comparison of Intermediate Stages of Money Systems (continued)

Commodity Money	Fiat Money	Debt-Based Money

		Money (credit)	**Anti-money (debt)**
Can be found with effort and luck, and made more valuable with effort	Created at great effort (mining, refining, minting, printing, transporting, guarding) with the authority of social approval, even if obtained by force.	Created relatively easily, by vetting the dependability of the debtor, executing agreements, enforcing payments, with the support of social norms that payments are obligatory, debtors up by debtors prison, or other means of social disenfranchisement.	
Explicitly physical in form	Physical form (e.g. coins) but with logical stamp of authority (e.g. King's face)	Exists as IOUs, which are a form of social contract. Possibly have some physical representations, ranging from almost purely physical form (e.g. sticks or tablets with marks), to paper form, to largely logical form (e.g. bits in computer data banks).	
No means to account for debt.	Debt management is external to this money management schema, managed as separate physical records.	Debt management is integral to this money management schema, recorded as negative money.	
Traded for goods and services	Used to pay taxes to the government in lieu of goods and services	Used by borrower to purchase goods and services	Used by moneylender to facilitate business (merchants) or to earn interest (bankers)

An understanding of the revolutionary qualities of debt-based money is key to the arguments I develop below, so I want to discuss it in more detail. When a bank loans money to someone else, there are two kinds of money created. The first kind can be called credits, or positive money, or just money. The other kind can be called debts, or negative money or anti-money. Created from nothing like an electron/positron pair, each type then has a life of its own and flies off into the economy never to be rejoined. The positive money enters the real economy and is used to purchase real estate, or agricultural or industrial inputs, or goods and services. It may or may not generate profits, depending on the vicissitudes of the market. Some positive money eventually aggregates in pools of credit such as pension plans or corporate or personal savings, or hoards that are isolated from the economy (no longer in circulation). The negative money on the other hand enters the financial economy and generates profits by earning interest. Some negative money eventually aggregates in massive pools of debt such as corporate and sovereign debt. In Table II I look at debt-based money more closely.

TABLE II – Comparison of Money and Anti-Money	
Money (Credit)	**Anti-Money (Debt)**

Borrower can use it to purchase a stake in the "real economy"	Lender gains a stake in the financial economy.
Borrower must pay interest on this.	Lender must earn interest on this.
Usage in the real economy can result in profits, or losses. In fact, every binary commercial transaction carries with it some measure of instantaneous profit or loss for each of the two participants.	Usage in the financial economy usually results in slow and steady long-term profits in the form of a stream of interest payments. Losses are realized suddenly as write-offs of debt.
Money can be loaned out again by the borrower to collect interest, and this is usually called the purchase of a bond. This creates a corporation-to-person debt. This does increase the supply of both positive and negative money. But if the lender is not a bank, then this increase in positive money is not counted as part of the national "money supply" and becomes part of a shadow money supply. In a sufficiently liquid market place the savings of investors are the basis for effective money-lending	Goods and services can be provided on the promise of later payment, i.e. in exchange for an IOU. This creates a person-to-corporation debt. This does increase the money supply, as the lender, the merchant, effectively loans the purchaser the required funds, which the borrower promptly used to pay for the goods. The borrower "invests" the goods and services in the real economy, and uses the profits to pay down the debt. In a sufficiently liquid marketplace, merchants play an effective role as money-lenders.
Can be sold in currency exchange markets subject to arbitrage.	Can be sold at discount in debt markets subject to arbitrage.
Demonstrates or exemplifies agricultural productivity, as profits (e.g. in food) = outputs (in harvest) minus inputs (in fertilizer, water, Sunshine).	Emulates agricultural productivity, as profits (e.g. in interest) = outputs (in principal plus interest) minus inputs (in principal plus write-offs)
Is subject to "2nd law taxes" in two forms: • When invested in the real economy is subject to thermodynamic 2nd law decay of living matter and wear, tear and depreciation of physical artifacts and infrastructure; and • When invested in the financial economy, is subject to the econodynamic 2nd law decay of interest payments.	Benefits from econodynamic 2nd law tax, in the form of interest.

It would appear that these two kinds of money are intimately tied together, by reason of their common origins, but fundamentally different by reason of their different characteristics. From the point of view of the history of mathematics, the negative numbers were invented, in Europe at least, in the period 1200-1600 by financiers who used them to manage debts, and this practice inspired some of the mathematicians of the time. Fibonacci (1170-1250) of Pisa, Italy, referred to them as losses or debits. Nicolas Chuquet (circa 1450-1500) of Lyon, France, referred to them as absurd numbers. Gerolamo Cardano (1501-1576) of Italy called them "numeri ficti". (See Ref G.) These fictitious numbers were used to account for fictitious money, also called debt, that I herein call anti-money or negative money. I also note that it was in this hotbed of the mercantile economy of Norther Italy that a tutor of the children of a merchant, Fra Luca

Bartolomeo de Pacioli (1447–1517), invented double-entry bookkeeping, a technique that does not require the use of "fictitious numbers" to manage debt. (See Refs H and I.) That practice is now used universally by merchants involved in international trade.

Perhaps this dual nature of debt-backed money is the distinction between M0 and M1, the two kinds on money defined in most national money supply systems that roughly correspond to checking accounts (M1), and savings accounts (M2). I note that savings accounts earn interest, while checking accounts tend to accrue fees. I also note that all countries mandate that banks offer both kinds of accounts to clients.

Each type of money system requires a broad support by many members of society if it is to function. That support exists as a number of types of social contract:

- There must be mutual understanding of property rights.
- There must be mutual understanding of the value of the currency.
- There must be standards of quality or value on both sides of the exchange.
- There must be trust between the participants in any exchange of goods and services for currency.
- There must be penalties for breach of the social contracts, administered by a "justice" system.

As a money system becomes more complex it requires a more complex set of social contracts to support it, with a higher cost in terms of energy. There is a feedback between the money system and the other institutions of society such as the education and justice systems. A complex money system supports a complex society with its many other social institutions, and the many social institutions support the complex money system. The effect of the MPP on the evolution of society is to increase the total flows (consumption) of energy through the system, but, at the same time, it squeezes the costs out of maintenance processes. A money system is surely the poster-child for such a maintenance system having little or no biophysical role. I would argue that only a highly sophisticated and effective society (i.e. effective at accessing energy and matter, as per Lotka's argument) can afford to develop and maintain a sophisticated money system.

There is a commonality among these particular money systems described in Tables I and II. Of all of the possible variations in money systems, these seem to emerge again and again, and they seem to be associated with social organization styles that have particular longevity. Of all possible means of barter, these appear to be selected for their stability and persistence, they become institutionalized in the form of standards, supply chains, manufacture and distribution systems, and usage mechanisms. Once this happens, complex societies can be built upon these memes. So, one can view these money systems as stable rungs of a ladder that emerge from the background continuum of possible money systems, supporting ever higher levels of complexity in the society.

5.4 - 2nd Law/4th Law Dynamics

In sections 6 and 7 I am going to develop my arguments for the existence of at least two parallel sets of laws governing the dynamics of systems, from the perspective of macro-level measurements and behaviour. The existence of the "Laws of Thermodynamics" is widely recognized, and used extremely effectively. I think there is a good argument for the existence of a 4th law of thermodynamics, for which Odum proposed the MPP as the best candidate. But, in addition, I see those laws as having a certain structure. The 0th, 1st and 3rd laws are clearly phenomenological, based on the underlying immutable laws of physics and chemistry. The 2nd and 4th laws, however, while also being phenomenological, use the immutable laws of probability and statistics to construct complex adaptive systems upon the base identified in the other three laws. In brief, the 2nd law implies that low-entropy systems cannot be persistent. On the other hand, the (proposed) 4th law implies that low-entropy systems must be persistent, and even expansive. If we look around us, we see that the 4th law usually wins, at least in the short term.

I argue that the 2nd and 4th laws, being caused by mathematical dynamics, are able to work their magic on any conserved quantity. They clearly work on energy. But I argue that they can work equally effectively on any economic commodity that is conserved in some fashion. This would include such things as farmland, uncommon metals such as gold, or modern debt-based money.

I believe that the economy is the product of several competing dynamics between the 2nd and 4th laws.

2nd law dynamics – The state of any system can be viewed as a point in a multi-dimensional Cartesian space of which each dimension represents a degree of freedom – a potential for variation. As such a system evolves, the probability that it transitions to a nearby point, or state, in any particular direction within the state space is, in theory, calculable, with the sum of probabilities of all such possible transitions adding to 1. Usually within a closed system the probability of repeated transition in one general direction is vastly greater than the follow-on probability of transition in the reverse direction. I characterize this asymmetric set of probabilities of transition as a probability gradient, and that determines the evolution of the system – that determines its trajectory through its state space. In a closed system this probability gradient is static – unchanging. Drawing insight from the paper by Dr Jeremy England (Ref J), the probability of moving from macro-state **I** to macro-state **II** can be denoted as $\pi(\mathbf{I}\rightarrow\mathbf{II})$ and the change in entropy can be denoted as $\Delta S = \ln[\ \pi(\mathbf{I}\rightarrow\mathbf{II})/\pi(\mathbf{II}\rightarrow\mathbf{I})\ ]$. (I explore the connection of this formula to my capital exchange models in EiLab at Refs Z and AA.)

This means that it is very highly probable that the system will automatically transition in a direction in which entropy increases. This is the phenomenon that drives energy to degrade (or to “do work” as physicists and engineers like to say). This is also the phenomenon that, within closed systems, causes complex structures of matter to decay, disintegrate, and generally wear down and wear out as entropy increases. Likewise, it is the phenomenon that causes spatial concentration of energy to disperse, and characteristic distributions of energy to emerge. In a closed system, the rate of entropy production is positive, and entropy increases to a maximum amount, and then the rate of production of entropy drops to zero as the expended energy is no longer able to “do work”.

The physical evidence of the action of the 2nd law might be the degradation of structures and patterns, the spread of a kind of sameness, or, in some circumstances, the appearance of high entropy distributions such as the Boltzmann energy distribution. In such a closed system the process is transient until a state of equilibrium is reached, and the tendency to approach a maximum level of entropy, and stay there, is often referred to as the Maximum Entropy Principle, or MEP.

I suppose these 2nd law effects would continue in almost exactly the same fashion when in an open system, but the effects are dramatically muted, or overwhelmed, by more powerful dynamics. Also, the process of entropy production is no longer transient, but continues at some positive rate determined by the rate of flow of energy through the system. In an open system, the tendency to continuously produce entropy at some high rate could be referred to as the Maximum Entropy Production Principle, or MEPP. I choose to consider the MEPP to be the system-level effect of the MPP in action.

4th Law Dynamics – I do not believe that 4th law dynamics are active in a closed system. If they are, they are muted and transient. But within open systems it becomes powerfully active. Within open systems two things happen. The flow of fresh energy into the system and of degraded energy out of the system changes the trajectory of the system through its state space, and must therefore change the probability gradient of state space making it dynamic and turbulent. The ongoing degradation of this fresh flow of energy ensures the continuous production of entropy in agreement with 2nd law expectations, as mentioned above. But, along this now turbulent trajectory, the MPP effectively increases and preserves complexity, steering the trajectory of the system into parts of the state space that has peculiar properties. Even though overall entropy production of the system remains positive, as the 2nd law requires, nevertheless, some parts of the system have lower internal entropy associated with protected complex structures.

The physical evidence of the action of the 4th law might be the appearance of structures and patterns, the spread of diversity, and movement away from high-entropy distributions.

Via the mechanisms of evolutionary dynamics such as variation and natural selection, the MPP must alter the gradient of probabilities in the state space to alter the direction of the trajectory to protect such structures. But, as I have said above in my assumptions, the MPP has its own internal antithetic dynamic:

- At the level of the overall system:
  - it increases the amount of energy captured, and the amount degraded (striving for 100% degradation),
  - while driving up the overall complexity of the system, and
  - while eliminating those complex structures and processes whose effectiveness has been surpassed.
  - In this process of removing ineffective structures and processes it mimics the 2nd law (or, perhaps, gives it free reign) by tearing down some of its own complexity in a creatively destructive sub-process; while
- At the level of individual energy transactions:
  - It maximizes the amount of useful energy that remains non-degraded,
  - Favouring those organisms and energy transformations that optimally preserve the quality of the energy, and
  - Favouring growth and reproduction over maintenance activities.

- In this process of favouring low-entropy structures, and processes that minimize the production of entropy, it defeats the 2nd law, overwhelming its effects, and selecting for and preserving increased complexity.

I prefer to characteristics these two kinds of dynamics as deep stochastic phenomenological dynamics that are expressed in thermodynamic systems, in ecosystems, and in economic systems alike. The interaction of these two stochastic dynamics with the physical world and its physical constraints lead to the five laws of thermodynamics. I would argue that, when they interact with the social memes that form the constraints of an economic system, they produce a modern economy.

So what if these very same deep stochastic dynamics were active within an economic system, and in that context we called them econodynamic laws? They would have broad explanatory powers, being applied to any of several possible conserved quantities (energy, farmland, money), and providing explanations at many hierarchic levels (economic agents, commercial transactions, national and international economies).

Figure 02 – Diagrams from the paper by Drăgulescu and Yakovenko (See Ref K)

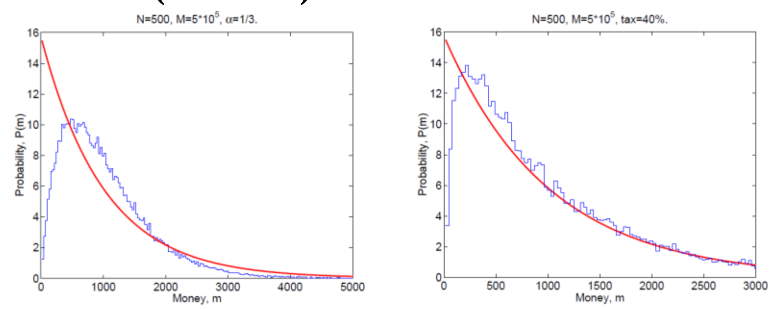


Fig. 4. Histogram: stationary probability distribution of money in the multiplicative random exchange model studied in reference [6]. Solid curve: the Boltzmann-Gibbs law.

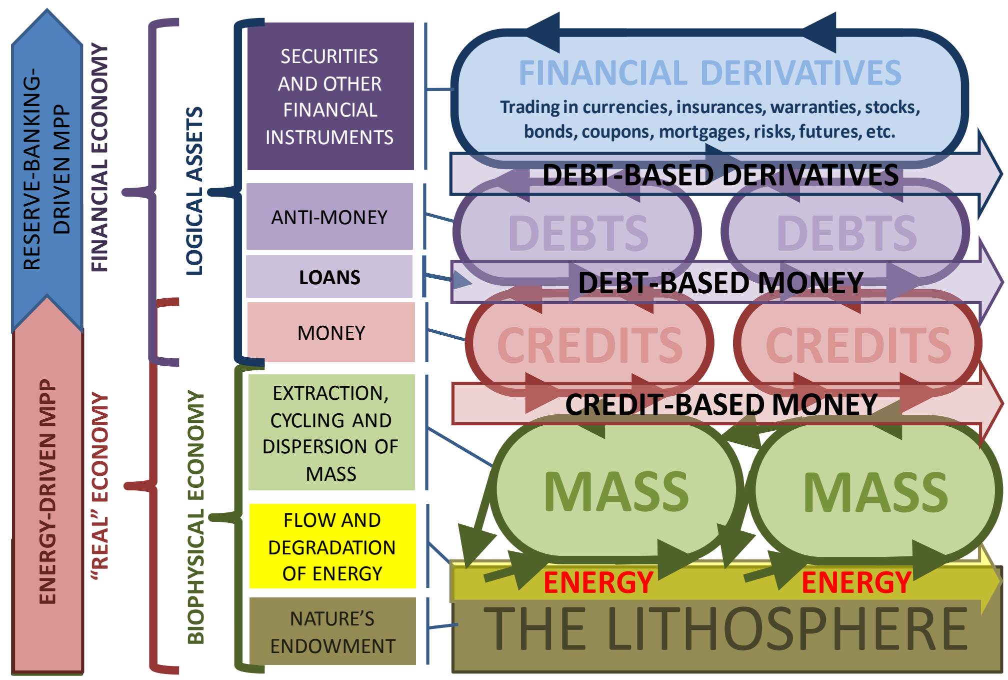
Fig. 5. Histogram: stationary probability distribution of money in the model with taxes and subsidies. Solid curve: the Boltzmann-Gibbs law.

What evidence is there that such deep stochastic dynamics are at work in the economies of the world? The work of Yakovenko (see Refs K-O) and other Econophysicists shows that economic systems tend to "relax towards equilibrium" in the sense that, on some relatively short time scale in the life of a nation, such as decades, both money and energy tend to accumulate in the hands of a few, while the bulk of people are poor (money) and have little access to energy. In fact, depending on the circumstances, the distribution of wealth, income, and/or access to income always approximates a Maxwell-Boltzmann or Boltzmann-Gibbs distribution, associated with a condition of maximum entropy in a closed system.

6 - The Big Picture

I am going to discuss the modern economic system in historical terms, thinking about how it came to be as it is, but also in the static terms of the modern global economy, thinking about how it works now. The historical approach provides me some insight into the role of the MPP that the static approach tends to hide. At the same time, many effects that appeared in the past have now largely disappeared, again due to the ability of the MPP to remove obsolete processes. Those effects may seem irrelevant to the modern situation, but they are certainly relevant to a discussion of the role of the MPP in economics. Figure 03 is the high-level diagram that puts it all together in my version of the modern global economy, high-lighting the role of different types of currency. The currencies are shown as horizontal arrows, and include energy, commodity currencies (not shown in final modern state), fiat currencies (not shown in final modern state), positive money, anti-money, and financial derivatives of many kinds. The parts of this diagram will be described piece-by-piece from the bottom up, starting with the physical world.

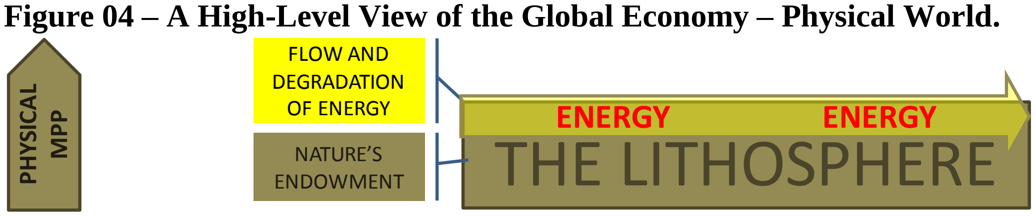
Figure 03 – A High-Level View of the Global Economy.



6.1 - The Physical World and the MPP

Figure 04 shows the bottom layer of the main diagram. In some sense this is what existed at the beginning, before life appeared on the Earth, but it also still exists now. There is a sense in which time increases as we move up the levels of Figure 03. This does not exactly mean that each layer, as it is added, represents a discrete step forward, because history is not that tidy.

Figure 04 – A High-Level View of the Global Economy – Physical World.



But, for this bottom layer, we can think of it as the primal state of the Earth, and we can also think of it as the base on which our modern society and economy currently rests.

The MPP was active in this primal state, and remains active today at this base level. The evidence of this is the occurrence, from time to time, of non-living self-organizing systems that have some persistence as long as suitable matter and energy are accessible to the system and continue to flow. Examples given by H.T. Odum were hurricanes, tornadoes, and water spouts, star formation and consumption, galactic formation. I would add to that the initial emergence of life.

6.1.1 - Laws of Thermodynamics and Statistics

There are four fundamental constraints on the behaviour of mass and energy that are called the laws of thermodynamics, numbered, curiously, from zero through three. (See Ref P.) In addition, there has been a long history of proposals for so-called fourth law, including Odum's maximum power principle (MPP) and another called the Maximum Entropy Production Principle (or MEPP). The various presentations of these two candidate principles make them appear to be incompatible concepts, but I would contend that they can be viewed as two different perspectives on the same phenomenon – two sides of the same coin. With this in mind I would contend that the MPP/MEPP meets all of the requirements to be recognized as a fifth law of thermodynamics, confusingly to be signified by the name "4^{th} Law of Thermodynamics".

I will continue in this NTF as if the MPP is widely accepted as the 4^{th} law, and as if the behaviour described above in Section 5.1 is widely accepted. I have convinced myself that these things are true, but understand that they are assumptions. In Section 6.1.2 I make my arguments in support of this assumption.

The laws of thermodynamics are macro-level phenomenological laws, because they are distinctively different from other laws of physics, such as Newton's laws of motion, or the universal law of gravitation. Typically such micro-level laws describe the interaction between two objects. Thermodynamic laws, in contrast, are applied to extremely large numbers of objects, such as the number of molecules in one mole of a chemical compound. Called Avogadro's number, there are approximately 6×10^{23} molecules in a mole of oxygen. To manage such immense numbers, macro-level measurements such as temperature, volume, pressure, density, concentration or entropy must be used in place of the typical micro-level measurements like position and momentum. In the early days of the development of thermodynamics, there were heated discussions over whether such an approach was valid. The great advances of Maxwell, Boltzmann and Gibbs came from their ability to connect the macro-level quantities measured by chemists in their laboratories with the micro-level quantities measured by classical physicists in their laboratories.

Before I outline the laws of thermodynamics, I want to talk briefly about their nature and relevance. We are all used to talking about energy and how it flows or can be stored. Of course, it does not flow, and it cannot be stored. These are metaphors that we use to describe events, effects and changes that we see in the world about us. Energy does not exist as a thing, nor as a substance like a soft wax, nor as a gas or a liquid or an ethereal substance. It is purely a mental and mathematical construct – a social meme. We see this wide range of phenomenological effects, and we call them energy. Nevertheless, these clear effects and behaviours are so close to the behaviour of a liquid that such metaphors are useful as a means to understand this weird concept we designate as "energy". There is a cloud of similar metaphorical words used in association with energy such as force, power, entropy, heat, etc. So, I will continue to talk in that metaphorical language, keeping in mind that all metaphors are approximations of something else. As stated by Alfred Korzybski (1879–1950), the developer of the field of study called general semantics, ***"The map is not the territory"***. That is to say, we must be careful not to confuse our models of reality – our words and equations – with reality itself.

As a pseudo-liquid, energy has some pretty odd behaviour. It is highly compressible, highly transformable, can "do work" – but only once, and in so doing can be degraded to become waste heat, and can only then be carried off on little red flying carpets we call infra-red photons. All of this sounds fanciful to the uninitiated, but careful study and discussion by serious scientists over a couple of centuries has worked out how all of this is true, and much, much more besides. This is all expressed as carefully defined metaphorical words that define natural "laws" that prescribe what this strange pseudo-material can and cannot do, and what the other associated metaphorical pseudo-materials are allowed to do or not do. Such laws exist as social memes, and we use those memes to understand the deeper real world modeled by them. But, such meme-expressed laws are metaphors of ***very real constraints that exist intrinsically within the biophysical world***. Those constraints are not merely social memes but real constraints. As the world changes, those constraints determine what changes cannot happen, what changes can happen, and the relative probability of occurrence of the possible changes. And so, the language and mathematics of statistical mechanics and thermodynamics has been developed to understand those constraints, and to build our modern societies on those understandings.

At this point, I must undertake a slightly more detailed review of the "laws of thermodynamics". There are several laws of physics that describe the behaviour of small numbers of large objects when they interact – usually two objects, such as two billiard balls. The concept of energy was first developed in this field of knowledge where many of the laws of physics were formulated. But many of the effects we see and measure in the world around us are due to the interaction of unimaginably large numbers of unimaginably small objects. The laws of physics were found to be impotent when applied to explain some very mundane experiences such as hot and cold. In the late 1800s there was a movement to apply the mathematics of probability and statistics to these problems. Men such as Maxwell, Gibbs and Boltzmann were leaders in this movement. The laws of thermodynamics, and then statistical mechanics, were eventually formulated to bridge the gap between the laws of physics, and such everyday experiences. There are four laws of thermodynamics that are widely accepted as true, and, curiously, as I said before, they are numbered from zero through three. When reading a modern text book you get the impression that these laws are in their final immutable form. But the 1^{st} law was not totally settled until the 1940s. The recent discovery of "dark energy" might open the books, again, on that 1^{st} law. And research on the 2^{nd} law is ongoing, with many journals dedicated to new discoveries. The work of E.T. Jaynes is seminal in this area of research. Then, there is an un-coalesced cloud of opinions about the need for a 4^{th} law.

These laws of thermodynamics are based on real-world constraints, but I am going to explain each in my own words in such a way that they might be seen as applicable to surreal social memes, later in this article. I will not be explaining each law in detail, as those details are covered in many text books. But, these are the laws that function at the base level shown in Figure 04. These are the laws that functioned to initialize life on Planet Earth, they functioned to initialize human society within that biosphere, and they functioned to initialize economies within human societies.

- **0th law of thermodynamics** – This is a subtle but important physical law based on empirical observation. It implies (my words) that ***thermal equilibria exist***, and it then implies, via a subtle chain of logic, that ***we can experience hot and cold as temperatures***.
- **1st law of thermodynamics** – This is a less-subtle and more important physical law, again, based on empirical observation. It can be viewed as a double-entry bookkeeping law. Total energy is a positive measure that can be associated with any system or sub-system. Energy can be viewed as existing in many forms and localized in many places. Energy can auto-transform itself from one form to another if given opportunity, and can auto-transport itself from place to place, again if given opportunity. ***Throughout all such autonomous changes, the total amount of energy is conserved.*** The nature, rate and magnitude of such changes are determined by probability gradients in the state space which represent other constraints arising from other laws of physics. I see this as an immutable physical law.
- **2nd Second law of thermodynamics** – This law arises from the interaction of the 1st law (and possibly the 0th law) with the immutable mathematical dynamics of probability and statistics. Entropy is a positive measure that can be associated with any system or sub-system. There are no good every-day metaphors for entropy, but there several interesting formulae in which it arises, almost always in association with the conservation of energy. When energy "does work" as it auto-transforms, the measure of entropy rises. ***In the course of autonomous changes, the sum of the entropies of the interacting thermodynamic systems is always greater than or equal to zero.*** Changes in entropy are directly associated with probability gradients in state spaces. (See Ref J, and section 5.4.) This law simply says that the trajectory of a system in its state space will most probably be in the most probable direction, and the most probable direction is overwhelmingly more probable that the opposite direction. Called the "arrow of time", this law says that systems cannot ever turn around and run backwards in time. In other words, the probability that the change in total entropy will be less than zero is the same as the probability that time will run backwards. I see this as an immutable mathematical law.
- **3rd law of thermodynamics**: This law returns to the definition of the concept of temperature, and places the measurement of temperature on a half-line continuum which has a definite lowest value called absolute zero. No system can ever be colder. Further, it ties the concept of zero temperature to the concept of minimum possible entropy. ***The entropy associated with a system approaches a constant value close to zero as the temperature approaches absolute zero.*** I do not really understand this one. I suspect it is a law based on physical constraints, and so becomes an immutable physical law, and not a mathematical law.

6.1.2 - A Possible 4th Law of Thermodynamics

I return to the issue of a 4th law one more time. Odum argued that the MPP should be elevated to be considered the 4th law of thermodynamics. As constraints, the other laws are necessary but insufficient to explain self-organizing behaviour within the physical and biophysical worlds. That self-organizing behaviour leads to the development and persistence of complexity of form and function that is the defining characteristic of the biosphere that gave rise to us. At least one more constraint must be identified to make the set of thermodynamic laws complete. One more law is needed to describe why and how self-organizing systems persist and evolve even as energy is conserved (1st law) and endlessly degraded as entropy is produced (2nd law).

As described in section 5.4, I would argue that every instance in which complexity of structure arises is evidence of the MPP at work, and every complex system that is persistent is strong evidence of the MPP at work. If that is true, then it is extremely important for us to understand, and, once understood, it deserves to be enshrined with the other laws. Some of the questions it must answer are:

- Why are self-organizing systems expansive, persistent and resilient as long as high-grade energy flows through them, but decadent as soon as it stops flowing?
- What is the exact connection between rising and falling entropy within distinct parts of a system (2nd law) and conserved energy (1st law) in continuously energized open systems?
- How does the MPP (4th law) interact with the 1st and 2nd laws to cause internal entropy of some sub-systems to decline even while the external entropy is driven upwards by the 2nd law?
- Is the self-organization of continuously energized open systems towards maximum power just as inevitable as is relaxation to equilibrium for closed systems?

There is one point that I wish to repeat before I move on to discussion of economics in the biophysical world. I have to ask myself "How would one more constraint be able to convert a system that is fundamentally inclined to destroy complexity into one that is fundamentally inclined to increase complexity? Two simple examples help me to believe that this is possible:

- **Ditch with protrusion** – Imagine a ditch with perfectly straight banks and a smooth bottom, and a gentle grade. The water in the ditch flows smoothly downhill. Then place a protrusion in the ditch that blocks the 50% of the channel on one side such that a small back-eddy forms. The gathered momentum of the water flowing downhill will cause some portion of the flow to turn around, in the back-eddy, and flow uphill, in defiance of gravity. The intrusion causes turbulence that results in water behaving in a counter-intuitive fashion.
- **Sailboat with keel** – Imagine a sailboat having a large triangular sail, and a rudder, with no keel. The rudder would be of little use other than to keep the nose of the boat pointed directly downwind, making it clip along more quickly. But, even if the boat was turned at 90° to the wind, it would still travel downwind. However, when you add a keel to the boat, it is able to travel at an angle upwind, in a process called tacking. The addition of a keel enables the sailor to maneuver his boat in a direction against the wind.

6.1.3 - Summary

In the purely physical world, as depicted in Figure 04, there are five laws that might be considered macro-level laws, associated with the discipline of study called thermodynamics. These can be classified as followed:

- 0th law – physical phenomenological law – explaining the phenomenon of temperature
- 1st law – an accounting law associated with a conserved quantity, energy – with a phenomenological basis
- 2nd law – a deep stochastic dynamic – dominating closed systems which obey the 1st law
- 3rd law – physical phenomenological law – putting temperature on a half-line axis
- Proposed 4th law – a deep stochastic dynamic – dominating open which obey the 1st law

6.2 - The Biophysical World and the MPP

Figure 05 is the next layer up and represents the biosphere. The MPP causes the biosphere to expand in biomass (i.e. get larger) and in scope (i.e. collect more energy). It adapts by expanding its arena of operations from the tidal pools by the seashore onto the continental shelves and into the abyss, and also onto the land and into the air. It causes biochemical pathways to diversify, working in many temperatures, or extracting energy from many diverse sources.

The two aspects of the MPP play a role. It causes organisms to expend as little energy as possible on maintenance, and as much energy as possible on growth and reproduction. A Darwinian-like process of natural selection enhances those processes that capture and consume more energy, and suppresses those that lose their former share. This internal antithetic tension within the MPP that both represses consumption of energy at the micro level and enhances consumption of energy at the macro level leads to all manner of emergent effects such as distinct species, distinct genders, variant ecosystems, nested hierarchies of structures and processes emerge, programmed death in the form of apoptosis and old age, and other evidence of self-organization leading to evolving complexity happening at all scales of size and time.

Figure 05 – A High-Level View of the Global Economy – Biophysical World.

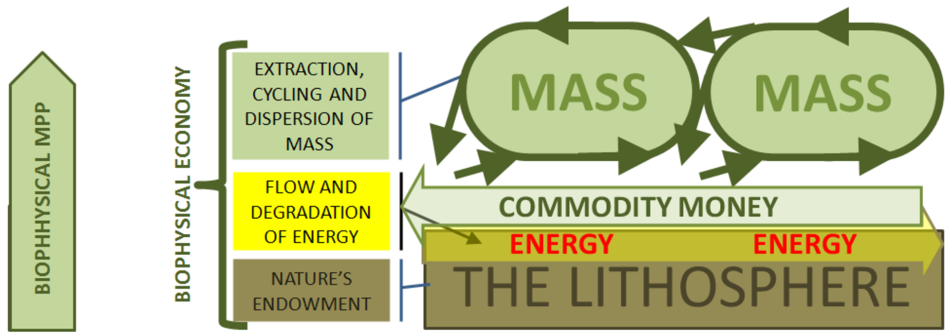


Figure 05 might represent hunter-gatherer societies, and primitive agricultural societies, and early multi-ethnic trading societies. At this level human society functions primarily without money, but the use of biophysical objects as commodity money appeared spontaneously in many independent societies around the world to facilitate barter, and may still exist in remote societies. The earliest long-distance trade in Europe, for example, tended to involve commodity money such as Anatolian obsidian, Baltic amber and Mediterranean seashells starting as early as 12,000 BC. Or, in many parts of the world the porcelain-like cowrie shells and their replicas were used as money. (See Ref Q.) As I understand it, even gold and silver were used as commodity money before the invention of coinage, so the distinction between fiat money and commodity money becomes a fuzzy grey line. Commodity money is the first semi-stable rung on the ladder towards complex societies and complex economies.

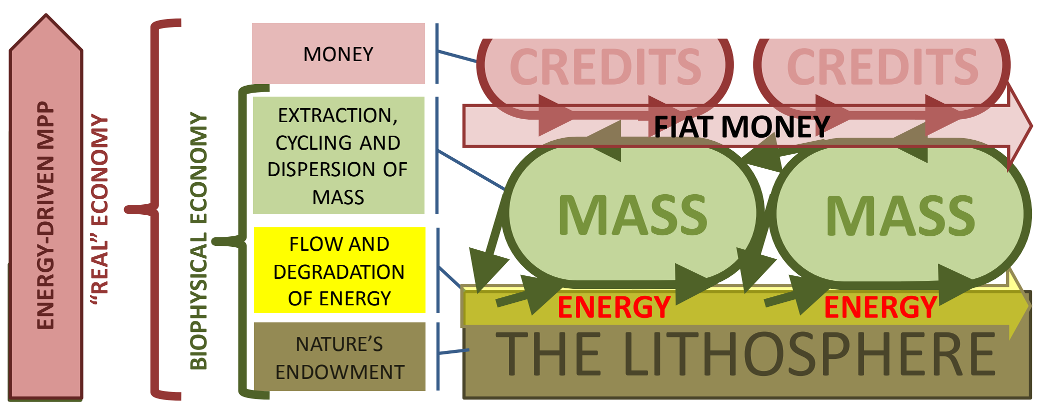
The two green loops in Figure 05 represent multiple organisms, ecosystems or biomes that each have their own biophysical economy. The arrows are meant to represent the circulation of matter in an endless cycle, and the right-pointing arrow for energy is meant to represent the flows of energy from source to sink. Commodity money flows in a direction opposing the flow of matter and energy.

6.3 - The Fiat Economic World and the MPP

The first level of economic activity above the purely biophysical level appears as what is commonly called fiat money. In Figure 06 I have removed the arrow for commodity money and added an arrow for fiat money. Eventually precious metals such as gold and silver were used to make coins, as they could easily be shaped and minted to make them more difficult to duplicate. The standard understanding of fiat money is that a Government (e.g. King, emperor, or senate) has a monopoly on gold and uses it to drive the economy. Money was minted and used to pay for goods and services. For example, it would be paid to the soldiers for services, or to artisans for manufactures products. The King then taxed it back from the population in general, who had to sell enough goods and services to get enough money to pay their taxes. In Modern Monetary Theory such money is often called vertical money, (see Ref R) or U-shaped money, because it comes from the top, goes through the economy, and returns to the top.

Unlike commodity money, the creation of fiat money is monopolized by the leaders of society, and that brings some stability to its dynamics. Sources of supply must be stabilized. Artisanal skills must be standardized and taught. Minting, transportation, storage, and security must be managed. Laws must be promulgated, and enforcement must be administered. The education of the populace must be undertaken, and compliance achieved. In short, a complex social system must be institutionalized, and there is a social cost (paid in energy) that must be born. That's a big challenge, but once achieved by societies, economies flourished, flows of goods and services (i.e. matter and energy) grew, kings arose. In ancient societies, farmland produced energy in the form of food. According to the dynamics of the MPP, those societies that garnered the greatest share of the flow of energy (usually due to the control of the most land) would out-compete those with a lesser share, and would add that share to their own. Villages were dominated by towns, towns were dominated by cities, by Kingdoms, and by empires.

Figure 06 – A High-Level View of the Global Economy – Fiat Economic World.



The flow of money at this level, again, is always in the opposite direction from the flow of matter and energy. In my diagram I show it flowing left to right but that only represents the contact between money and matter and energy. I suppose that I could put the "fiat money" arrow on top of the "energy" arrow, but right to left, as

I did with commodity money, but that doesn't work with the next layer above, so I leave it like this, opposing the flow of matter. The tops of those purple loops are missing to indicate it is U-shaped money.

The flow of fiat money both mandates and accelerates the rate of exchange of goods and services between people, adding to the rate of consumption of matter and energy, and enabling faster growth of the biomass and the economy. So, in a sense the MPP causes people to invent fiat money. Due to the dynamics of the MPP it is inevitable that those societies, in which people specialize their production, will learn to trade. And, it is then inevitable that such societies will then invent fiat money of some kind. So, it was invented independently all around the world in a wide variety of societies.

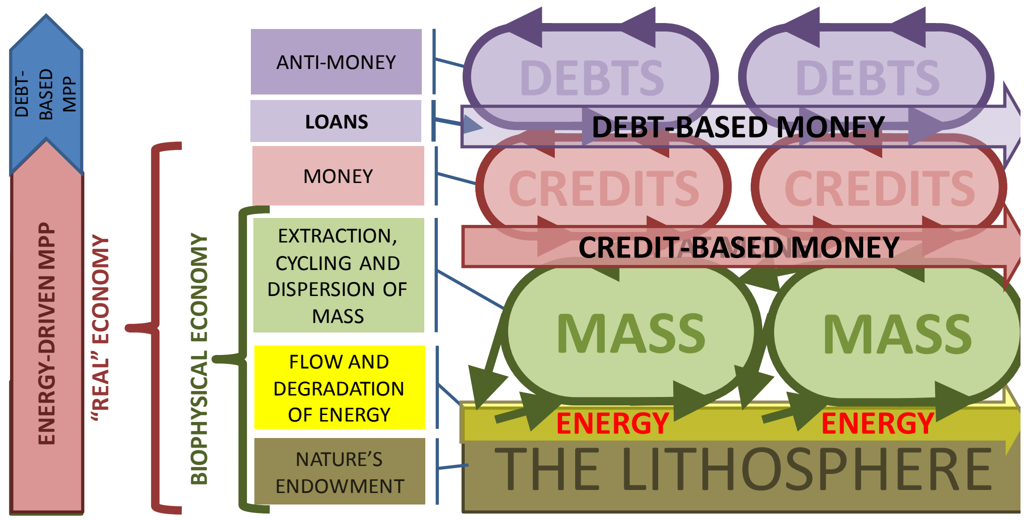
So, I am not saying that the MPP forces us to invent fiat money. I am saying that our best interests (growth of our economy, growth of our nation's power, dominance of our society over other neighbouring societies) are all aligned with the direction of evolution of the biosphere towards higher rates of capture and consumption of energy. Those societies that do not out-compete their neighbours falter and fail. The winners often-enough have more vibrant economies. So, by our actions we support and enhance the natural direction of evolution of the system in which we live. We hunt, we grow potatoes, we have children because it is good for us to do these things. It makes our species, and our society persistent. We are programmed genetically to increase the probability of survival of our children in any way we can, and cooperation, trade, and the invention of fiat money are all ways to do that. We invent fiat money because it is good for us to do so. Those evolutionary forces become our genetic imperatives, and we do what we do because we are schooled to align our actions with the laws and forces of nature that expand the scope and scale of the biosphere. The MPP does the schooling, by reason of the fact that philosophies and practices that do not align with the MPP are not selected for, and have an unstable existence.

What has happened is the MPP has caused several facets of human society to co-evolve, including the development of agricultural technology (better plants and animals), the construction of infrastructure and artifacts, the trade of goods and services, and the development and use of fiat money.

6.4 - Debt-Based Money and the MPP

What I am here calling "debt-based" money (see Figure 07) exists because of the reserve banking system organized around double-entry bookkeeping. When a bank makes a loan, two accounts are created. In one account the person receiving the loan, the borrower, gets credit for, say, $1,000. In the other account, the borrower gets a debt for $1,000. This money and anti-money are created, like matter and anti-matter, from nothing. Credit-based money replaces fiat money. While debt has been around as long as money has, debt-based money emerges from sophisticated techniques used to manage debt.

Figure 07 – A High-Level View of the Global Economy – Debt-Based Economic World.



The two purple loops in Figure 07 represent the multiplicity of banks and merchants and other lenders that now have the ability to create debt-based money out of nothing.

The replacement of fiat money with credit-based money, and the simultaneous creation of debt-based money was and is a spectacular step forward for two reasons.

- **First**, it enables the release of the top side of the economy from the shackles of the biophysical world. The total amount of money no longer needs to be dependent on the amount of gold that can been mined, minted, and put into circulation. Such a potential removal of the shackles of biophysical reality became an inevitable reality once the reserve banking system and debt-based money were invented. But that release was not immediate.
- **Second**, it also establishes a form of conservation law for economies. The total positive money equals the total negative money, creating a kind of monetary symmetry. I know such a law has a lot of leakages that tend to break symmetry, or break conservation. Alterations to money supply due to counterfeiting activities, or wanton destruction of circulating cash cause breaches of conservation rules. But, apart from such leakages, normal economic activity proceeds on a vast scale, and money is more-or-less conserved. So, we have a financial analogue of the 1st law of thermodynamics which I choose, in this NTF, to call the 1st law of econodynamics.

I explore these ideas in the computer model CmLab (Conservation of Money laboratory) and the associated diary notes. (See Refs AB through AD.)

I would argue that this lays a platform – a logical platform – on which the 2nd and 4th laws, and similar deep stochastic dynamics, can build a logical financial system almost as varied and complex as the biophysical system we call the biosphere. Within the social memes that are embodied in, and realized in the reserve banking system are fundamental logical constraints that have similar effects to the fundamental biophysical constraints that govern thermodynamics.

But, this logical platform is made manifestly biophysical in the mortar and bricks of our banks, in the paper, glue and ink of our law-books, and in the widespread social acceptance of the associated practices around property rights. So, reserve banking leads to conservation of money, which in turn leads to dramatically more powerful self-organization of the financial economy, which we might call the "econosphere", or the "financiosphere". ☺

I am not saying that loans (and debt) did not exist under regimes representing commodity money or fiat money. Money-lenders and debt are as old as money. What I think I am try to say is that, at some point, roughly in the late 1700s and early 1800s, somewhere in Europe and the USA, the monopoly on making money slowly shifted from government fiat to banker fiat, and bankers can now create money from nothing, while governments can no longer do so. At one phase in this transition, merchants also had the ability to create money ex nihilo, but the monopoly ultimately passed to bankers. I would argue that, due to the dynamics of the MPP, such a transition was inevitable. In fiat money systems there were artificial constraints on the flow of matter and energy, such as limited quantities of gold, and excessive costs of storage and security. The MPP now had two platforms on which it could stand to do its work:

- Within the biophysical economy, those economic processes that were able to garner a larger share of the flow of matter and energy at less cost grew in energetic power and displaced those that lost share. The artificial constraints were flanked, and the processes of higher power became standard.
- At the same time, within the financial economy, those economic processes that were able to garner a larger share of the flow of money at less cost grew in financial power and displaced those that lost share. The maximum power principle found new footing on a higher platform constructed out of social memes, as embodied in banks, laws, and social acceptance.

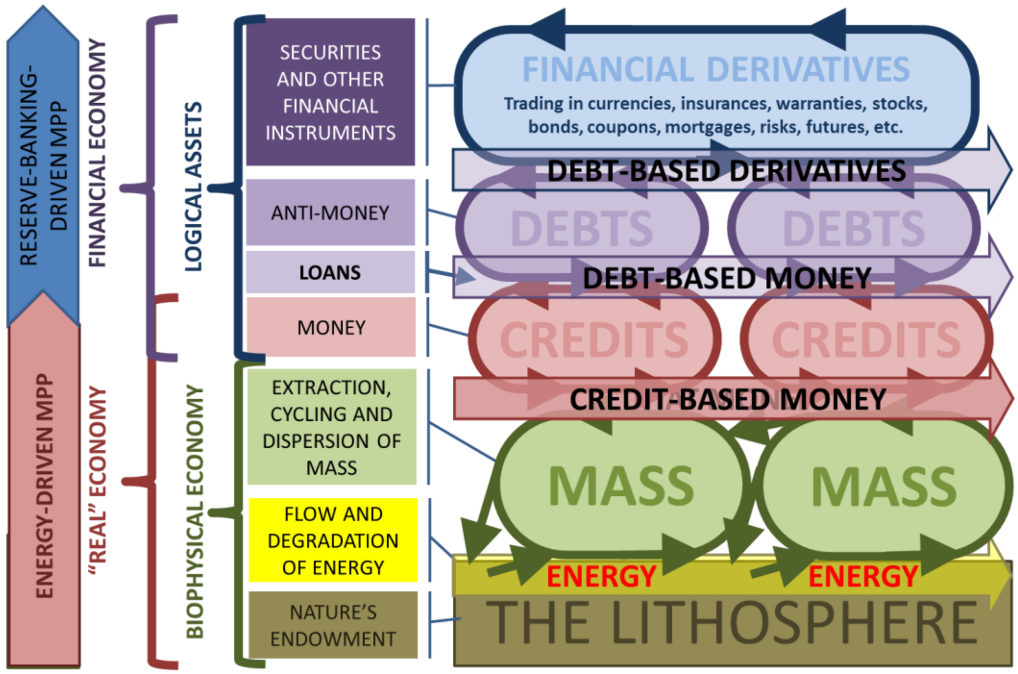
6.5 - The MPP and Financial Derivatives

I admit that I am now getting highly speculative. But I believe we are seeing a new kind of "money" being invented during our generation, since 1970, and that I am referring to, here, as derivative money. Financial derivatives are portions of a real-economy asset, such as a mortgage contract – portions that are separated out and sold apart from the contract. These are things like future values (as opposed to present values), risks of default, insurances against defaults, tranches of mixed assets, etc. Certainly these are bought and sold using debt-based money most of the time, but for many financiers, the money is background noise to the reality of the derivatives and their interactions. These derivatives are the blue area at the top of Figure 08.

However, getting back to this "spectacular step forward", the process of release of the financial economy from the biophysical constraints, of which the derivatives are a hallmark, took a while to be effected due, I suspect, to the countervailing pressures of the Kings' and governments' reluctance to give up their monopoly on money, and their general reluctance to dispense with the gold standard. For example, in Europe and the USA the reserve banking system grew into prominence in the mid-to-late 1800s making fiat money obsolete, and putting governments in debt to bankers. But the gold standard was not abandoned until the 1900s, about 100 years later. The governments to date still maintain some pretense of control over the money supply, but it is a delusional pretense. Many, if not most, are deeply in hock to bankers of some sort.

But we should not be too enamoured by the idea that the economy has broken free from energy. What I mean to say is just that the dynamics of the financial economy have achieved some substantial independence from the biophysical world. Energy from the Sun and matter from the lithosphere still fuels all of this. Hubbert's curve provides clear evidence of the ability of the MPP to "school" us to discover, access and use such previously unknown or inaccessible sources of energy. Our climb up the rungs of the economic ladder is all fueled by the rising consumption of energy, and enabled by the advance of technology, all of which is made possible by the high level of complexity achieved all across the global society. The growth of the "real economy" has been dramatically facilitated by the development of the reserve banking system and the move away from fiat currency, and the associated move away from metal-based (coin-based) currency. This is clear evidence, if you wish to see it, of the selective power of the MPP to develop complexity where simplicity was once the only option. But, at the same time, a new platform has been created, and a less biophysical version of the MPP is ready to go to work, standing on that higher logical rung.

Figure 08 – A High-Level View of the Global Economy – Derivatives-dominated Global Financial and Real Economies.



I suppose I should give a thought to paper currency. Originally there was a lot of "commercial paper" that essentially existed as IOUs that competed with the "bearer on demand" notes that governments produced. Government notes were backed by gold. Commercial notes were backed by reputation and evidence of ability to pay. In either case, IOUs (debt-based paper money) was used in lieu of coins, and so the rise of paper money is part of the process towards purely logical money.

I discussed the reserve banking system above, because it was an important innovation to better enable the debt-based economies of the period of roughly 1850 to 1980. It enabled the financial economies of the world to loosen the shackles that tied them to the real economies, but it did not enable them to immediately and entirely break free. Like a float-plane fitted with pontoons trying to take off from a choppy lake, hindered and slowed by contact with the water and waves, the financial economies did not really take flight until the decades of the 1970s and 1980s. I looked at some of these things in my presentation on the BDY model at the CANSEE conference in Vancouver. (See Refs S and T.)

Certainly, all of the things mentioned in the blue area at the top of Figure 08 have been around for a very long time. E.g. the Bible mentions the money-changers of the Roman Empire. Or, stocks have been around since at least the 1600s when corporations were being first formed. So I don't mean to imply they did not exist until the 1970s. What I mean to say is their role changed dramatically at about that time. But, this diagram is not really meant to be a history lesson so much as a dynamic structure. This is the crown of the modern global economy.

What happened in the 1970s? Up until that time there was a surplus of energy available in the form of fossil fuels to be taken freely from the lithosphere. This source of wealth was used in some fashion to back all government money. In the 1970s the US, the largest economy in the world, suffered a peak in its oil production which, for the most part, has been in decline ever since.

A number of other things happened at the same time to cause the "financial economy" to lift off and take flight somewhat independently of the "real economy". I do not have the expertise to prove these things, but it seems to me that the oil crisis of 1972 had some influence in making these things all happen about the same time. Most countries had already abandoned the gold standard for money in principle, and took final steps in that direction. Indirectly, I suppose they abandoned the oil standard for money. The standards for Electronic Funds Transfer (EFT) were established which allowed financial instruments to be transferred machine-to-machine and bank-to-bank without being committed to paper, or without even being reviewed by a person. I recall in the late 70s and early 80s, as a computer analyst, being involved in discussions about 2^{nd} generation banking systems and EFT. The tethers to matter and energy were being dramatically reduced. A typical stock exchange can now execute more transactions per second than could be completed in an entire year not many years ago.

Social changes happened as well, also precipitated by the change in availability of oil. As the economies faltered, the past dependence of governments on vertical fiat money to manage their own accounts became no longer tenable. Governments reverted to selling bonds, and started to pass "deficit budgets" with the plan to "pay off loans in small current dollars with big future dollars", counting on inflation to wash away their debts. The balanced portion of their budget is based on vertical fiat money, but the deficit portion is horizontal debt-based money. Sovereign indebtedness started to grow. At the same time, the growing middle class stopped growing and started to shrink, causing the per capita tax base to decline. Cost reduction started to become a significant means of gaining market share, in place of innovation. Jobs with security and benefits started to be replaced with part-time, contract, or fee for services work. Jobs were exported "offshore" to Japan, the Philippines, and Mexico. The 1980s was also the decade of the "jungle fighters". They were young financial wizards who learned how to game the system of corporate controls for personal advancement to the detriment of their employers. Gutting corporation after corporation, teams of these people used stock manipulations, acquisitions and mergers and reverse takeovers to dis-assemble social structures and cash in the pieces. Clearly the game had changed. I view all of these social changes as evidence that the MPP had started to disassemble some of the old lower-power processes that were out-competed by higher-power processes. The very events that caused the financial economy to take flight also caused the real economy to falter, and start its decline.

So, what is the role of the MPP in this scenario? The impact of the law of conservation of energy is direct and massive at the level of the lithosphere and biosphere, at the bottom of my diagram (i.e. Figure 03.), but gets less strong and less direct as you move upwards. When dealing with the upper layers of this diagram, and considering the abstract nature of the assets being bought and sold (e.g. derivatives of insurance risks) and the money used (bits in a computer), one might wonder whether energy derived from the biophysical world has any ability to cause self-organization at this stratospheric height. Sure, energy keeps the lights turned on, but does the MPP, which selects for maximum power (in energy terms), have much effect on which derivatives will sell better? It is still there, but weakly effective, as it was in the days of the money changers in the Assyrian and Roman Empires. But, the phenomenon of the conservation of money provides a higher platform closer to the action on which the MPP can act. But, in this case it is not maximizing the flow of matter and energy so much as the flow of money in its logical form. Such a revitalized and strengthened version of the MPP has a dramatically increased ability to bring about increased complexity in these upper layers of the economy. I would argue that the impact of this logical version of the MPP is both direct and massive due to the raised platform of operation.

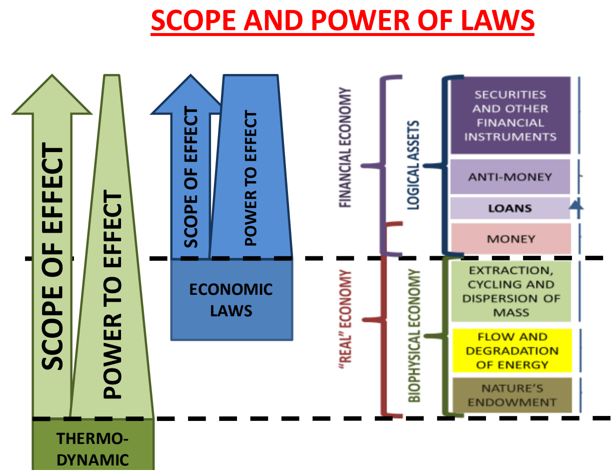
7 - Parallel "Laws of Econodynamics"?

I propose that we can write five "laws of econodynamics" to parallel the five "laws of thermodynamics". The concept of energy is the basis of the five laws of thermodynamics that govern the biophysical economy. Just so, with care, the concept of money can be the basis of a similar set of "laws" governing the dynamics of the financial economy.

I suppose it is rather naïve to think that there should be a five-to-five correspondence. I strongly believe that there are corresponding laws for econodynamics for the 1st, 2nd and 4th laws. The 0th and 3rd – maybe not. Others? Maybe so. But for now, I propose a set of five for five.

7.1 - Why would this work?

Figure 09 – Relative Scope and Power of Laws



Argument #1 – The conservation of money mimics the conservation of energy very closely. Energy is a logical construct – a social meme. Energy does not really exist. It is not a thing or a substance. It can be viewed as simply a book-keeping system with measures, formulae and conversion factors. We can use this system of measurement, formulae and factors to calculate a number that can be called the total energy of the system. But this number has this outstanding and incomparable quality: no matter what biophysical event happens, this measure of the system is conserved. Well, under the reserve banking system we again have this comparable situation. We have a very complex book-keeping system to track money. If we limit the definition of money to the product of loans under the reserve banking system, then, for the most part, there are measurements, formulae and factors we can use to determine the total money in the system. And, in the course of most economic transactions, the total money in the system does not change (well, not by much). So, at the base of the biophysical economy we have energy conserved. At the base of the financial economy we have money conserved, for the most part.

Argument #2 – The three most important laws of thermodynamics (1st, 2nd and 4th (proposed)) are based on mathematical phenomena that happen to be exhibited in the biophysical economy, but are also exhibited in their own way in the financial economy. This is not just because the financial economy exists as part of the biophysical world, which would be argument enough. It is also because the financial economy is able to exhibit those phenomena in its own right.

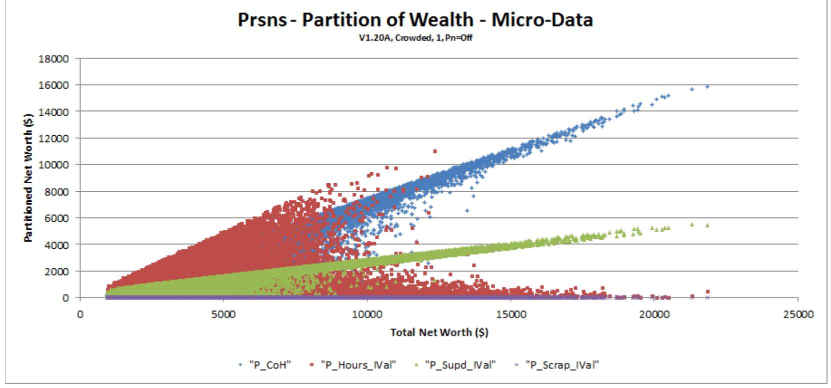
As shown in Figure 09, the laws based on energy and associated phenomena affect all levels of both types of economy, but have reduced levels of effect in those parts of the financial economy that are largely independent of energy flows. In fact, the connection between the biophysical processes and the financial processes hindered the rapid self-organization of complexity in the financial economy until that connection was greatly diminished, when the gold standard was fully abandoned and EFT came into vogue. But analogous phenomena exist in the financial economy, and, once unshackled from the biophysical hindrances, have quickly resulted in rapid development of staggering complexity in that arena – and they are potent.

What follows is, essentially, a mock-up of what the (five?) laws of econodynamics might look like.

7.2 - 0th Law of Econodynamics – Economic Equilibrium

According to the work of Yakovenko (See Ref N.), there is a financial analogue to the concept of temperature, and that is the average wealth per capita. This was true both in his logical models and in his empirical studies. In thermodynamics there is a complicated relationship between the concepts of temperature and energy. In an ultra-simplified version of that, temperature is a measure of energy per degree of freedom, so, if there are three degrees of freedom (three ways to store energy) then a change in energy will result in a change of temperature of about 1/3 the size. The rule of equipartition of energy determines now much energy goes into each "partition" – each degree of freedom. (See Ref U.)

Figure 10 – Per Capita Partition of Wealth in ModEco



In my ModEco model (see Ref V), a model of an intergenerational hybrid biophysical/financial economy, I found that agents must store wealth in several ways to be fully enfranchised. So while equipartition of wealth was not a necessity for sustainability, a predictable pro-rationing of wealth by agents was emergent. Figure 10 shows one of the charts from my Refs W and X NTFs. This graph contains a lot of data points representing data for approximately 150,000 agents living in a sustainable multi-generational economy. For each agent there are three dots – one of each of three colours – representing wealth held as cash (blue), supplies (green) and infrastructure (brown). The value of each is plotted against total net worth, so no point can be above the line y = x. The relevant point to notice here is that agents tended to maintain their wealth in a predictable pattern, especially those agents that were well off compared to the rest of the cohort.

Given all of this, I believe it is possible to research and define an analogue of thermodynamic temperature that plays a similar role in the laws of econodynamics.

7.3 - 1st Law of Econodynamics – Conservation of Money

This is a book-keeping law. Total money in all accounts and ledgers is a positive measure that can be associated with any economy or sub-economy. ***"In every legal economic transaction (except for willful destruction and counterfeiting) the total money in the financial economy does not change."*** The mathematical version of this might require the inclusion of a term about economic entropy, similar to the terms in the parallel thermodynamic law. This law works for money because money is a purely logical and abstract concept. Sure, money has temporary physical embodiment in various forms (coins, paper, ledger entries, bits in computers), but these are merely the bottles into which the ethereal elixir of logical money is poured. Perhaps this law can be expanded to include other types of capital such as real estate, but they might be less conservative suffering more leakage, and biophysical capital assets in the real economy (such as infrastructure) would be subject to degradation due to the 2nd law of thermodynamics. It would seem there is a continuum of types of capital assets from clearly biophysical (real estate) to clearly logical (insurance risks). Different types of capital may be subject to 2nd law taxes of different types in different proportions.

7.4 - 2nd Law of Econodynamics – Economic Entropy

This is a statistical law. Economic entropy is a positive measure that can be associated with any economy or sub-economy. ***"In any economy which is closed to interaction with other economies (i.e. the total money supply is conserved), the economic entropy associated with the economy will rise to a maximum value, and then remain at that value. The economy at maximum entropy will be considered to be "at equilibrium", and will be characterized by a Maxwell-Boltzmann-like distribution of wealth. In the course of autonomous changes, the sum of the entropies of the interacting economies is always greater than or equal to zero."***

I can think of several reasons why this wording is inadequate. On the other hand, there is plenty of evidence to show that such a 2nd law is active in the economies of the world, and has played a role in every civilization in history (See Ref F).

7.5 - 3rd Law of Econodynamics – Absolute Zero?

For this law to make sense I would have to define a notion of economic temperature, as for the 0th law. I am unsure whether there is a sensible analogy to be found here.

7.6 - 4th Law of Econodynamics – Economic MPP

I would use the wording of hypothesis MPP III here. (From Ref B.) ***"All persistent adaptive autocatalytic financial systems evolve to capture and degrade capital at a maximal possible rate consistent with available inputs."*** This version of the MPP is both an active factor in the financial economy, but also amplifies the effect of the Thermodynamic MPP. This is a statistical law.

8 - Last Thoughts

This NTF is long enough. Two additional thoughts deserve consideration before I close it out:

- The really big picture; and
- The role of the MPP in the degrowth of society as we slide down the slope of Hubbard's curve.

8.1 - The Really Big Picture

I discussed the rungs of the ladder as stable money systems on which stable societies and economies could be built. For each rung there is a pre-requisite level of complexity needed to establish the stable rung, and a sort of feedback between the society and the money system. A complex money system enables the establishment of a complex society. At the same time, a complex society requires a complex money system. They co-evolve, but they seem to coalesce at predictable stable levels leading to fiat money systems.

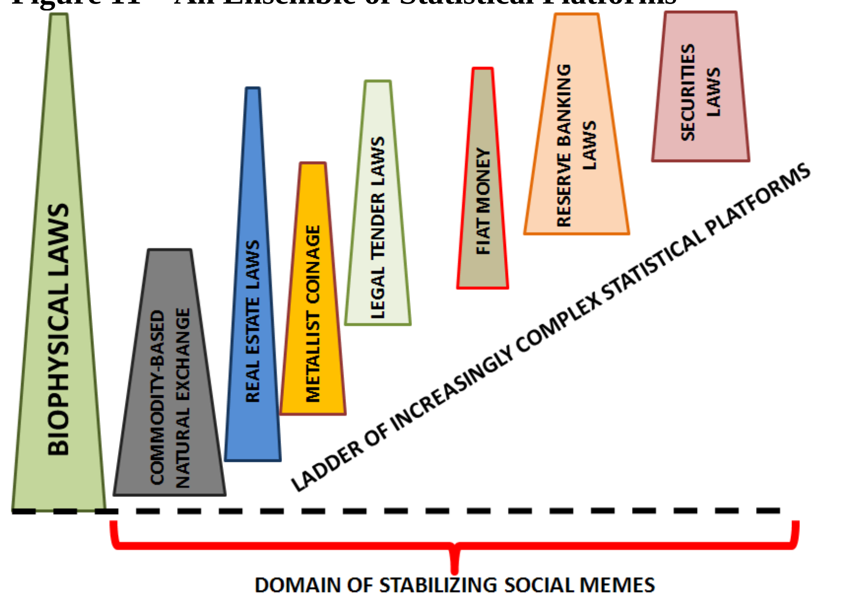
I discussed how the reserve banking system provides a peculiarly stable high-level rung on which the modern financial economy could be built. However, there are probably many sorts of semi-stable rungs on the ladder that I have not discussed. The most obvious example is real estate. The capture of a flow of energy, derived from agricultural holdings, was largely based on the capture and control of farmland in much of history. The Roman Empire based its governance on holdings of land in "hundreds" (able to support 100 men-at-arms) and this was carried over into European feudal society. Both types of society existed for many centuries, during which time the total amount of farmland changed slowly when compared to the length of time required to mine, mint and spend a gold coin. So, the ownership of real estate provided a social meme in which there was a conserved base, a solid rung, on which economies and societies could be built.

The rungs of the ladder that societies were climbing upon were not all money systems, but many faceted. For example, the specialization of skills and organization of guilds and professions forms its own ladder with semi-stable rungs of ever higher complexity. The associated development of ever more complex technology providing access to ever wider forms of matter and energy also forms its own ladder with semi-stable rungs. There was a time when horse-trading and the profession of farrier were common. I would argue that each such semi-stable profession or technology in some fashion formed a rung, a platform, on which society could develop more complex practices which could be shaped by the statistical laws of economics.

I call them, here, semi-stable, because the action of the MPP is two-edged. It selects and grants persistence to those social systems that enable a greater flow of matter and energy. It selects not just money systems, but also grants persistence to skills, professions, technologies and many other characteristics of society. But, by the same means, it is de facto deselecting many of those characteristics of society that have been surpassed and are no longer adaptive. So a trading system based on Anatolian obsidian may be an economic enhancer at one stage, and an economic drag at a later stage. The action of the MPP will enhance the prevalence of the monetary system and encourage the growth of supporting social institutions as long as it confers evolutionary advantage, and then will disassemble the social institutions around the monetary system when it no longer confers advantage.

One more question is of interest. Why are they "rungs" on a ladder and not just slug-like progress up a slippery slope? I would argue that the same two-edged action that removes the trailing edge of progressive social characteristics also prevents incremental creep. A stable base is good for business. A moving base causes turbulence. This has been true all through history right until the financial economy took flight in the 1970s. An economy established on a stable base was able to self-organize the consumption of more matter and energy more effectively than an ever-changing economy on a moving base. Change has a cost, and small changes may have large costs. For example, if costs rise linearly with technological change, and benefits rise as the square of technological change, widespread adoption of new technology will not happen until the benefits exceed the costs of change.

Figure 11 – An Ensemble of Statistical Platforms



So innovations that moved the base incrementally in the biophysical economy were suppressed until they became massively more advantageous. Why, then, would this change for the financial economy? I suspect that it is functioning the same way, but is happening so much faster that semi-stable rungs appear and disappear at a rate so fast that they seem to merge into a slope. Riding the magic carpet of information technology, one that gives these economies a means to function at ever higher levels of complexity, buoyed up by Moore's law, the technological rungs appear and disappear on a bi-annual basis.

So, while the thermodynamic version of the MPP discussed originally by Lotka and Odum would dominate the picture, there are many, many rungs on the ladder of increasing social and economic complexity, and each would form a platform on which society would evolve MPP-selected practices of ever more complexity. In Figure 11 I show how I see these rungs overlapping in effect. Admittedly, there is a lot wrong with this diagram, but there is a sense in which it is right. The width of each icon represents the 4^{th} law power to exert a selective organizing effect on the elements of a "rung" found to the right. A book could be written on this slide, and what is right or wrong about it, but here are a few comments:

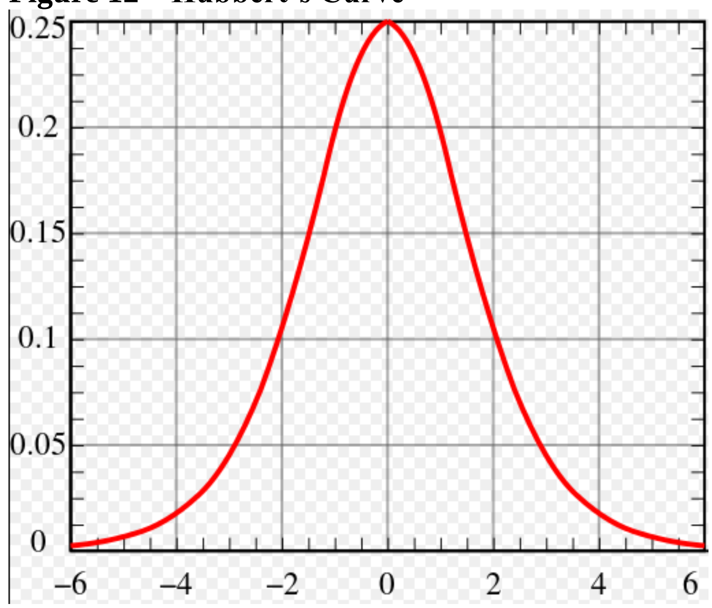
- Thermodynamic laws affect all levels of complexity in society, but have less selective power at the rarefied upper levels, where the econodynamic laws, perched on the upper rungs of legislation governing securities exchanges, have great power to self-organize the markets around securities and their derivatives. These markets appear to be almost independent of biophysical reality, but they are not.
- Commodity-based money systems are fundamentally biophysical in nature, and the usefulness or value of the underlying commodity determines its persistence. Within such a system real-estate transactions can be organized, coins minted, standards of legal tender established, and fiat money organized. So this sort of money system puts the elements within reach that will eventually coalesce into higher semi-stable rungs. For example, money-lending and money-changing existed in such societies, and these are the elements of a reserve-banking and securities-based systems. But, in commodity-based money systems such elements do not usually coalesce, and do not form a stable base upon which the econodynamic laws can operate effectively.
- In a sense, real estate is a commodity of a peculiar sort. It is conserved, for the most part, and so forms the basis of a kind of stable social meme on which the laws of econodynamics can act. And so, under the action of the 2nd law, as the economy relaxes towards equilibrium of a sort, all real estate tends to collect in the hands of a small elite. This is a condition that many societies experience just before collapse. However, prior to that collapse, functioning on the platform of laws around real-estate, societies experience a self-organizing power that pushes them to great heights. Land-backed mortgages are elements that form the basis of loans in the banking systems, and securities in the securities and derivatives systems.
- Metallist coinage systems, like commodity-based systems, have many of the elements of more complex systems but lack the organizing power to coalesce into a higher platform, or rung. The large biophysical costs in mining, minting, transport, storage, and security all prevent them from being selected as high-powered systems. The vicissitudes of dependency upon non-renewable biophysical stocks with varying degrees of accessibility keep such systems constantly destabilized. For example, the discovery by Spain of the "silver mountain" in South America greatly destabilized the economies of Europe for almost a century leading to the Napoleonic wars.
- At each step along the way either monopoly on money supply is tightened or ties to biophysical reality are loosened, and with each step the 4th law is given a more free reign to organize existing economic elements of society into more complex stable platforms on which a society, and the economies of that society, can be built.

In summary of this point, as I said before, history is never tidy, and the modern global economy is not tidy. The biophysical economy still plays an overarching role, under the effects of the laws of thermodynamics, working from a rock-solid biophysical base. But its power to organize ultra-high levels of complexity are limited by those close ties to biophysical reality. I see a multiplicity of semi-stable platforms constructed out of social memes by the action of the 4th law (either biophysical or economic version). The laws of econodynamics build reinforcing and amplifying feedback into those thermodynamic effects, maintaining the high levels of complexity of the modern world.

8.2 - The Dark Side of Hubbert's Curve

Hubbert's curve describes the theoretical distribution of oil production plotted against time. It was a bumpy ride as we climbed the bright side of Hubbert's curve. (See Ref Y, and Figure 12.)

Figure 12 – Hubbert's Curve



We are now just passing over the peak of Hubbet's curve, and starting our journey through what Dr Hall refers to as the second half of the age of oil. As the immense flow of energy derived from fossil fuels declines, we will no longer be able to support the current level of complexity, and the twin powers of the 2nd and 4th laws will select which complex processes to remove. But, can they reconstruct the missing less complex processes, the missing rungs of the ladder, on the way down – the rungs that the MPP effectively removed on the way up? In other words, having removed the lower rungs as we climbed up the ladder, can we reconstruct them at need on the way down again?

That, I think, is a topic for another note. And that is the dilemma that will face future generations that try to maintain civilization on the way down the dark side of Hubbert's curve, in the second half of the age of oil.