Abstract

My contribution to "Worrying Trends" was a concern that conservation concepts were, consciously or otherwise, being applied in some econophysics research. Though these have been very powerful in physics, they are inappropriate in economics because there is no economic parallel to the entities that are conserved in physics.

It has also been persuasively argued that economics "went wrong" in the 19th century in precisely this manner, by "aping" conservation concepts from physics, and at a time before the fundamental aspects of these principles had been set in physics itself.

One variable that some econophysics papers (especially on income distribution) treat as conserved is the amount of money. In this paper, I review the empirical record on money, and present a foundational model of money creation that shows that this is a dissipative process, not a conservative one.

Conservation "Laws" in Econophysics, and the Non-conservation of Money

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In this paper, I elaborate on my particular reason for co-authoring "Worrying Trends" [3], in the context of my overall support for econophysics. I believe that econophysics has made, and continues to make, extremely worthwhile contributions to a scientific understanding of economics (and in particular, finance). However, there are ways in which econophysics is not living up to its full potential, and also ways in which it is unwittingly repeating some of the methodological errors that have made modern economic theory such a problematic discipline. To put my criticisms in context, I will refer to an excellent survey paper on one areas of concern to several of my co-authors, the modelling of distributions of income and wealth [13].

1 Empiricism and theory

A crucial puzzle in the development of econophysics is how did the possibility of it arising occur? If economics had developed as had physics, then economists would already have solved, or at least considered, the issues that econophysics has raised. Instead, there is something pathological in economics that has meant that these empirical regularities have *not* been properly analyzed[1]—thus leaving vacant an intellectual niche that econophysicists have now occupied.

Crucial here is the fundamentally non-empirical nature of current economics: econophysicists are justifiably critical of what they regard as a lack of respect for

[1] More accurately, they had been ignored by the majority of the profession. There is always a minority that does consider such issues, but seems to be ignored by the majority. Thus Mandelbrot [?] highlighted the importance of volatility clustering in economic data in 1963, and proposed a nonequilibrium explanation; his contribution languished while Fama's [2]equilibrium analysis of the same data took sway within economics for the next thirty years.

the data within conventional economics. Richmond, for example, in commenting upon Pareto's attempts to explain the income distribution regularities he discovered, observes that Pareto provided an "explanation based on opinion", whereas

> Physicists are basically driven by empiricism, an approach exemplified by Kepler who as a result of rather painstaking observations of the motion of planets, proposed his law of planetary motion.[13, p. 133]

Likewise, in his reply to our paper [3], McCauley describes econophysics as

> empirically based modelling where one asks not what we can do for the data (give it a massage), but instead asks what can we learn from the data about how markets really work.[9, p. 603]

We agree that economics has failed by not being data-driven. It has instead, to quote McCauley, tended to "assume a preconceived model with several unknown parameters, and then try to force fit the model to a nonstationary time series by a 'best choice of parameters'" [9, p. 603]. However, some econophysics research does not quite live up to the Keplerian standards of empiricism cited with approval by Richmond.

Kepler, as Richmond notes, developed his law of planetary motion after "painstaking observations of the motion of planets". The equivalent procedure within econophysics would be to develop models after having undertaken "painstaking observations of the actions and interactions of economic agents and phenomena". Econophysicists have instead frequently accepted a given set of economic or financial time series as the data, and then attempted to fit statistical distributions and mathematical functions to it—and also, in some instances, to develop parsimonious models that replicate it. While this procedure has clearly had successes, I feel that it lacks two crucial aspect of the early practice of physics: firstly, a deep empirical examination of the economic and financial system, and secondly, attempts to build *causal* models that explain that deep empirical data. There are of course important exceptions to this, but these points are still relevant to the econophysics literature on financial markets and income distribution.

Consider the development of the model of atomic structure, where the proposition that the atom had a nucleus superceded Thomson's "plum pudding" model, as a causal explanation for the Geiger-Marsden experimental result that a tiny fraction of alpha particles were dramatically deflected when fired at a thin sheet of gold. Rutherford's new model of negatively charged electrons orbiting a nucleus of positively charged protons was in turn superceded by Bohr's—and ultimately the quantum-mechanical model—because the persistence of atomic structure defied the Maxwellian predictions of a synchrotron radiation-induced atomic collapse. The quantum mechanical model thus arose out of the interplay between detailed empirical research and theory, and is regarded, not as a parsimonious replicant of the atomic data, but as an attempt to describe the actual structure of atoms.

A comparable interplay between detailed empirical observation and the development of theoretical causal models has not yet happened in econophysics. It could be argued that this is simply a product of the infant nature of the discipline, and there is some truth to this. However, if this were an infancy akin to that of astronomy at Kepler's time, then there would be far more empirical data collection than has in fact occurred. There has instead been a trend to apply refined techniques from physics, with too little empirical investigation to work out the economic equivalent of the nature and movement of planetary bodies.

It can also be argued that the nature of economic and financial systems makes data collection of this kind too difficult. While there is also some truth to this, one need only look at where such a convenient defeatism has led neoclassical economics to see that, difficult or not, it is a task that must be undertaken. What economists have largely not done, econophysicists must do better.[2]

2 Income distribution and money

Richmond et al. [13, p. 138] survey econophysics papers that consider a range of income distribution datasets, and attempt to fit this data with parsimonious models of a monetary exchange process. While some econophysics characterisations of this data may prove to be of enduring worth—notably the capability of both a Generalized Lotka-Volterra model and a Tsallis distribution to fit the data from both low and high incomes—there are aspects of these studies that illustrate both the spurious conservation issue which inspired my contribution to "Worrying Trends", and a lack of attention to basic concepts. These problems are seen most clearly in the discussion surrounding three "Collision models" for the process of income distribution:[3]

$$\begin{pmatrix} m_{i,t+1} \\ m_{j,t+1} \end{pmatrix} = \begin{pmatrix} \lambda_i + \varepsilon\left(1-\lambda_i\right) & \varepsilon\left(1-\lambda_j\right) \\ \left(1-\varepsilon\right)\left(1-\lambda_i\right) & \lambda_j + \left(1-\varepsilon\right)\left(1-\lambda_j\right) \end{pmatrix} \begin{pmatrix} m_{i,t} \\ m_{j,t} \end{pmatrix} \tag{1}$$

[2] A truly remarkable instance of the anti-empirical attitude in economics occurred in a discussion between Nobel Laureates in Economics who made contributions to the theory of Finance. In this discussion, William Sharpe, who developed the original "Capital Assets Pricing Model", expessed the following opinion of the relationship between empirical facts and theory in economics:

> SHARPE: I'd put a different twist on it. I've been amazed at how little you can trust any empirical results, including your own. I have concluded that I may never see an empirical result that will convince me that it disconfirms any theory. I'm very suspicious. If you try another time period, another country, or another empirical method, you often will get different results. Fischer Black, in a wonderful talk that was published toward the end of his life, explained why theory is much more important than empirical work.[1, p. 43]

[3] Richmond cites Angle, Chatterjee, Chakraborti, Kaski, Patriarka and others for 1; Repetowicz, Hutzler and Richmond for 2; and Slanina for 3.

$$\begin{pmatrix} m_{i,t+1} \\ m_{j,t+1} \end{pmatrix} = \begin{pmatrix} \lambda_i + \varepsilon(1-\lambda_i) & \varepsilon(1-\lambda_j) \\ (1-\varepsilon)(1-\lambda_i) & \lambda_j + (1-\varepsilon)(1-\lambda_j) \end{pmatrix} \begin{pmatrix} m_{i,t} + \gamma m_{i,q} \\ m_{j,t} + \gamma m_{j,q} \end{pmatrix} \quad (2)$$

$$\begin{pmatrix} m_{i,t+1} \\ m_{j,t+1} \end{pmatrix} = \begin{pmatrix} 1-\beta+\varepsilon & \beta \\ \beta & 1-\beta+\varepsilon \end{pmatrix} \begin{pmatrix} m_{i,t} \\ m_{j,t} \end{pmatrix} \quad (3)$$

All 3 models involve multiple agents interacting in an iterative pairwise exchange process, where $m_{i,t}$—a proportion of agent i's money at time t—is transferred to agent j (and vice versa). In equations 1 and 2, ε is the random exchange proportion, and λ is an agent-specific savings propensity. In equation 3, β is the random exchange proportion (ε's role is discussed below).

In equation 1, the total amount of money is conserved, both in each exchange and in the system as a whole. In equations 2 and 3, on the other hand, additional money is generated in the exchange process. Equation 2 gets this result via a "'money accumulation' parameter" γ times $m_{i,q}$ (which represents money holdings by the i^{th} agent at a random time q in the past) while equation 3 does so via the assumption "that additional money, $\varepsilon(m_i + m_j)$, is created in the exchange via some sort of wealth creating process." [13, p. 144]

The discussion of these equations implies that the conservation property is a *strength* of 1, and a *weakness* of 2 and 3. It is noted with respect to 1 that "An important feature of this model is that the total money held between two agents remains conserved during the interaction process", and that the resulting distribution of m could be shown to follow the Gibbs rule by applying "the maximum entropy approach familiar to physicists. One only has to propose the existence of the Boltzmann Gibbs entropy $S = \int dmP(m)lnP(m)$ and maximize this function subject to the constraint that money is conserved, i.e, $M = \int dmP(m)m$." [13, p. 143] Richmond et al. explain that 2 was developed to overcome a deficiency of 1 that, contrary to the empirical data, its Pareto coefficient was in general 1—but note that "The penalty however is that money is no longer conserved in the model."[13, p. 144]

It is certainly an *analytic* penalty that money is not conserved in 2 and 3, in that techniques that depend on conservation laws cannot be used with this model. But from an *empirical* point of view, the non-conservation of money is not a weakness, but a strength. Figures 1 to 3 show the US money supply and its key components from 1959 till 2006 in terms of absolute values, monthly growth rates, and percentages of the total money supply. As is obvious, the quantity of money normally grows rapidly and irregularly, though its components—and less frequently the aggregate measure—also on occasions fall.

The narrowest component (Currency) grew by an average of 0.573% *per month* over the 47 years of data, with a maximum *monthly* growth rate of 2.5% and a maximum fall in any one month of 1.3%. The broadest measure grew at the slightly lower average rate of 0.558% per month over the whole time period, but with higher volatility.

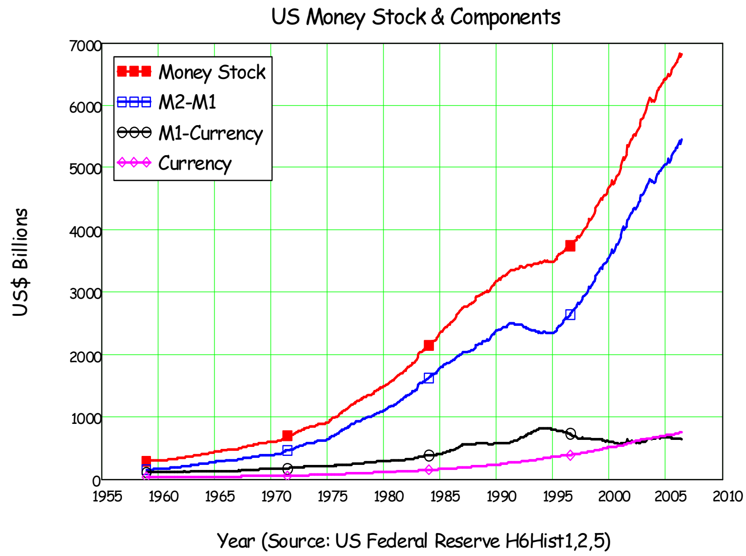

Figure 1: US money stock & components, 1959-2006.

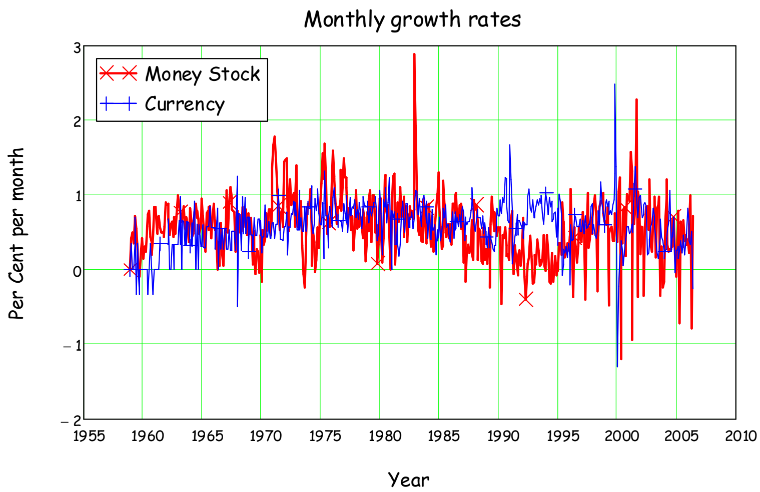

Figure 2: Monthly growth rates of money and currency, 1959-2006

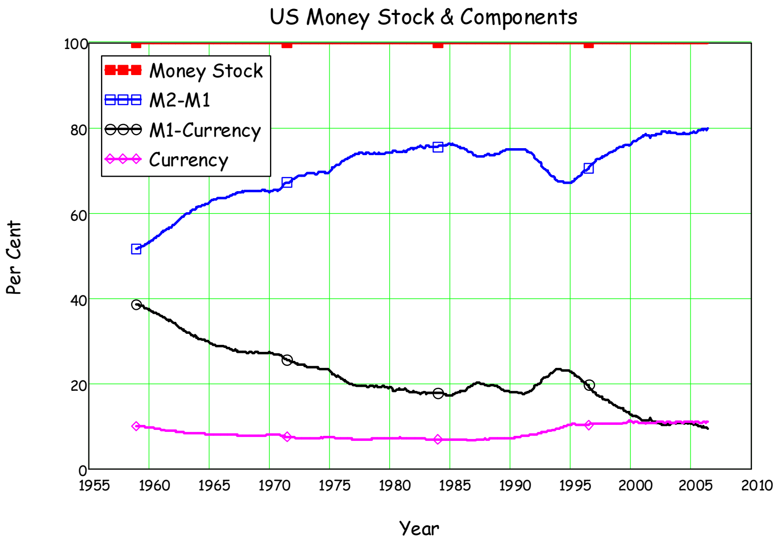

Figure 3: Components of money stock, 1959-2006

The relative growth rates of the components of the money supply also varied over time: currency fell as a proportion of total money from a high of 9.44% of total money in 1959 to a low of 6.63% in 1986, only to rise once more to 10.96% of total money in 2006. Given this data, I contend that any model of any economic process that presumes money is conserved will be misleading.

This raises one of the important differences between true empiricism in physics and economics. Though modern physics has transcended reductionism with the development of complexity theory, much empirical work was able to be done in a reductionist fashion. In economics however, not only are controlled experiments almost impossible, it is also impossible to isolate one variable from another. Contrary to the flawed neoclassical concept of "ceteris paribus" ("all other things held equal"), in economics "everything depends on everything else": feedbacks between variables cannot be ignored, even at an elementary level of analysis.[4] Keplerian empiricism in economics requires accounting for the relationships between economic entities and economic data series, not merely examining the dynamics of one data series in isolation. More so even than the physical world, the economy is a complex system and needs to be empirically analysed at that level.

[4] The neoclassical attempt to account for feedback—general equilibrium analysis—is also fatally flawed, not the least because it presumes that all feedbacks have tapered to zero. The same observation applies to most game theoretic papers in economics.

3 Empiricism in economics

Such an empiricism is possible, and there are instances of it in the economic literature that we encourage econophysicists to emulate and transcend. One of the best such papers is [8], in which the authors applied a Kalman filter to US economic data from 1954 to 1989 in order to deduce the correlations and time lags—and thus infer the causal relations—between a swathe of economic variables.

Despite the staunchly neoclassical leanings of the authors, they conceded that their results contradicted most neoclassical expectations: real wages were pro-cyclical when neoclassical marginal productivity theory predicts the opposite; changes in credit money ($M_2 - M_1$, as graphed above) preceded changes in base money (predominantly though not exclusively currency), whereas conventional monetary theory argues that causation flows from base to credit money; and so on (as explained below). The following table lists some of their major results.

Variable	Neoclassical expectation	Empirical result
Real wages	Negative correlation with GDP	Positive correlation with GDP
CPI	Pro-cyclical	Anti-cyclical
Base Money (M_0)	Leads GDP	Lags GDP (1 quarter)
Credit Money ($M_2 - M_1$)	Lags M_0	Leads M_0 (3 quarters)

Predictably, this empirical research has been almost completely ignored in economics—largely, I believe, because it contradicts neoclassical theory.[5] Econophysicists could build a proper, inter-related empirical foundation for *econo*physics if they continued on where economists stopped. The challenge would then be to explain the inter-relations found in this complex empirical data. In general, an econophysics model of a given data series would be evaluated, not only by the fit it achieves with its specific data, but also by its correlation with other empirically determined significant economic variables, given the extent to which inter-relations between variables dominate a complex system.

Without such a modified Keplerian approach to empirical data in economics, there is a prospect that econophysicists might unwittingly reproduce some of the same mistakes that led neoclassical economics down its parlous anti-empirical path. Foremost among these, I feel, is the application of conservation laws to economic entities that are not, in fact, conserved.

[5] Kydland and Prescott later received the Nobel Prize in Economics for their contributions to "real business cycle" theoretical models, which in spirit are very contrary to the findings in this paper.

4 The lure and danger of spurious conservation

Conservation laws are, as the Wikipedia observes, "the ultimate basis for most solutions of the equations of physics" [16], and it is thus not amazing that physicists are loathe to abandon them, even when entering such unfamiliar territory as the economy. For instance, Richmond et al. dismiss the concerns we have expressed about hypothesising that money is conserved:

> The criticism by some economists that the model is not valid because money is conserved and other levels of money such as credit are not accounted for seems to these authors to be ill founded. It is certainly possible to develop any model to include, for example, debt. This could be simply a matter of allowing the money held by an individual to take negative values...[6] [13, p. 145]

I disagree, primarily because "laws of conservation" should have to meet the same empirical standards as econophysicists set in general. They should only be introduced if they are established empirically, are found to be indispensible to explaining empirical data, or can be generated by transformations of the data that do not then omit essential causal relations.

There is also an irony to the casual application of conservation concepts by econophysicists. As I note above, econophysics itself has only been made possible by the failure of economics to be empirical, and early neoclassical economics was marked by a blasé attitude towards employing conservation laws in economics. Mirowski makes a convincing case that neoclassical economics was shaped in part by a flawed attempt to ape what Walras and Jevons perceived as the physics of their time. As he puts it, "the progenitors of neoclassical economic theory boldly copied the reigning physical theories in the 1870s ... mostly term for term and symbol for symbol, and said so." [11, p. 3]

These 19th century founders of neoclassical economics were not themselves physicists, and borrowed concepts they did not fully understand at a time of serious flux in physics—well prior to the development, not only of relativity and quantum mechanics, but even of thermodynamics and the concept of entropy. Mirowski asserts that, given this accident of timing, neoclassical economics appropriated "a type of physical theory that includes the law of conservation of energy and the bulk of rational mechanics, but excludes the entropy concept and most post-1860 developments in physics."[11, p. 63.] He coins the phrase "proto-energetics" to describe this hodgepotch, and argues that this muddled conception of physics forms the core of neoclassical economics to this day.

A crucial aspect of this appropriation was the concept of conservation, embodied most crucially in the proposition known as "*Walras' Law*". This "Law" states that, in an n-market exchange economy, if the vector of relative prices p is such that supply equals demand in $n-1$ markets, then supply also equals

[6] They continue "Furthermore, the distribution of wealth away from the Pareto regime is now known to have followed the form currently observed even in ancient times and would seem to predate considerably the development of modern concepts of different kinds of money."

demand in the n^{th} market. It is, therefore, a "Law" that only applies in equilibrium—which partly explains the ferocity with which neoclassical economists cling to the concept of equilibrium in their theories. It is clearly also violated by equations 2 and 3 above, whereas 1 obeys it. Yet as Richmond et al. note, 1 notably failed to replicate the empirical data (in part by returning a Pareto index of 1), whereas 2 and 3 returned empirically much more acceptable results.

From my non-neoclassical point of view, the reasons for the empirical failure of this particular conservation law is obvious: *it specifies an exchange-only economy in which no net income is generated*.[7] Capitalism however is a social system predicated upon a production system that produces both a physical and a monetary *surplus*: outputs exceeds inputs, and the monetary value of output exceeds the monetary cost of inputs. Walras's "Law" is thus violated, and this violation is crucial to explaining the phenomenon of income distribution in a capitalist economy—an issue I return to below.[8]

On this basis, I regard the still parsimonious equation 3 as the most acceptable of the collision models surveyed. While it does not explain or model the process of net income generation, it at least encapsulates the empirical datum shown above, that the money supply normally increases over time. However, *money is not income, and nor are transactions between agents.* This raises my next concern about inadequate empiricism in econophysics: the lack of deep empirical knowledge of the economic system is leading to the confusion of basic terms. I hasten to add that economists are in general just as guilty on this front—if not even more so. Econophysicists should, however, aspire to a higher standard.

4.1 Confusion of terms

Several instances of the confusion of basic terms occur in the income distribution literature cited by Richmond. Firstly, although the data that the models seek to fit is of the distribution of *income*, the models themselves are of the *aggregate bank balance levels* resulting from *money transactions* between agents. However, income, bank balances, and monetary exchanges, though related, are *not* the same phenomenon. To draw analogies, the relationship between money transactions and income in economics is similar to that between heat and work in thermodynamics, while the relationship between bank balances and money transactions is similar to that between temperature and heat. Just as a model of heat will set the upper bound for the work that a closed system can generate,

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[7] Its reliance upon equilibrium is also a source of failure. The argument that this was the only failing of Walras' Law lay behind the influential attempt by Axel Leijonhufvud and Robert Clower to remodel Keynes's economics as disequilibrium analysis, whereas the neoclassical model applied in equilibrium.

[8] This is acknowledged in [14], a paper not cited in Richmond et al.'s survey. The situation they find is also more complex than a simple Marxist "capitalists get profits, workers get subsistence wages" model, with their model only fitting the data if it is assumed that the wage exceeds the value of labour.

but not model the work itself, these models of bank balances and money transactions may generate results that have superficial similarities to the dynamics of income distribution, but do not properly capture the phenomenon itself.

Secondly, though money transactions play an essential role in the models put forward by econophysicists, there is no clear understanding of what money is. Allusion is made to "other levels of money such as credit" [13, p. 145], without any definition of these terms. This is an acceptable practice in physics, where one can assume that other physicists know what a "strange quark" is; but the same level of intimate knowledge of the "fundamental particles" of economics has not yet been acquired by econophysicists—nor can they rely upon the dominant economic theory to supply appropriate definitions for them.

Thirdly, the false identification of money account balances with income repeats a far too common mistake made by economists, of confusing a stock with a flow. Whereas that mistake is predictable given the inappropriate reliance upon simultaneous equation analysis in economics, it is one that physicists should instinctively avoid.

The issue of the nature of money is in fact a crucial one for far more than simply the issue of how one should model the distribution of income. Understanding the nature of money goes to the heart of understanding economics, and here, as in many other cases, the conventional beliefs of economists cannot be relied upon by econophysicists.

5 The conventional "semi-conservative" economic model of money creation

In the conventional economic model of money creation, money is defined as "any good or token that functions as a medium of exchange" [17], and the stock of money in existence is seen as being determined in a two-stage process known as the "money multiplier":

1. The government creates money by fiat;[9]
2. The banking system creates additional money by amplifying the government's initial creation of "fiat money", in a process of depositing, lending and re-depositing known as "fractional banking".

The total stock of money is then the sum of the government-created currency (or "fiat money"), and the deposits generated by the money multiplier. Spelling this process out in more detail:

1. the government creates $100 in currency, and pays this to an individual, who deposits it in a private bank account;
2. The bank then holds a proportion of this cash to cover anticipated withdrawals (say 10% or $10), and lends the rest (90% or $90);

[9] Essentially but not exclusively in the form of currency.

3. This in turn is deposited in another bank account, and this bank then lends out a proportion (90% of $90, or $81), and so on until the process stabilizes, with credit money (in this example, $900) being created as a multiple of base money by the deposit–and–re-lend process.

In some countries (including the USA but not, for example, the UK and Australia), a government regulation stipulates the proportion that a bank must retain of any deposit—known as the "reserve requirement". The program shown in Figure 9 implements this model, and a sample outcome (with an initial injection of $100 and a reserve requirement of 20%) is shown in Figure 4.[10]

				Sum in Banks			
Week	**Deposit**	**Loan**	**Cash**	**Deposits**	**Loans**	**Cash**	**Assets**
0	$100.00	$0.00	$0.00	$100.00	$0.00	$0.00	$0.00
1	$66.67	$66.67	$33.33	$166.67	$66.67	$33.33	$100.00
2	$44.44	$44.44	$22.22	$211.11	$111.11	$55.56	$166.67
3	$29.63	$29.63	$14.81	$240.74	$140.74	$70.37	$211.11
4	$19.75	$19.75	$9.88	$260.49	$160.49	$80.25	$240.74
5	$13.17	$13.17	$6.58	$273.66	$173.66	$86.83	$260.49
6	$8.78	$8.78	$4.39	$282.44	$182.44	$91.22	$273.66
7	$5.85	$5.85	$2.93	$288.29	$188.29	$94.15	$282.44
8	$3.90	$3.90	$1.95	$292.20	$192.20	$96.10	$288.29
9	$2.60	$2.60	$1.30	$294.80	$194.80	$97.40	$292.20
10	$1.73	$1.73	$0.87	$296.53	$196.53	$98.27	$294.80
11	$1.16	$1.16	$0.58	$297.69	$197.69	$98.84	$296.53
12	$0.77	$0.77	$0.39	$298.46	$198.46	$99.23	$297.69
13	$0.51	$0.51	$0.26	$298.97	$198.97	$99.49	$298.46
14	$0.34	$0.34	$0.17	$299.31	$199.31	$99.66	$298.97
15	$0.23	$0.23	$0.11	$299.54	$199.54	$99.77	$299.31
16	$0.15	$0.15	$0.08	$299.70	$199.70	$99.85	$299.54
17	$0.10	$0.10	$0.05	$299.80	$199.80	$99.90	$299.70
18	$0.07	$0.07	$0.03	$299.86	$199.86	$99.93	$299.80
19	$0.05	$0.05	$0.02	$299.91	$199.91	$99.95	$299.86
20	$0.03	$0.03	$0.02	$299.94	$199.94	$99.97	$299.91
Sums	**$299.94**	**$199.94**	**$99.97**	**$299.94**	**$199.94**	**$99.97**	**$299.91**

Figure 4: Money Multiplier Example

[10] The Wikipedia gives a fairly standard rendition of this model; see http://en.wikipedia.org/wiki/Money_multiplier and http://en.wikipedia.org/wiki/Money_creation.

If this model did accurately capture the entire process of money creation, then it might be valid—as a first approximation at least—to treat money as conserved, since the supply of money would be controlled by the government, which can be treated as "exogenous" to the market economy.[11] Empirically however, this conventional analysis cannot be correct, given the time sequence reported by Kydland and Prescott. In the money multiplier model, government-created money comes first (Currency and the "Monetary Base" as they are described in the statistics),[12] and bank-created money is created afterwards, with a time lag reflecting the time needed to find potential borrowers and the iterative process of depositing and relending. But as emphasized above, in the empirical data, the creation of bank money ($M_1 - M_0$, $M_2 - M_1$ in the statistics—where the higher index numbers represent the inclusion of progressively wider classes of bank deposits)[13] *precedes* that of government money.

An alternative perspective, known as "endogenous money", instead proposes that money creation by private banks is independent of money creation by the government ([4], [12]), and fundamentally characterizes the creation of money as a dissipative process.[14]

6 An alternative "dissipative" model of money creation

This alternative "endogenous money" hypothesis begins with a strict definition of a truly monetary economy that rules out the use of a commodity as money, on grounds that this is really no different to barter:

> A true monetary economy is inconsistent with the presence of a commodity money. A commodity money is by definition a kind of money that any producer can produce for himself. But an economy using as money a commodity coming out of a regular process of production, cannot be distinguished from a barter economy. A true monetary economy must therefore be using a token money, which is nowadays a paper currency. [4, p. 3]

Therefore money must be a token with no intrinsic worth, and which cannot be produced, as commodities themselves can, by a standard production process. This model also distinguishes money from credit, on the grounds that the transfer of money from agent A to B (in return for the transfer of a commodity from

[11] I put exogenous in inverted commas because there are feedbacks from the economy itself to the government—as illustrated by the recent turmoil on financial markets leading the US Federal Reserve to drop its cash rate by half a percent, in addition to numerous large injections of cash to prop up liquidity. The government's behaviour is therefore not truly exogenous to the market system.

[12] See http://www.federalreserve.gov/releases/h3/Current/

[13] See http://www.federalreserve.gov/releases/h6/Current/

[14] The term "endogenous" distinguishes this approach from the conventional analysis above in which the government—an entity "outside" the pure market economy—is seen as setting the quantity of money.

B to A) completes the commercial process between A and B, whereas a credit transfer (A giving B an "IOU" in return for the commodity) does not.[15]

The final component of this model's definition of a monetary economy is that, since an essentially valueless token is being used to facilitate exchanges of goods, there must be some control to stop the issuer of that token abusing the privilege: the issuer can't directly use its own tokens to purchase commodities. This is only possible if the token issuer is neither A nor B above, but a third agent: a bank C that records A's payment to B as a transfer of funds from A's account at the bank to B's:

> The only way to satisfy those three conditions is to have payments made by means of *promises of a third agent*, the typical third agent being nowadays a bank... Once the payment is made, no debt and credit relationships are left between the two agents. But one of them is now a creditor of the bank, while the second is a debtor of the same bank. [4, p. 3; emphasis in original.]

This model can explain the creation of bank money in the complete absence of government-created money.[16] The basic model consists of three (classes of) agents: banks who lend money to firms, and record all transactions between agents as transfers between deposit accounts; firms who own factories that produce output; and workers who work in those factories. The process begins with the granting of a loan $\$L$ by the bank to the firm, and two accounts are needed to record this: a loan account F_L which records the amount the firm owes, and a deposit account F_D where the money created by the loan is deposited.[17]

Account Type	Loan	Deposit
Account	Firm Loan	Firm Deposit
Name	F_L	F_D
Initial Loan	$\$L$	$\$L$

A loan imposes payment obligations on both the borrower and the bank: the borrower must pay interest on the loan, while the bank must pay interest on the balance in the deposit account. The rate of interest on loans is r_L, on deposits r_D, and $r_L > r_D$. Since all payments are transfers between bank deposit accounts, a third account is now needed: the bank's deposit account B_D. The firm's payment of interest on its debt $r_L \cdot F_L$ is deducted from its deposit account and paid into the bank's, and this fact is also recorded against the outstanding debt so that it does not grow; the bank then transfers the lesser amount $r_D \cdot F_D$ from its deposit account to the firm's. This flow process is recorded in the next table, along with the sum of the transfers between deposit accounts (which is of course zero at this stage):

[15] In giving an IOU in return for a commodity, A remains indebted to B.

[16] This extreme "pure credit" model has been developed to show that credit money can be created even in the complete absence of government-created money. The actual monetary system is a blend of the government money, "money multiplier" credit money, and the pure credit system modelled here.

[17] In a modern computerized system, both would be entries in a database; in a private paper money system, such as existed in 19th century America, the debt would be an accounting record in a debtors book, while the deposit would be physical notes stored in a vault.

Account Type	Loan	Deposit		
Account	...	...	Bank Deposit	Sum
Name	F_L	F_D	B_D	$\sum$
Interest	$r_L \cdot F_L - r_L \cdot F_L = 0$	$r_D \cdot F_D - r_L \cdot F_L$	$r_L \cdot F_L - r_D \cdot F_D$	0

The firm has borrowed to finance production,[18] and for this workers must be hired. This necessitates a fourth account W_D for Workers' Deposits, and a flow of wages at the rate $w \cdot F_D$ out of the firm's deposit account and into the workers:

Account Type	Loan	Deposit			
Account	...	...	...	Workers' Deposits	Sum
Name	F_L	F_D	B_D	W_D	$\sum$
Wages	0	$-w \cdot F_D$	0	$w \cdot F_D$	0

Now that workers have bank balances, they too must be paid interest at the rate r_D times the balance in their accounts; this is transferred out of the bank's Deposit account for another zero sum transfer:

Account Type	Loan	Deposit			
Name	F_L	F_D	B_D	W_D	$\sum$
Interest	0	0	$-r_D \cdot W_D$	$r_D \cdot W_D$	0

With the firm producing output, workers and bankers purchase commodities with additional flows $\omega \cdot W_D$ and $\beta \cdot B_D$ respectively, which both flow into the firm's deposit account:

Account Type	Loan	Deposit			
Name	F_L	F_D	B_D	W_D	$\sum$
Consumption	0	$\beta \cdot B_D + \omega \cdot W_D$	$-\beta \cdot B_D$	$-\omega \cdot W_D$	0

Up until this stage, the amount of money in the system has been conserved at the value of the initial loan L—to this point, the system *is* conservative. The full set of flows is specified in the following table:

Account Type	Loan	Deposit			
Name	F_L	F_D	B_D	W_D	$\sum$
Interest	0	$r_D \cdot F_D - r_L \cdot F_L$	$r_L \cdot F_L - r_D \cdot F_D$	0	0
Wages	0	$-w \cdot F_D$	0	$w \cdot F_D$	0
Interest	0	0	$-r_D \cdot W_D$	$r_D \cdot W_D$	0
Consumption	0	$\beta \cdot B_D + \omega \cdot W_D$	$-\beta \cdot B_D$	$-\omega \cdot W_D$	0

[18] This is treated implicitly in this model; a larger model with an explicit but simple production component is detailed in [7]

The sum of the entries in each column of the composite table specifies a differential equation for the relevant account, so that the overall *conservative* system is given by equation (4): .

$$
\begin{aligned}
\frac{d}{dt}F_L &= 0 \\
\frac{d}{dt}F_D &= r_D \cdot F_D - r_L \cdot F_L - w \cdot F_D + \beta \cdot B_D + \omega \cdot W_D \\
\frac{d}{dt}B_D &= r_L \cdot F_L - r_D \cdot F_D - r_D \cdot W_D - \beta \cdot B_D \\
\frac{d}{dt}W_D &= w \cdot F_D + r_D \cdot W_D - \omega \cdot W_D
\end{aligned} \tag{4}
$$

Figure 5 shows a simulation run of this model, in which it is obvious that the aggregate sum of money is conserved. Parameter values are $L = \$100, r_L = 5\%, r_D = 3\%, w = 3, \omega = 26, \beta = 1$:

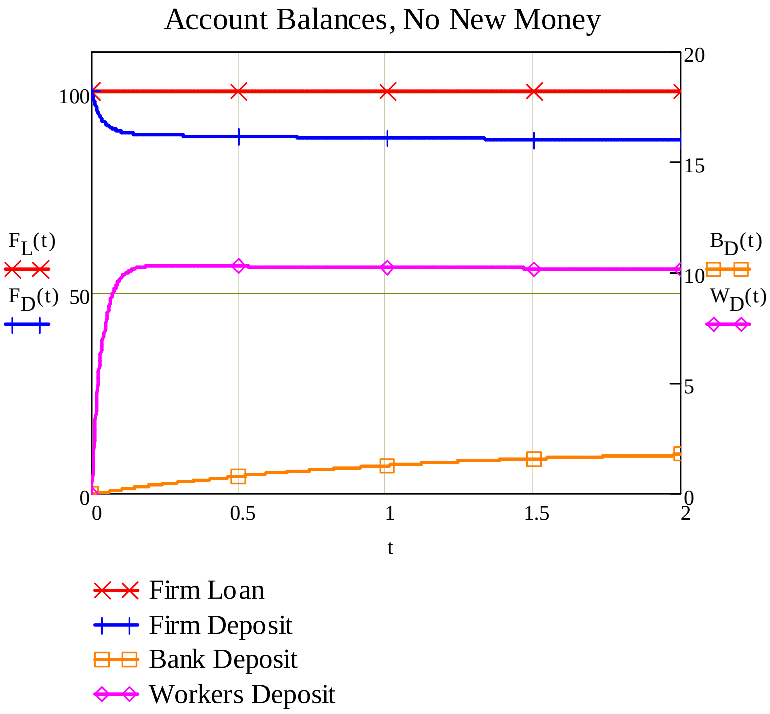

Figure 5: Conservation of Endogenously Created Money in a Constant Income Model

However, if expanded production is to be financed, then additional money must be borrowed (both to hire more workers and to pay for more intra-firm purchases—which are netted out in this simple model). This results in an entry of a new amount of money at the rate $n_M \cdot F_D$ in the firm's Deposit Account, and a matching entry in the record of outstanding debt in the Loan Account.[19]

Account Type	Loan	Deposit			
Name	F_L	F_D	B_D	W_D	$\sum$
New Loans	$n_M \cdot F_D$	$n_M \cdot F_D$	0	0	$n_M \cdot F_D$

This is *not* a transaction, and hence this time there is not an offsetting deduction from any other account in the system: *new money is created and the system is dissipative, not conservative.* As with the initial loan, this continuous flow of new loans is created simply by the bank's creation of matching assets (the loans, which are an asset to the bank) and liabilities (the deposits) in a double-entry book-keeping system. The new system is given by equation (5):

$$\begin{aligned}
\frac{d}{dt}F_L &= n_M \cdot F_D \\
\frac{d}{dt}F_D &= r_D \cdot F_D - r_L \cdot F_L - w \cdot F_D + \beta \cdot B_D + \omega \cdot W_D + n_M \cdot F_D \\
\frac{d}{dt}B_D &= r_L \cdot F_L - r_D \cdot F_D - r_D \cdot W_D - \beta \cdot B_D \\
\frac{d}{dt}W_D &= w \cdot F_D + r_D \cdot W_D - \omega \cdot W_D
\end{aligned} \tag{5}$$

This system now generates growing bank balances and incomes over time, with a money supply that grows continuously—but this in turn is only possible because production, which is implicit in this model, generates a physical surplus of outputs over inputs (a net product) that the financial system both distributes and monetizes. This is the "sort of wealth creating process" assumed in equation (3) (which economists have to date modelled poorly, if at all) and which is created, not in the exchange process itself, but in the financial system—in turn because of production of a net surplus in the input-output system. One therefore can't make sense of income distribution in isolation from finance or production, but a parsimonious model of income distribution has to assume processes that occur in the other systems— as (3) does.

7 Clarifying Terms

This extremely simple linear model would need to be greatly expanded to capture the actual dynamics of the financial system; but in its skeletal state, it still indicates that conservative concepts should not be used to model financial processes. It can also, with slight modifications, be used to clarify some of the distinctions between terms noted above—notably the distinction between income, transactions and bank balances. Bank account balances are obviously

[19] The simplest way this is done in the real world is by firms accessing "lines of credit", rather than having to negotiate new loans. Parameter $n_M = \frac{1}{12}$ in the simulation shown in Figure 5.

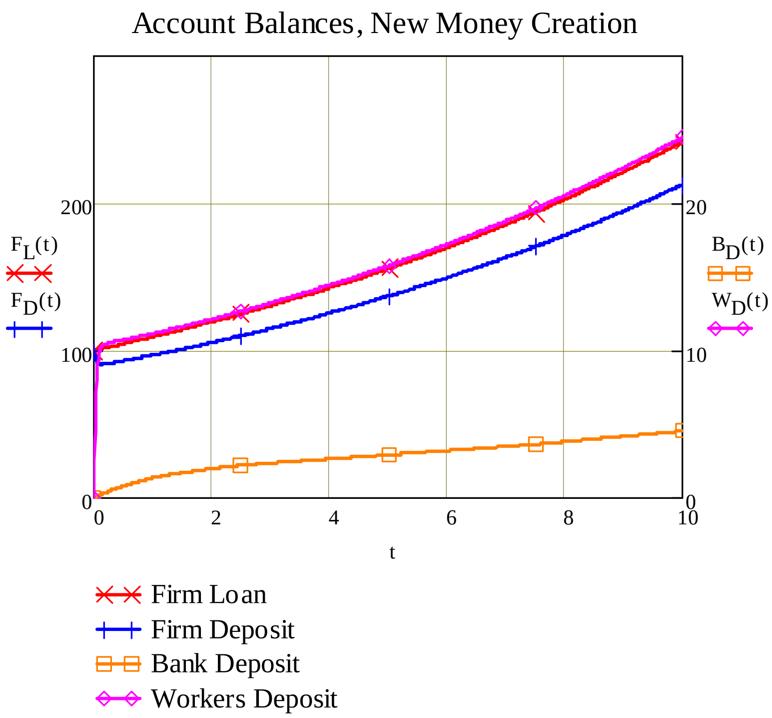

Figure 6: A Growing Supply of Endogenously Created Money in a Growing Income Model

the integral of the transaction flows in and out of these accounts, where aggregate transaction flows are the sum of the entries in each column. Annual incomes are a subset of these transactions at a point in time.[20] For workers and the bank, these are easily identified: they are $w \cdot F_D$ and $r_L \cdot F_L$ respectively. As the system is specified here, no single transaction corresponds to capitalists' income; however this can be deduced from workers' income, which represents the monetized share that workers take of the net product from the input-output system. This in turn reflects both the share of wages in the net product, and the time lag between the financing of production and the receipt of revenue from sales.

Using s for the capitalists' share of net product—and therefore $1-s$ for the workers's share—and P for the rate at which production turns over per year, we have $w = (1-s) \cdot P$, so that annual wages are $(1-s) \cdot P \cdot F_D$, and profits are $s \cdot P \cdot F_D$. Using $s = 1/3$ in this model implies a value of $P = 4.5$, which means that the time lag between financing production and reaping profits from sales is just under 3 months.[21] We can now summarize the transactional flows, income, and account balances as follows:

[20] Since the time dimension of the model is years, the value of each account variable at time t is the annual rate of flow of that account. Once the transaction that generates income is identified, the instantaneous value of this at time t is the annual income at that point in time.

[21] ω, β and P in this model are inverse time lags, with time measured in years. Thus a value of $\omega = 26$ means a 2 week time lag between the receipt of wages by workers and its expenditure.

Account Type	Loan	Deposit			
Name	F_L	F_D	B_D	W_D	$\sum$
Interest	0	$r_D \cdot F_D - r_L \cdot F_L$	$r_L \cdot F_L - r_D \cdot F_D$	0	0
Wages	0	$-(1-s) \cdot P \cdot F_D$	0	$(1-s) \cdot P \cdot F_D$	0
Interest	0	0	$-r_D \cdot W_D$	$r_D \cdot W_D$	0
Consumption	0	$\beta \cdot B_D + \omega \cdot W_D$	$-\beta \cdot B_D$	$-\omega \cdot W_D$	0
New Loans	$n_M \cdot F_D$	$n_M \cdot F_D$			$n_M \cdot F_D$
Transaction Flows at 20 Years					
Flows in	$n_M \cdot F_D$	$r_D \cdot F_D + \beta \cdot B_D + \omega \cdot W_D + n_M \cdot F_D$	$r_L \cdot F_L$	$(1-s) \cdot P \cdot F_D + r_D \cdot W_D$	
Flows out	0	$r_L \cdot F_L + (1-s) \cdot P \cdot F_D$	$r_D \cdot (F_D + W_D) + \beta \cdot B_D$	$\omega \cdot W_D$	
Incomes at 20 years					
Class		$s \cdot P \cdot F_D$	$r_L \cdot F_L$	$(1-s) \cdot P \cdot F_D$	
Gross Income		$s \cdot P \cdot F_D + r_D \cdot F_D$	$r_L \cdot F_L$	$(1-s) \cdot P \cdot F_D + r_D \cdot W_D$	
Net Income		$s \cdot P \cdot F_D + r_D \cdot F_D - r_L \cdot F_L$	$r_L \cdot F_L - r_D \cdot (F_D + W_D)$	$(1-s) \cdot P \cdot F_D + r_D \cdot W_D$	
Net Surplus		$P \cdot F_D$			

The numerical correspondences in the table below indicate various structural aspects of a pure credit economy—such as the identity of bank balances and outstanding loans; the equivalence of net surplus, net income and wages plus profits (interest earnings are not a source of net income, but do distribute some of net income between classes). A comparison the ratios of balances to gross and net incomes also indicates the problems that can arise from confusing bank balances with incomes—as the parsimonious equations (1), (2) and (3) do.

Values at 20 Years	Loans	Deposits			
Account/Class	F_L	F_D	B_D	W_D	$\sum$
Transaction Flows & Account Balances					
Flows in	31.80	1194.39	21.69	1146.05	2362.13
Flows out	0	1166.42	21.08	1142.83	2330.33
Net Flows	*31.80*	27.97	0.61	3.22	*31.80*
Balances	*433.85*	381.58	8.32	43.96	*433.85*
Annual Incomes					
Class		*572.37*	21.69	*1144.73*	1738, 79
Gross Income		583.81	21.69	1146.05	1751.56
Net Income		562.12	8.93	1146.05	*1717.10*
Net Surplus		*1717.10=572.37+1144.73*			*1717.10*
Ratios (%)					
Balances & Net Flows		88	2	10	
Gross Incomes		33.33	1.24	65.43	
Net Incomes		32.74	0.52	66.74	

Models of aggregate bank balances as determined by net transactions—which is what (1), (2 and (3) really are—are therefore potentially quite a poor fit to empirical data on the distribution of income.

8 Conclusion

I hope that this paper has clarified why I co-authored "Worrying Trends". I am still highly enthusiastic about the contribution that econophysics can make to understanding the economy, and equally resigned to the conclusion that economics cannot be expected to escape from its current malaise without econophysics. However I feel that econophysicists have taken some wayward steps by, to some extent, standing too comfortably on the shoulders of giants in a very different discipline.

Physics got to where it is today in part by painstaking attention to the empirical data in physics, from which empirically incontrovertible concepts like the conservation of energy were derived. Those same concepts cannot simply be lifted from physics to economics, because comparable conservation principles have not been established in economic data—and they may never be. But we will only find out by first taking the steps of babies ourselves, rather than those of giants. If it turns out that conservation laws do not exist in economic systems, then while the work of econophysics will be much harder, it will still only be econo*physics* if that empirical reality is respected.

Conversely, it can only be *econo*physics if one essential difference between social physical and systems is also respected. Physical systems are timeless; the laws of physics do not change (certainly not on the time scale of the observer). Economic and social systems, on the other hand, are timely: systems evolve, and issues of great importance at one time can be very unimportant at others. Thus though there is a need to base analysis on a deep empirical understanding of the economic and financial system, there is also a need to address the issues of the day.

I strongly believe that the accumulation of excessive private debt, and its impact upon our financial and economic systems, will be *the* economic issue of the early 21st century[22]—and I have physics-strength correlation coefficients to support that assertion. The next two charts show the private (business and household) debt to GDP ratios for the USA and Australia respectively.

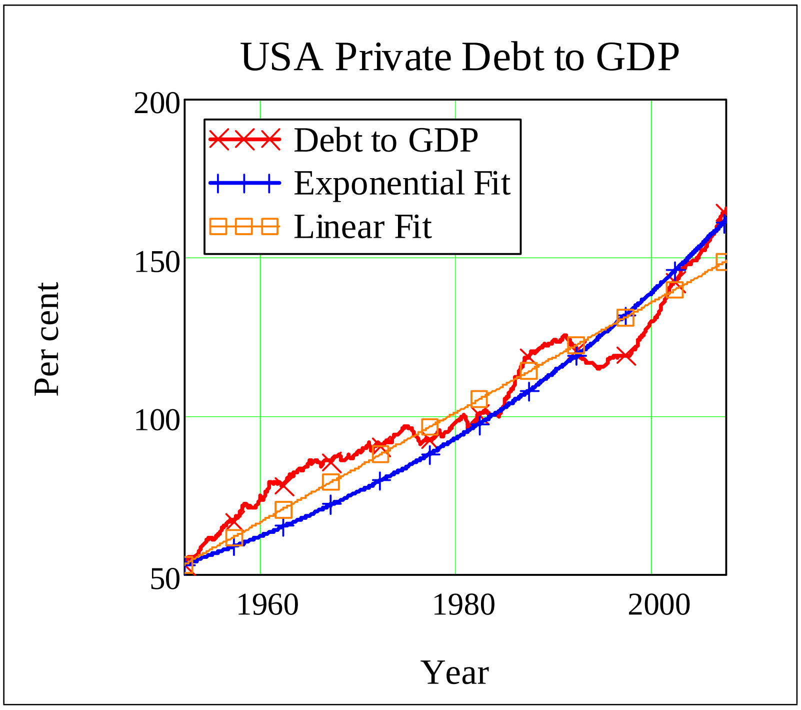

Figure 7: USA Debt To GDP Ratio

According to conventional economic theory, these ratios should show no time trend—at worst, they should rise and fall in counterpoint to changes in interest rates. As is obvious, there is a secular trend to increasing debt to GDP ratios. Linear and exponential growth rates and correlations are shown in the next table. Obviously, both correlations are very high—at least when compared to the norm in economic modelling (economists are frequently ecstatic to achieve coefficients above 0.5)

[22]I won't venture an opinion on the prospects that it may in turn be trumped by the environmental issues of global warming and peak oil.

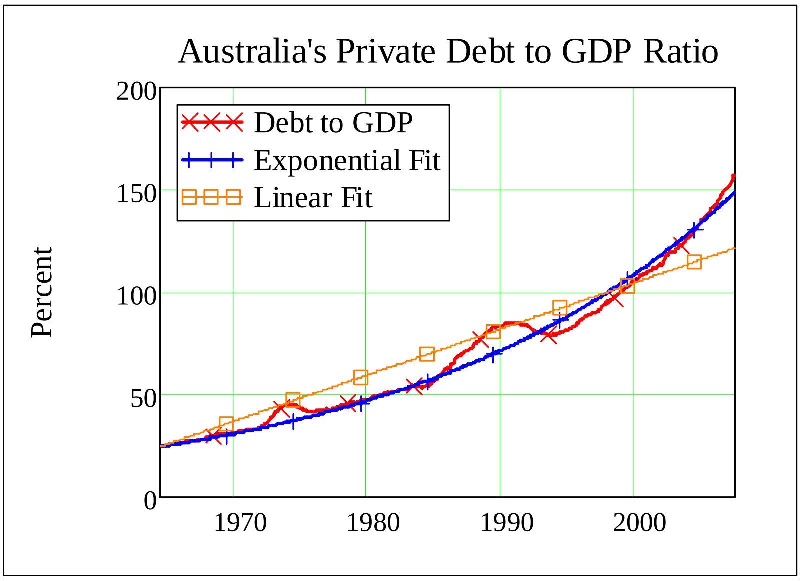

Figure 8: Australia's Debt to GDP Ratio

Debt to GDP Ratios				
Fit	Linear		Exponential	
Country	Rate	Correlation	Rate	Correlation
USA	3.24%	0.9719	2.01%	0.9755
Australia	9.14%	0.9689	4.18%	0.9914

An extended version of the simple model developed in this paper, which includes both loan repayment ($L_R \cdot F_L$) and the recycling of repaid loans ($R_L \cdot B_V$) gives some clue as to why this "unexpected" trend has surfaced:[23] the bank profits from increasing the rate of new money creation, the more rapid recycling of repaid money, and a slower rate of loan repayment.[24] All these tendencies mean that a deregulated financial system contains an enticement to pump out as much credit as it can—until such time as an economic crisis ensues.

[23]The new Asset type "Bank Vault" is introduced here as the repository in which the bank places repaid loans—since to place repaid loans in its own Deposit account would enable it to exploit seigniorage, which this model expressly forbids (of course, that does happen in practice, and did so repeatedly during the 19th century in the USA, which is one reason why the State took over the issuance of currency there).

[24]Using B_Y to signify equilibrium Bank Income, $\frac{dB_Y}{dn_M} > 0$, $\frac{dB_Y}{dR_L} > 0$, and $\frac{dB_Y}{dL_R} < 0$.

Account Type	Asset		Liability			
Account	...	Vault	...	...	...	...
Name	F_L	B_V	F_D	B_D	W_D	$\sum$
Interest			$r_D \cdot F_D - r_L \cdot F_L$	$r_L \cdot F_L - r_D \cdot F_D$		0
Wages			$-(1-s) \cdot P \cdot F_D$		$(1-s) \cdot P \cdot F_D$	0
Interest				$-r_D \cdot W_D$	$r_D \cdot W_D$	0
Cons-umption			$\beta \cdot B_D + \omega \cdot W_D$	$-\beta \cdot B_D$	$-\omega \cdot W_D$	0
New Loans	$n_M \cdot F_D$		$n_M \cdot F_D$			$n_M \cdot F_D$
Repay-ment	$-L_R \cdot F_L$	$L_R \cdot F_L$	$-L_R \cdot F_L$			$-L_R \cdot F_L$
Re-cycling	$R_L \cdot B_V$	$-R_L \cdot B_V$	$R_L \cdot B_V$			$R_L \cdot B_V$

One may already be upon us, with the recent turmoil in finance markets being a reflection the so-called "Subprime Lending Crisis". Subprime loans were marketed as a way of making money by lending money to people who had lacked the capacity to repay it—something which is known in the literature as a "Ponzi Scheme". The economic mainstream has no way to explain how this came about, and certainly no idea how to manage the economy if a serious downturn ensues.[25] If econophysics provides a scientific explanation of this phenomena, it could assume a far greater prominence than it ever could hope to achieve from the more timeless, but less relevant practices of analyzing income distribution and financial time series data.

9 Appendix: Money Multiplier Model

The program shown in Figure 9 (written in Mathcad—see www.ptc.com/mathcad) is a simple version of the standard "money multiplier" model of money creation.

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[25] Better guidance is available in from non-mainstream economists, and in particular, Hyman Minsky's "Financial Instability Hypothesis"; see [10] and [5]

```
MM(HPM, RR, t, Graph) := | "Loans, Cash in the Bank, and Bank Assets all start at zero"
                         | L_0 ← 0
                         | C_0 ← 0
                         | B_0 ← 0
                         | C_Sum_0 ← 0
                         | B_Sum_0 ← 0
                         | "Government creates high powered money HPM; then..."
                         | "Recipient deposits money in bank account"
                         | D_0 ← HPM
                         | D_Sum_0 ← D_0
                         | "Money multiplier process begins"
                         | for i ∈ 1.. t
                         |   | "After it finds a borrower, bank lends out most of money deposited"
                         |   | L_i ← D_(i−1)·(1 − RR)
                         |   | "and keeps reserve amount in cash"
                         |   | C_i ← D_(i−1)·RR
                         |   | "Bank assets are the sum of the cash they hold plus loans"
                         |   | B_i ← L_i + C_i
                         |   | "Recipient of a loan deposits the money in a bank account"
                         |   | D_i ← L_i
                         |   | "We are now at week one of the process..."
                         |   | W_i ← i
                         |   | "Process repeats, and cash, deposits & loans build up in banking system"
                         |   | C_Sum_i ← ∑C
                         |   | D_Sum_i ← ∑D
                         |   | L_Sum_i ← ∑L
                         |   | B_Sum_i ← ∑B
                         | Ans ← augment(W, D, L, C, D_Sum, L_Sum, C_Sum, B_Sum)
                         | return Ans if Graph
                         | otherwise
                         |   | label ← concat("After ", num2str(W_last(W)), " weeks")
                         |   | return stack[ stack[ ("Week", "Deposit", "Loan", "Cash retained",
                         |   |                       "Sum Deposits", "Sum Loans", "Sum Cash",
                         |   |                       "Bank holdings")^T , Ans ],
                         |   |               (label, ∑D, ∑L, ∑C, D_Sum_t, L_Sum_t, C_Sum_t, B_Sum_t)^T ]
```

Figure 9: Money Multiplier Program

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