The Economic Turmoil: A Case for the Engine-Pump Perspective of Complex Holism

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1 Introduction

Science of the last 400 years has essentially evolved by the reductionist tools of linear mathematics in which a composite whole is regarded as the sum of its component parts. Increasingly however, a realization has grown that most of the important manifestations of nature in such diverse fields as ecology, biology, social, economic and the management sciences, beside physics and cosmology, display a holistic behaviour which, simply put, is the philosophy that parts of any whole cannot exist and be understood except in their relation to the whole: the system as a whole determines in an important way how the parts behave. These complex self-organizing systems evolve on emergent feedback mechanisms and processes that "interact with themselves and produce themselves from themselves": they are "more than the sum of their parts". Thus society is more than a collection of individuals, life is more than a mere conglomeration of organs as much as human interactions are rarely dispassionate.

Complexity results from the interaction between parts of a system such that it manifests properties not carried by, or dictated by, individual components — complexity resides in the interactive competitive collaboration between the parts. The properties of a system with complexity are said to "emerge, without any guiding hand". A complex system is an assembly of many interdependent parts, interacting with each other through competitive nonlinear collaboration, leading to self-organized, emergent holistic behaviour.

In his remarkable explorations on *The Road to Reality*, Roger Penrose repeatedly stresses his conviction of "powerful positive reasons to believe that the laws of present-day quantum mechanics are in need of a fundamental (though presumably subtle) change", basing his arguments on the "distinctly odd type of way for a Universe to behave" in the reversible unitarity of Schrodinger evolution being inconsistently paired with irreversible state reduction. This leads him to posit that "perhaps there is a more general mathematical equation, or evolution principle, which has both as limiting approximations". In fact, "a gross time-asymmetry (is) a necessary feature of Nature's quantum-gravity union": gravity "just behaves differently from other fields". All observable manifestations in Nature are interpreted to be *always* gravity induced, quantum superpositions decaying into one or the other state.

This philosophy is operationally consistent with our view of complex holism [5], the details being however, conspicuously different. The homeostasy of top-down-engine and bottom-up-pump endows the state of dynamical equilibrium with the distinctive characteristic of competitively cohabitating opposites in its continual search for life and order. The reality of the natural world of *not* being in a "flat" [3] state of dispersive maximum entropy is infact the quest of open systems to stay alive by temporarily impeding this eventuality through self-organized competitive homeostasis. Hierarchical top-down-bottom-up complex holism does not support "flatness"; because of its antithetical stance toward self-organization and emergence: such a world is essentially a dead world. The survival of open living systems lies in its successfully guarding against this contingency through the expression of gravity.

A socially significant remarkable example of this competitive collaboration is the open source/free software dialectics, developed essentially by an independent, dispersed community of individuals. Wikipedia as an exceptional phenomenon of this collaboration, along with Linux the operating system, are noteworthy manifestations of the power and reality of self-organizing emergent systems.

How are these bottom-up community expressions of "peer-reviewed science" — with bugs, security holes, and deviations from standards having to pass through peer-review evaluation of the system (author) in dynamic equilibrium of competitive collaboration with the reviewing environment — able to "outperform a stupendously rich company that can afford to employ very smart people and give them all the resources they need? Here is a posible answer: Complexity. Open source is a way of building complex things" [4]. Note too that "the world's biggest computer company (IBM) decided that its enginners could not best the work of an ad-hoc open-source collection of geeks (Apache Web server), so they threw out their own technology and decided to go with the geeks!" [3].

Which brings us to the main issue: Building anything, open-source or otherwise, requires investment of resources, financial and human. While the human incentive of open-sourcing for personal recognition through peer-review is a major deciding factor for the individual component, "collaborating for free in the open-source manner (as) the best way to assemble the best brains for the job" guarantees the collective ingredient needed for emergence of these complex systems that are far beyond the capacity of any single organization to handle. The blended model of revenue generation followed by most of the major open source groups contributes to the financial assets required for the self-generation of the backward pump as operationally viable, with the dispersive engine of a readily available market completing the engine-pump paradigm [5]; *economics infact is about collectivism to inhibit human selfish individualism and promote evolution to a state of sustainable homeostatic, collective and societal holism.* The (social) unit "may be the individual or a collective of individuals. If it is a collective, could its behaviour be deduced from the sum of the behaviour of its components? Or could its behaviour be governed by other things than the sum of its components?" Unlike other customs in the analysis of social phenomena, the through and through individualistic character of neoclassical economics based almost entirely on the analysis of the behaviour of a single individual and his interaction with others "begins and ends with the individual, and sadly, there is barely any role to anything which is a reflection of the collective. $\cdots$ From the utility maximizing behaviour of individuals we derived the demand; from the profit maximizing behaviour of firms we derived the supply. The opposition of forces here is quite clear and well depicted by the demand and supply analysis (founded on Newtonian mechanics). Market is where the conflicting forces meet, and the most basic question is what might influence the outcome of an encounter between a consumer and a seller?" [6]

The science of collective holism [5] is specifically addressed to issues such as these leading to an understanding of their true perspective.

2 The Engine-Pump Paradigm: Thermodynamic Landscape

We assume that a complex adaptive system is distinguished by the complete utilization of a fraction $W := (1-\iota)W_{\text{rev}}$ of the work output of an imaginary reversible engine (T_h, E, T_c) to self-generate a reversible pump P in competitive collaboration with E. The *irreversibility factor*

$$\iota \triangleq \frac{W_{\text{rev}} - W}{W_{\text{rev}}} \in [0,1] \tag{1}$$

accounts for that part ιW_{rev} of available energy W_{rev} that cannot be gainfully utilized but must be degraded in increasing the entropy of the universe. It is now possible to show [5], with reference to Fig. 2(a), that the irreversibity expressed as

$$\iota = \frac{T - T_c}{T_h - T_c} \tag{2}$$

is formally identical to the quality

$$x = \frac{v - v_f}{v_g - v_f}$$

of a liquid-vapour two-phase mixture.

Define the equilibrium steady-state of homeostatic E-P adaptability $\alpha := \eta_E \zeta_P$, the *equation of state of the participatory universe*

$$\alpha(T) = \left(\frac{T_h - T}{T_h}\right)\left(\frac{T}{T - T_c}\right) \triangleq \frac{q}{Q}\left(\frac{T_c}{T_h}\right) \tag{3}$$

with q the heat generated by the pump P and Q the mandatory heat rejection of the engine E, in the form $pv = f(T)$, where $p \equiv \zeta_P = 0$ at $T = 0$ and $v \equiv \eta_E$, be the product of the efficiency of a reversible engine and the coefficient of performance of a reversible pump.Then the engine-pump duality has the significant property of supporting two different states

$$T_\pm(\alpha) = \frac{1}{2}\left[(1-\alpha)T_h \pm \sqrt{(1-\alpha)^2 T_h^2 + 4\alpha T_c T_h}\right] \tag{4a}$$

$$= \begin{cases} ((1-\alpha)T_h,\, 0) = (0,0), & T_c = 0,\, \alpha = 1 \\ (T_h,\, -\alpha T_h) = (T_h, T_h), & T_c = T_h,\, \alpha = -1 \end{cases} \tag{4b}$$

for any given value of α, with the balancing condition

$$\iota(T) = \alpha(T) \tag{5}$$

based on the reasonable premise that the adaptibility of the engine-pump opposites defining the most appropriate equilibrium criterion

$$T_\pm = \frac{T_h(T_h + T_c) \pm (T_h - T_c)\sqrt{T_h^2 + 4T_c T_h}}{2(2T_h - T_c)} \tag{6a}$$

$$= \begin{cases} (0.5T_h, 0), & T_c = 0 \\ (T_h, T_h), & T_c = T_h \end{cases} \tag{6b}$$

directly determines the irreversibility of the interaction because the tendency to revert back to the original condition (small ι: predominance of pump P) implies large E-P adaptability α inviting E-opposition and the homeostasy of Eq. (5); see Fig. 2(a). These temperatures are used [5] to characterize the real functional world W for $T_+ > 0$ with its multifunctional negative counterpart $\mathfrak{W}$ where $T_- < 0$. The dual $(W, \mathfrak{W})$ defines a non-reductionist sum of a *top-down engine* E and its complimentary *bottom-up pump* P that behaves in an organized collective positive-negative feedback loop with properties that cannot be identified with any of the individual components but arise from the structure as a whole; these systems cannot dismantle into their parts without destroying themselves. Analytic methods cannot simplify them as such techniques do not account for characteristics that belong to no single component but relate to the whole with all their interactions. Complexity is a dynamical, interactive and interdependent hierarchical homeostasis of P-emergent, ordering instability of collaborative positive feedback in cohabitation with the adaptive, E-organized, disordering stability of competitive negative feedback generating non-reductionist holism that is beyond the sum of its constituents.

The mathematical foundation of competitive-collaboration is based [5] on various mathematical constructs of the initial and final topologies, inclusion and exclusion topologies, multifunctional extension of function spaces involving chaos, and inverse and direct limits. These complimentary limits are generated by opposing directional arrows whose existence follow from very general mathematical principles; thus for example existence of the union of a family of nested sets entails the existence of their intersection, and conversely. A concrete example of the limits specializes to the *rigged Hilbert spaces* $\Phi \subset \mathcal{H} \subset \Phi^\times$

$$\overleftarrow{\Phi^\times \triangleq \cup_k H_{-k} \supset \cdots \supset H_{-i} \supset \cdots \supset H_{-1}}^{\text{Direct limit, Anti-Thermo, Collaborative}} \supset \mathcal{H} \supset \underrightarrow{H^1 \supset \cdots \supset H^i \supset \cdots \supset \cap_k H^k \triangleq \Phi}_{\text{Inverse limit, Thermo, Competitive}} \tag{7}$$

of the entropy-increasing, second-law, dispersive thermodynamic arrow inducing an opposing constructive anti-thermodynamic arrow comprising a dynamic positive-negative feedback loop; here Φ is the space of physical states prepared in actual experiments and $\Phi^{\times}$ are antilinear functionals on Φ that associates with each state a real number interpreted as the result of measurements on the state. The space of test functions Φ and the space of distributions $\Phi^{\times}$ represent definite and well-understood examples of the inverse and direct limits that enlarge the Hilbert space $\mathcal{H}$ to the *rigged Hilbert space* $(\Phi, \mathcal{H}, \Phi^{\times})$, with $\mathcal{H}$ the homeostatic condition; observe that in the true spirit of homeostatic holism, Φ and $\Phi^{\times}$ are meaningful only with reference to each other.

The negative world $\mathfrak{W}$ induces in its real dual W two simultaneous effects: the thermodynamic arrow of compression generates the dispersive thermodynamic arrow of W while its anti-thermodynamic expansion is responsible for the gravitational attraction in W. This is how Nature's holism operates through unipolar gravity, with the anti-thermodynamic concentration in $\mathfrak{W}$ completing its bipolarity. Gravity is uniquely distinct from other known interactions as it straddles $(W, \mathfrak{W})$ in establishing its sphere of influence, with the other known forms residing within W itself. It is this unique expression of the maximal multifunctional nonlinearity of $\mathfrak{W}$ in the functional reality of W that is responsible for the inducement of "neg-entropy" effects necessary for the sustenance of life.

This representation of a complex system can then be formalized as

Definition. Complexity. An open thermodynamic system of many interdependent and interacting parts is *complex* if it lives in synthetic competitive cohabitation with its induced negative dual in a state of homeostatic, hierarchical, two-phase dynamic equilibrium of top-down, self-organizing, dispersive thermodynamic engine and a self-induced, bottom-up, emergent, concentrative anti-thermodynamic pump, coordinated and mediated by the environment ("universe").

2.1 The Logistic Map $\lambda \mathbf{x}(1 - \mathbf{x})$: A Nonlinear Qubit

The logistic map $\lambda x(1 - x)$, with the direct iterates $f^i(x)$ corresponding to a self-generated "pump" and the inverse iterates $f^{-i}(x)$ to the "engine", with its rising and falling branches denoted $(\uparrow)$ and $(\downarrow)$ respectively, constitutes a perfect example of a *nonlinear qubit,* not represented as a (complex) linear combination: nonlinear combinations of the branches generate the evolving structures, as do the computational base $(1\ 0)^{\mathrm{T}}$ and $(0\ 1)^{\mathrm{T}}$ for the linear qubit of quantum mechanics. The nonlinear qubit can be prepared efficiently by its defining nonlinear, non-invertible, functional representation, made to interact with the environment through discrete non-unitary time evolutionary iterations, with the final (homeostatic) equilibrium "measured" and recorded through its resulting complex structures.

In the linear setting of quantum mechanics, multipartite systems modeled in 2^N-dimensional tensor products $\mathcal{H}_1 \otimes \cdots \otimes \mathcal{H}_N$ of 2-dimensional spin states, correspond to the 2^N "dimensional space" of unstable fixed points in the evolution of the logistic map. This formal equivalence illustrated in Fig. 1 while clearly demonstrating how holism emerges in 2^N-cycle complex systems for increasing complexity with increasing λ — the emergent 2^N-cycle are "entangled" in the basic $(\uparrow)$ and $(\downarrow)$ components as the system self-organizes to the graphically converged multifunctional limits indicated by the brown lines: the parts surrendering their individuality to the holism of the periodic cycles also focuses on the significant differences between complex holism and quantum non-locality.

The converged holistic behaviour of complex "entanglement" reflects the fact that the subsystems have combined nonlinearly to form an emergent, self-organized structure of the 2^1, 2^2 and 2^3 cycles in Fig. 1(a), (b) and (c) that cannot be decoupled without destroying the entire assembly; contrast with the quantum entanglement and the notion of partial tracing for obtaining properties of individual components from the whole. Unlike the quantum case, the complex evolutions are not linearly superposed reductionist entities but appear as emergent, self-organized holistic wholes. In this sense complex holism represents a stronger form of "entanglement" than Bell's nonlocality: *linear systems cannot be chaotic, hence complex, and therefore holistic.* While quantum non-locality

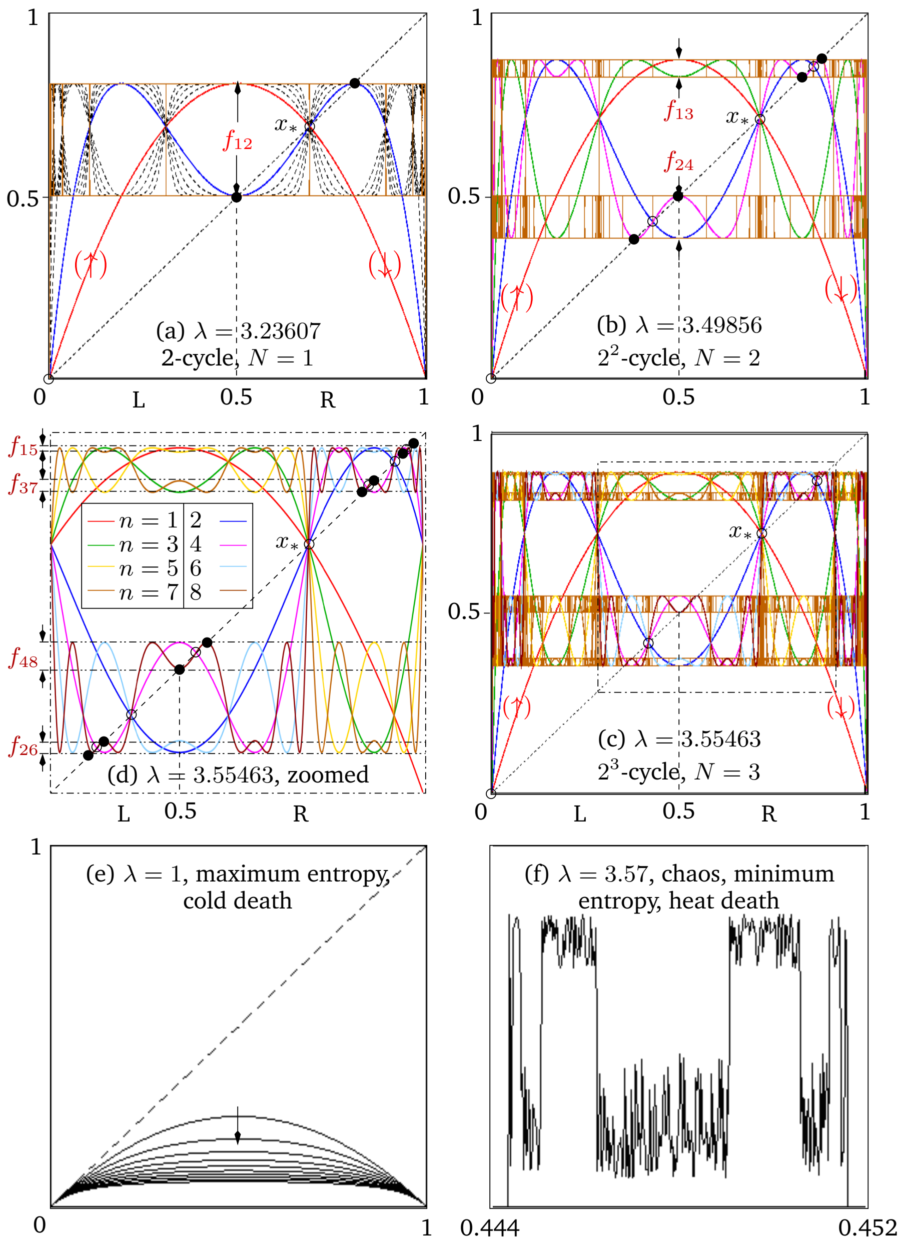

Figure 1: Complex entangled holism (a)-(d), generated by the logistic map $f(x) = \lambda x(1 - x)$. The effective nonlinearity $0 \leq \chi \leq 1$ in the representation $f(x) = x^{1-\chi}$ rises with λ, as the system becomes more holistic with an increasing number of interacting parts of unstable fixed points shown unfilled, the stable filled points being the interacting, interdependent, parts of the evolved pattern. The resulting holistic patterns of one, two, and three hierarchical levels in magenta, are entangled manifestations of these observables, none of which can be independently manipulated outside of the collaborative whole. Forward iterates $f^i(x)$, (f), of entropy decrease, collaboration, concentration comprises the anti-thermodynamic arrow, the inverse iterates $f^{-i}(x)$, (e), of entropy increase, competition, dispersion is its holistic opposite, with the homeostasy of (a)-(d) a dynamic equilibrium between these collaborating opponents.

. Unification of thermodynamic and logistic $f = \lambda x(1 - x)$ up-down ($\uparrow\downarrow$) dynamics of the self-induced engine-pump system is achieved by extending (5) to $\iota = \alpha = \chi$ [5]. This identification of thermodynamic and dynamic properties in the evolution of a complex system by associating its dynamical degree $\chi := 1 - \frac{\ln\langle f(x)\rangle}{\ln\langle x\rangle}$ of cha(os)-no(nlinearity)-(comple)xity linearly increasing with λ, with thermodynamic competitive collaboration α, focuses on the distinction between χ and the complexity σ_+ [5] representing homeostatic balance between dispersion and concentration.

is a paradoxical manifestation of linear tensor products, complex holism is a natural consequence of the nonlinearity of emergence and self-organization.

Nature uses chaos as an intermediate step in attaining states that would otherwise be inaccessible to it. Well-posedness of a system is an extremely inefficient way of expressing a multitude of possibilities as this requires a different input for every possible output. The countably many outputs arising from the non-injectivity of f for a given input is interpreted to define complexity because in a nonlinear system each of these possibilities constitute a experimental result in itself that may not be combined in any definite predetermined manner. This multiplicity of possibilities that have no predetermined combinatorial property is the basis of the diversity of Nature.

3 Economic Holism: A Re-Evaluation of the Mess

Modern individualistic, neo-classical Western economics, is a static Newtonian equilibrium theory, where supply by the firm equals the demand of the consumer. Linear stablity is central to this variant of economic thinking that has come under severe strain in recent times, Ref. [1] reflecting some of the manifestations of this disillusionment. The linear mathematics of the neoclassical enterprise is founded in calculus with maximization and contraint-based optimization being the ground rules. These Marshallian linear static models seeking to maximize utility for the consumer and profit for firms, as epitomized in Pareto optimality, Nash equilibrium, Prisoner's Dilemma for example, work as might well be expected with reasonable justification, as long as its canonized axioms of people with rational preferences acting independently with full and relevent information make sense. This framework of rationality of economic agents of individuals or company working to maximize own profits, of the "invisible hand" transforming this profit-seeking motive to collective societal benefaction, and of market efficiency of prices faithfully reflecting all known information about assests [1], can at best be relevent under severely restrictive conditions: "the supposed omniscience and perfect efficacy of a free market with hindsight looks more like propaganda against communism than plausible science. In reality, markets are not efficient, humans tend to be over-focused in the short-term and blind in the long-term, and errors get amplified, ultimately leading to collective irrationality, panic and crashes. Free markets are wild markets. Surprisingly, classical economics has no framework through which to understand 'wild' markets" (Bouchaud [1]). These "perfect world" models are meaningful under "linear" conditions only: "these successfully forecast a few quarters ahead as long as things stay more or less the same, but fail in the face of great change" (Farmer and Foley[1]), "as long as the influences on the economy are independent of each other, and the past remains a reliable guide to the future. But the recent financial collapse was a systemic meltdown, in which interwined breakdowns $\cdots$ conspired to destabilize the system as a whole. We have had a massive failure of the dominant economic model" (Buchanan[1]).

These authors advocate an agent-based computer-modelling of economics, for simulating the interdependence and interactions of autonomous individuals with a view to assessing their effects on the system as a whole: the complex behaviour of adaptive system emerges from interactions among the components of the system and between the system and the environment. Individual agents are typically characterized as boundedly rational, presumed to be acting in what they perceive as their own interests such as economic benefit or social status, employing heuristics or simple decision-making rules. The computer keeps track of multiple agent interactions, monitoring a far wider range of nonlinear intercourse than conventional equilibrium models are capable of; "because the agent can learn from and respond to emerging market behaviour, they often shift their strategies, leading other agents to change their behaviour in turn. As a result prices don't settle down into a stable equilibrium[1], as standard economic theory predicts" (Buchanan[1]).

This cellular automata generated computer-graphics evolution of the economy bears a strong formal resemblance with the engine-pump realism of chanoxity as summarized in Fig. 2. The competitive collaboration of the engine and its self-generated pump is identified as the tension between the consumer with its dispersive spending engine in conflict with the resource producing

[1]Interactive complex holism!

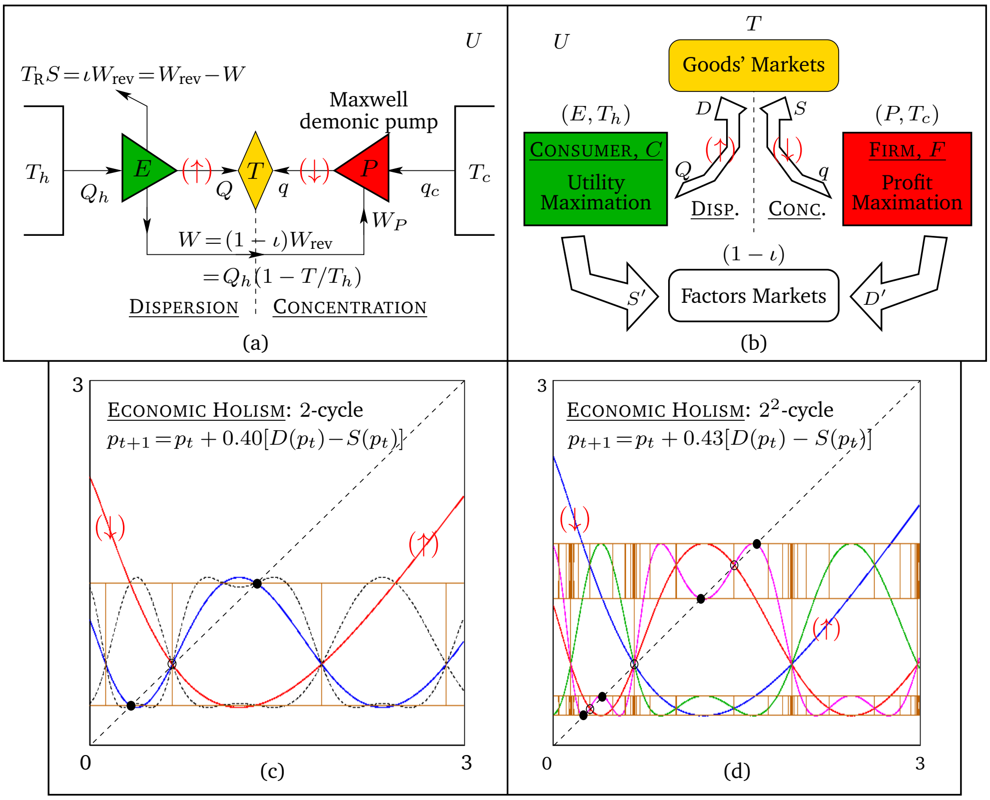

Figure 2: The economy as a complex holistic system, U is the "universe". Display (b) on neoclassical economics is adapted from Witztum [6]. According to this philosophy, economics as the principal instrument of collective interaction in society, is to be distinguished from the exclusive individualism of neo-classical theory. The Samuelson tatonnement (c) and (d) illustrate emergence of economic complexity for *nonlinear* demand and supply profiles $D(p) = \frac{8.0}{1.1+p} - 1.75$, $S(p) = 10p^{1.5}e^{-p}$, with p the price of the commodity; compare Fig. 1 (a)-(d).

Figure (a) embodies the essence of competitive collaboration: the entropic dispersion of E is proportional to the domain $T - T_c$ of P, and the anti-entropic concentration of P depends on $T_h - T$ of E, recall Eq. (2). Thus an increase in ι can occur only at the expense of P which opposes this tendency; reciprocally a decrease in ι is resisted by E. The induced pump P prevents the entire internal resource $T_h - T_c$ from dispersion at $\iota = 1$ by defining some $\iota < 1$ for a homeostatic temperature $T_c < T < T_h$, with E and P collaborating with each other in a spirit of competition at the induced interface T.

pump in mutual feedback cycles, attaining market homeostasis not through linear optimization and equilibrium of intersecting supply-demand curves, but through nonlinear feedback loops that generate entangled holistic structures. Supply and demand in human society are not independent of each other: aggressive advertising for example can completely dominate the individual behaviour of these attributes. To take this into account, the interactive feedback between the opposites of engine consumption and pump production can be modelled as a *product* of the supply and demand factors that now, unlike in its static manifestation of neo-classicalism, will evolve in time to generate a condition of dynamic equilibrium, see Fig. 2 for the different evolution strategy of Samuelson tatonnement [2] for *nonlinear* Walrasian demand and supply profiles.

In the *linear* case, let $D(p) := 1 - \beta p$, $S(p) := \lambda p$, $\beta, \lambda > 0$, rescaled and normalized as $D(0) = 1$, $D(1) = 1 - \beta$, $S(0) = 0$ for $0 \leq p \leq 1$, be mappings on the unit square. Then supply and demand interact in the market via the shifted logistic $f_{DS}(p) = \lambda p(1 - \beta p)$ with a maximum $f_{DS}(p_m) = \frac{\lambda}{4\beta}$ at $p_m = \frac{1}{2\beta}$; note that at $\beta = 1$, f_{DS} reduces to the usual symmetric form $\lambda p(1-p)$ and at $\beta = \frac{1}{2}$, $p_m = 1$. Since we are interested only in the range $\frac{1}{2} \leq f_{DS} \leq 1$ for possible complex effects, let the slopes of the two opposites be related by $\beta = 0.25\lambda$ for the expected $f_{DS}(1) = 0$ at $\lambda = 4$.

The market clearing condition $D(p^*) = S(p^*)$ at $p^* = \frac{1}{\beta+\lambda} = \frac{4}{5\lambda}$ apparently does not have any significance in the interactive evolution of $p_{t+1} = f_{\rm DS}(p_t)$ with fixed point $p_* = \frac{\lambda-1}{\beta\lambda} = \frac{4(\lambda-1)}{\lambda^2}$, except at the uninteresting "solid-state" $\lambda = 1.25$ for $p^* = p_*$. The time evolution of the p_m-shifted, demand-supply-logistic

$$f_{DS}(p) = \lambda p(1 - 0.25\lambda p) \tag{8}$$

is similar to the symmetric $\lambda p(1-p)$, except for a right-shift of p_m for $2 \leq \lambda < 4$.

The identification of $D(p)$ with mandatory heat rejection Q by E and of $S(p)$ with heat generated q by P requires some comment. While the supply correspondence $S \Leftrightarrow q$ in this positive-negative, auto-generated, feedback loop is not difficult to justify, the demand analogy with Q is based on the argument that the job of E (of C) being to generate work (to consume from the market), any enforced allocation of resources like Q (and D) elsewhere constitutes a privileged diversion for the overall benefit of the interacting, interdependent system. Putting $Q = q$ in Eq. (3) *for a constant* α in Newtonian equilibrium, gives

$$\begin{aligned} T_\pm &= \frac{1}{2}\left(T_h - T_c \pm \sqrt{T_h^2 - 2T_hT_c + 5T_c^2}\right) \\ &= (403.21, -223.21), \end{aligned} \tag{9}$$

to be compared with the holistic $T_\pm = (406.09, 161.18)$ of Eq. (6*a*), with limits

$$T_\pm = \begin{cases} (T_h, 0), & T_c = 0 \\ (T_h, -T_h), & T_c = T_h, \end{cases}$$

that are inconsistent with the holistic condition $\iota = \alpha$: the static equilibrium of supply and demand, as noted earlier and in contrast with the Samuelson tatonnement of Fig. 2, is irrelevant for complex holism.

The remarkable correspondence of this evolutionary profile with the logistic interaction is far too pronounced to be dismissed as incidental. In situations as in the Prisoner's Dilemma for example, the agents are infact not free to take unilateral decisions but are in entangled holistic states of competitive collaboration; thus a "good" individual in a stable "useful" state represented by the evolved holistic profile of Fig. 2(c), in his transition to "badness" "entangles" with an accomplice — the two (unfilled) unstable fixed points of figure (d) — denoted by the (filled) stable fixed points, leading to the iterated dilemma corresponding to the converged holism of (d). When the entanglement is weak (linear) however, it is possible to consider the dilemma in terms of the Bell states in the base $(|\uparrow\uparrow\rangle + |\downarrow\downarrow\rangle)/\sqrt{2}$ resulting in the Nash equilibrium $(\downarrow\downarrow)$. Carrying this type of reasoning a step further, it is conceivable that globalization has effectively transformed the world economy into a single-celled monolith from its complex multi-cellular form, with the inevitable consequence that it is incapable of any self-organization to a meaningful homeostatic form.

Nonlinear self-organization and emergence are fascinating demonstrations of dynamical homeostasis of opposites, apparenly the source and sustenance of Nature's diversity.

References

[1] J-P. Bouchaud. Economics Needs a Scientific Revolution. *Nature*, 455:1181, 2008; J. D. Farmer and D. Foley, The Economy Needs Agent-Based Modelling, *Nature*, 460:685–686, 2009; M. Buchanan, Meltdown Modelling, *Nature*, 460:680–682, 2009.

[2] R. H. Day. *Complex Economic Dynamics. Vol I.* The MIT Press, Cambridge, Massachusetts, 1998.

[3] Thomas L. Friedman. *The World is Flat: A Brief History of the Twenty-First Century*. Picador, New York, 2007.

[4] John Naughton. *Guardian Newspaper Limited*, 2006.

[5] A. Sengupta. Is Nature Quantum Non-local, Complex Holistic, or What? I–Theory & Analysis; II–Applications. *Nonlinear Analysis: RWA*, doi: 10.1016/j.nonrwa.2008.09.001; doi: 10.1016/j.nonrwa.2008.09.002, 2008.

[6] A. Witztum. *Economics: An Analytical Introduction*. Oxford University Press, 2005.