A CRITIQUE OF DOPFER AND POTTS'S EVOLUTIONARY REALISM[1]

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ABSTRACT: Influenced by both the Classical Economics of Malthus and Marx and the Austrian economics of Joseph Schumpeter, Evolutionary Economics has developed into a significant school of economic thought that offers a conception of growth and innovation markedly different to that afforded by neoclassical economics. This paradigm has informed analysis in economic geography and regional economics, and contributed to the development and evaluation of science and technology policy. In Australia, the recent Venturous Australia policy document prepared by Terry Cutler and Associates for the Commonwealth Government, owes much to the Evolutionary Economic way of thinking about innovation. In a recent methodology paper Dopfer and Potts (2004) establish three axioms of "evolutionary realism" with the intention of illuminating the ontological commitments of Evolutionary Economics. This paper subjects these axioms, and the manner in which they are applied, to a critical interrogation grounded in a comprehensive interpretation of Whitehead's categorical logic. On this basis it is argued that Dopfer and Pott's axiomatic approach lacks in both rigour and depth, thus failing to achieve its methodological objectives. While theoretical cross-overs between thermodynamics and economics are well known, the paper goes on to examine recent developments in non-equilibrium thermodynamics and complexity theory, arguing that Dopfer and Potts provide few insights into how recent developments in non-equilibrium thermodynamics could inform economic analysis.

1. INTRODUCTION A REVIEW OF DOPFER AND POTTS'S ONTOLOGY

Dopfer and Potts (2004) commence their overview by arguing that there is a need for "empirical generalization" of evolutionary realist methodology with the aim of refining analytical research. The authors set out three "ontological axioms", suggesting that these axioms will help to illuminate the ontological commitments of Evolutionary Economics. In turn, the latter is viewed as a "nascent analytical framework" approaching the economy as an open system. This "theoretical hybrid" supposedly weaves together "evolutionary theory, complex systems theory, self-organization, and agent-based computational theory", while merging the methodologies of "Austrian, Behavioural, Institutional, Post-Keynesian and Schumpeterian economics".

Just how such an overarching and integrative framework could be constructed to span such a diverse range of antagonistic implacably opposed schools of thought is never discussed. From epistemological and ontological perspectives, this would seem a Herculean, if not an impossible, task given the

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divergent ontological commitments made by members from each of these traditions. The authors eschew mathematical formalism, largely because they define mathematics as a "methodology for achieving logical consistency in theory". In contrast, they prefer a "meta-ontological" approach, contending that "ontology structures analysis, analytical frameworks structure theory, theoretical frameworks structure models, and the combination of these structures understanding of real phenomena". The economy is conceived as an "open, complex, emergent, rule system". It is "made of economic agents and the rules they carry". However, agents are also "implicated in the origination of novel rules and the adoption and adaptation of extant rules". Moreover, because theory formation is influenced by the ontological preconceptions held by researchers, the authors argue that these preconceptions must be identified, clarified, reframed, and defended.

Because ontology deals with all of reality the authors argue that ontological commitments must be drawn from the empirical axioms or preconceptions situated within the paradigmatic core of the fundamental disciplines of economics, physics and biology. Here, axioms are defined as inductive empirical generalizations across a domain of science. These are to be judged in terms of their "ability to represent the underlying conditions of existence of real phenomena".

An "evolutionary ontology" is defined in relation to a distinction between "mechanistic-physicalist" and "evolutionary" world view. According to this distinction, the former world view is predicated on the notion that one unified set of laws governs the existence and behaviour of all entities. In contrast, the evolutionary world view recognises a variety of sets of rules or laws marked in synchronistic terms by heterogeneity and diachronically by change, novelty, and recombination (204). The resulting axioms are:

1) all existences are matter-energy actualizations of ideas
2) all existences are associate
3) all existences are processes

Axiom 1, which the authors characterize as the axiom of bimodality (primarily to focus on Whitehead's efforts to overcome the Cartesian bifurcation of nature between things of thought and things of extension), provides the analytical frame for their evolutionary analysis (Dopfer & Potts, 2004: 205). It does so by describing existences as the product of a process of co-supervention such that the world of ideas and the world of matter-energy are mutually implicated in existence. Matter-energy actualizations of an idea are manifold due to the potential for replication. Populations are then defined as the resulting set of actualizations. Each idea has a population of matter-energy actualizations. According to the authors, Axiom 1 implies that each idea possesses unique and non-arbitrary properties, which are not evident on an a priori basis but must instead be revealed through association (Dopfer & Potts, 2004: 206). Ideas amount to rules or mechanisms that yield criteria for distinguishing between actualisations where distinction, in turn, is correlated both with associations that are established with other ideas and with variations on any given idea.

In stating that all existences associate, Axiom 2 introduces the possibility that

novelty can be introduced through establishing new associations between existences. Information is the revealed property of ideas by association. However, this information is not conserved under energy transformations because it changes when associations between ideas themselves undergo change (Dopfer & Potts, 2004: 206-7). The authors draw a distinction between their own more qualitative and semantic concept of information and that of Shannon information, arguing that a richer construct is required to engage with issues of knowledge creation and social organization, including an explanation of the division of labour and network externalities. The qualitative dimension is explained by introducing the notion of complementarity—in the sense of adaptation and fit between components. On this basis they distinguish between a narrow conception of economic efficiency and the more comprehensive notion of efficacy.

Finally, axiom 3 states that all actualisations unfold as processes in space and time while simultaneously generating historical space and time (Dopfer & Potts, 2004: 207). They claim that this axiom provides the wherewithal for distinguishing between continuity and discontinuity. This distinction, in turn, grounds their tri-partite classification of micro-, meso- and macro-regimes. They define the meso-regime in evolutionary terms based on the three standard components: origination, adoption and adaptation, and retention (Dopfer & Potts, 2004: 207). A meso-unit is the combination of a rule and its associated population of actualisations. Micro-agents are then conceived as "complex systems of meso-rules" (Dopfer & Potts, 2004: 210). While the meso-regime is the domain of rules all structure is carried by micro-agents who possess the capacity both to understand existing rules and to generate new ones. The macro-domain represents the structure of these meso-rules, their variation across agents, and the manner of their interactions and evolutionary transformations. Within the meso-regime, evolutionary trajectories can be described in terms of diffusion processes and discontinuities of transformation.

By combining axioms 2 and 3, the authors construct a notion of emergence conceived in terms of structures processing energy in conformity with the second law of thermodynamics (Dopfer & Potts, 2004: 208). In this context, knowledge is viewed as a dissipative system: in far-from-equilibrium systems characterised by emerging complexity and self-organization. On this view, ordered structures are seen to build systems by importing high-grade energy and exporting low-grade energy.

In Australia, the recent Venturous Australia policy document prepared by Terry Cutler and Associates for the Commonwealth Government, owes much to the evolutionary economic way of thinking about innovation. The objective of this paper, however, is to raise more specific concerns about the value of Dopfer and Pott's interpretation of Whitehead, especially with regard to what it might contribute by way of strictly economic applications of complexity theory. In the paper's conclusion it is argued that Post Keynesian macroeconomic applications currently seem to offer greater potential in regard to theoretical developments in 'far-from-equilibrium' thermodynamics. In this sense, it is congruent with the arguments of economic geographers like Mcleod and Jones (1999), who urge a

return to more Keynesian approaches to issues of regional development.

2. ELEMENTS OF A CRITIQUE

The first and most obvious criticism of Dopfer and Potts's (2004) methodology is that they attempt to preserve the neo-classical, Popperian, and neo-Austrian penchant for methodological individualism, with the micro-agents viewed as the ultimate instigators of novelty and creative endeavour. In other words, instead of embracing the market as the vehicle of 'natural selection' as argued by Nelson and Winter (1982), Dopfer and Potts see individual agents as mediators between macro- and micro-scales. In this mediating function they are held ultimately responsible for processes of selection, the generation of variety, and for mechanisms of inheritance (e.g. corporate memory resides in individuals in the form of standard operating procedures). The vehicles of this evolutionary process are organizational routines and meta-routines, which govern processes of search and the transformation of lower-order routines.

Moreover, as Nelson and Winter (1982) have argued in their own seminal work, a whole sphere of organizational activity (that of higher-order law-governed behaviour) is situated beyond the limits to which their own evolutionary methodology can be meaningfully applied. Dopfer and Potts (2004) do not seem concerned about any such limitations, perhaps this is because they feel more confident about the philosophical framework that they have constructed by drawing upon the work of Whitehead and Kant. However, such confidence must surely be misplaced unless (i) the profound philosophical differences between Kant and Whitehead have been examined in some detail to establish exactly where Dopfer and Potts stand in this regard; and, (ii) the authors can establish the precise relationship holding between the higher-order consciousness and communicative abilities of human beings, the prehensions or feelings of lower order organisms, and those of inorganic structures such as crystals, for this is something that Whitehead attempted through his categorical logic of concrescence.[2] As Epperson (2004: 115) says of Whitehead:

> *His drive was instead to show how traditionally incompatible areas of inquiry such as modern physics, philosophy, and even religion, could be brought together in a mutually illuminative way within the framework of a*

[2] Concrescence is a process through which prehensions are integrated into a fully determined feeling or satisfaction. Thus, concrescence achieves an integration of diverse and definite elements. Prehensions are concrete modes of analysis of the world. To prehend is to have a concrete idea or concept of that thing. However, a prehension is also a process of appropriation of an element of, or derived from, an actual entity, which changes the internal constitution of the prehending subject. It is also the process through which the prehending subject, through a series of appropriations, becomes itself. Feeling is the integration of an actual entity or occasion into the internal constitution of a subject. Primary feelings may be physical, conceptual or transmuted. Hybrid feelings combine physical and conceptual feelings. Transmutation occurs when feelings of one kind are transformed into those of another kind. The transmission of feelings contributes to the process of concrescence of actual entities. Conceptual feelings can be integrated into more complex feelings such as 'propositional' or 'comparative' feelings.

logical, coherent, empirically applicable, and empirically adequate metaphysical scheme.

In this regard, while it is undoubtedly true that we require a richer measure of knowledge than that afforded by Shannon-Weaver information, more generalized conceptions of entropy are unlikely to satisfy the demand for metrics that can accommodate the semantic and syntactical richness of human communication. Precisely what kind of metrics do Dopfer and Potts have in mind?

A third criticism must be directed at the skeletal reduction of Whitehead's categorical logic down to three axioms of an evolutionary ontology, which surely amounts to a travesty of what he was trying to achieve through process philosophy. It also exposes their reading of Whitehead to criticism on the grounds that it privileges idealism over materialism. Whitehead's analysis of concrescence spans a continuum ranging from the pattern forming behaviour of crystals at one end of the spectrum through to the highest aesthetic sensibilities of a Wordsworth or Shelley at the other end of the spectrum.3 The Spinozan character of Whitehead's metaphysical thinking, with its logic of expression, contrasts favourably not only with a Gnostic logic of emanation or a more neo-Platonic logic of participation, but also with the "logic of scientific discovery" championed by Critical Realism. Whitehead (1978: 10) specifically acknowledges the fact that the philosophy of organism is closely allied to Spinoza's scheme of thought:

But it differs by the abandonment of the subject-predicate forms of thought, so far as concerns the presupposition that this form is a direct embodiment of the most ultimate characterization of fact. The result is that the 'substance-quality' concept is avoided; and that morphological description is replaced by description of dynamic processes.

Moreover, Whitehead (1968: 81) attempted to find a balance between Spinoza's infinite and Leibniz's "windowless" monads:[4]

Among philosophers, Spinoza emphasized the fundamental infinitude and introduced a subordinate differentiation by finite modes. Also conversely, Leibniz emphasized the necessity of finite monads and based them upon a substratum of Deistic infinitude. Neither of them adequately emphasized the fact that infinitude is mere vacancy apart from its embodiment of finite

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[3] From a Lacanian perspective, Alain Badiou would claim that, at the very limits of thinking, we are also confronted by a materialism of the letter rather than that of the signifier (see Clemens, 2003).

[4] This affinity of Whitehead's conception of eternal objects, concrescence, and actual occasions with Spinoza is rendered more clearly in Whitehead's 1925 Lowell Lectures, published under the title Science and the Modern World rather than in Process and Reality, where Whitehead, for strategic reasons places more emphasis on John Locke's approach to human reason (compare Whitehead, 1985: 38, 50, 87, 102-3, 156, 177, 220). In this regard, Whitehead's Chapters (1985: Chp. 10 & 11) on Abstraction and God from this text can usefully be compared with Deleuze's (1990: Chpt. 12) Chapter on Modal Essence: the Passage from Infinite to Finite in Expressionism in Philosophy: Spinoza to establish the isomorphism between each philosopher's reading of the expressive relationship Spinoza traces out between infinite modal essences and singular finite modes.

values, and that finite entities are meaningless apart from their relationship beyond themselves.

But more than this, it also provides us with a richer and more comprehensive ground for ethico-political intervention. Well known exemplars of this approach include the Spinozan environmental ethicist Arne Naess (1990) as well as members of the Althusserian circle, such as Warren Montag (1989) who turned to Spinoza's Theological-Political Treatise and the famous Appendix to Book I of the Ethics, to inform their critique of ideology.

Finally, we need to ask just what the implications are for economic analysis of far-from-equilibrium systems, which are characterised by emerging complexity, symmetry-breaking, and self-organization. In the remainder of the paper, a necessarily brief overview of Whitehead's philosophy is provided, first, to demonstrate Whitehead's subversion of the Kantian tradition, and second to throw some light on the structure of his own, decidedly non-Kantian, categorical logic of concresence. This overview is followed by a discussion of different versions of complexity theory, asking what they have to offer from an heterodox economics perspective.

3. AN OVERVIEW OF WHITEHEAD'S ONTOLOGY OF PROCESS

In his book, "The Rehabilitation of Whitehead", George Lucas (1989) identifies four distinct schools of thought within the Process Tradition. The Romantic Naturphilosphie of Goethe, Schelling and Hegel acts as a counterbalance to the evolutionary cosmology of Diderot and Lamarck. Moreover, Whitehead's contribution and, to a lesser extent, the British Realist tradition must be clearly distinguished from its American counterparts attributed by Lucas (1989: 36) to Parry, Dewey, Lewis, and Mead.

In justifying this latter demarcation Lucas (1989: 41) sets out four essential claims of what he calls the Realist revolution. First, Realists embrace an ontological pluralism rather than a mystical monism of the One. Second, they adhere to an objectivism rather than any conception of reciprocal internal relatedness. Third, they hold to an epistemological monism rather than to the Cartesian dualism of the Enlightenment. Finally, some hold to a Platonic conception of essences of pattern, endurance and form (Lucas, 1989: 42). However, the major problem for Realism is that the first two principles render the last two impossible, while the fourth is ultimately destined to "wither away". In this light, Lucas argues that Whitehead's alternative doctrine is to abandon Objectivism for the notion of internal relatedness. This approach makes ontological pluralism compatible with epistemological monism (presumably because the dualism between res cogito and res extensa can be overcome through a philosophy of expression emphasizing processes of 'actualization' and 'realization', which are in turn predicated on some notion of internal relatedness). Whitehead, however, is then obliged to reconcile ontological pluralism with his own quasi-Platonic conception of eternal essences. Clearly, Process Philosophy also rejects the Kantian notion of a transcendental subject.

As Whitehead (1978: 135) explains:[5]

> *The philosophy of organism is the inversion of Kant's philosophy. The Critique of Pure Reason describes the process by which subjective data pass into the appearance of an objective world. The philosophy of organism seeks to describe how objective data pass into subjective satisfaction, and how order in the objective data provides intensity in the subjective satisfaction. For Kant, the world emerges from the subject; for the philosophy of organism, the subject emerges from the world.*

Whitehead's philosophy is based on a clear repudiation of fundamental mechanistic materialism, accompanied by a reconceptualization of the latter as a form of "mathematical abstraction", which arises due to the "fallacy of misplaced concreteness". For Whitehead, classically described objects are better conceived as examples of what he calls "historical routes of atomic events". In his conception of historical routes, past events influence, but do not determine future events. This is because some events are more relevant as prehended data than others, with many past events being eliminated through a process of cancellation.

In accordance with his categorical logic, data can be objectified by an occasion through reproduction, transmutation, and reversion. Whitehead contends that simple reproduction gives rise to enduring objects, which include such phenomena as waves and probability functions. This process is encompassed by Whitehead's Category of Conceptual Reproduction. In contrast, his Category of Transmutation operates through the integration of manifold, microcosmic prehensions into a macrocosmic "collective observable". Finally, the Category of Conceptual Reversion conveys the idea of novel potential forms ingressing into the becoming occasion from somewhere else.

Whitehead's repudiation of the Cartesian "bifurcation of nature" is displayed by his notion of the mutual implication of materiality and mentality. Each atomic occasion is conceived as dipolar (see Epperson, 2004: 109). On one hand, the physical pole captures the actual occasion's real physical relation with antecedent data that are thereby causally efficient in its becoming. On the other hand, the mental pole captures the actual occasion's evolving form of definiteness—via the above-described processes of reproduction, reversion, and transmutation—such that potentiality gives way to actuality.

Accordingly, this implicated dipolarity can be analysed in two corresponding and complementary ways: namely, coordinate and genetic division. Through coordinate division data are appropriated according to the concrete, spatiotemporally coordinated character of actualities. Through genetic division,

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[5] Furthermore, Whitehead (1978: 111) points out that Kant, in his struggle to defend the Newtonian universe against Hume's devastating critique of causality:

> *[…] only saved it [Newton's doctrine of space and time as actual things] by reducing it to a construct by means of which 'pure intuition' introduces an order for chaotic data; and for the schools of transcendentalists derived from Kant this construct has remained in the inferior position of a derivative from the proper ultimate substantial reality. For them it is an element in 'appearance'; and appearance is to be distinguished from reality.*

data that are manifest (under presentational immediacy) as nexūs and societies with ill-defined loci and characteristics are integrated by the prehending subject's immediate, spatial "strain locus" into distinct forms of definiteness that are organized into a "presented duration" (Epperson, 2004: 110).[6]

This analysis is governed by cooperation between two principles: the Principle of Relativity and the Ontological Principle. The Principle of Relativity states that the "potentiality for being an element in a real concrescence of many entities into one actuality is the one general metaphysical character attaching to all entities" (Epperson, 2004: 111). The Ontological Principle states that "every condition to which the process conforms in any particular instance has its reason either in the character of some actual entity in the actual world of that concrescence, or in the character of the subject which is in the process of concrescence" (Epperson, 2004: 14). In this light, the objects of coordinate analysis and their conditioning influences are derived from antecedent actual occasions, whereas the objects of genetic analysis and their conditioning influences are derived from the non-actual, real world of potentia. The latter are revealed as formative elements known through participation in the actual world. As pure potentia, they contribute to a creative process of on-going novelty, ultimately derived from what Whitehead describes as the primordial nature of God. However, each actuality is also creative of itself, through its own deployment of real data and pure potentia (See Epperson, 2004: 112).

While every occasion entails a mental pole, a further distinction obtains between low-grade and high-grade occasions (see Epperson, 2004: 113). For low grade occasions (pertaining to simple reproductions, reversions and transmutations, including the quantum mechanical, and more broadly, the public order of electromagnetic occasions characterising our epoch). For high-grade occasions (which include advanced conceptual forms of proposition, hypothesis, imagination, and dream characterising the private order of societies of occasions) the mental pole dominates.

Thus, structured societies are conceived to subsume less or more specialized subordinate societies whose definition is independent of the environment (e.g. the molecules of a cell, the phenomenon of quantum decoherence) and subordinate nexūs whose definition is dependent on environment (e.g. the

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[6] Epperson (110-11) provides a quantum mechanical interpretation of this analysis into coordinate and genetic division, where each division is presupposed by the other. The physical pole (reflecting actualizations of the potentia defined by reduced-form solutions of the Schroedinger equation) describes the evolution of system from an initial state to a final state, entailing the integration of antecedent data with respect to the matrix of potential forms of definiteness. However, all outcome states can only be confirmed retrodictively because actualisations are only characterised in probabilistic terms. From this physics-informed perspective Epperson argues that the "strain locus" is to be distinguished from a "duration" which does depend on its physical content. Rather, a strain-locus depends merely on its geometrical content. This geometrical content is expressed by any adequate set of "axioms" from which the systematic interconnections of its included straight lines and points can be deduced. (Whitehead, 1978: 330). In the context of relativity theory, it is the reason for "a certain absoluteness in notions of rest, velocity, and acceleration" (Whitehead, 1978: 321).

cytoplasm of a cell, novelty of appetition) (Epperson, 2004: 114). As illustrated below, Whitehead's Categorical Logic traces the process of concrescence in terms of a detailed series of stages and phases.

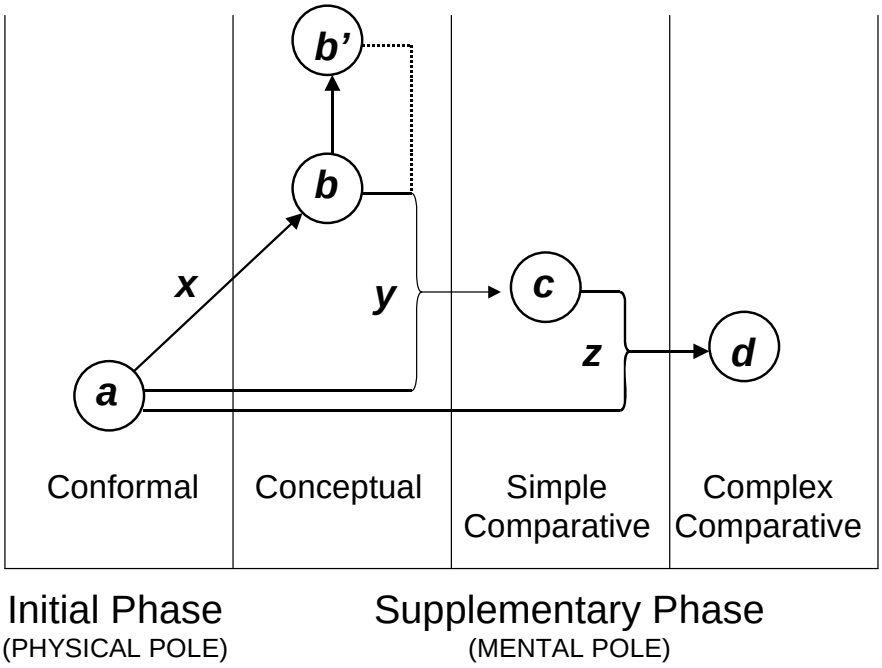

Figure 1. Phases and Stages in Whithead's Categorical Logic

Stage I is the initial stage, which also corresponds to Phase I (the conformal phase), which represents the responsive stage or physical pole. Here, the notion of responsiveness" captures the manner in which the actual world as a multiplicity of fact is prehended by the subject (thus exemplifying the Principle of Relativity). In his quantum mechanical interpretation of Whitehead's stages of concresence Epperson argues that the initial stage is correlated with the initial state of system, the introduction of a measuring apparatus, and the environment within which the system is embedded.

In Figure 1, taken from Sherburne (1981), the author interprets a as a causal or physical feeling (i.e. a prehension of an actual entity), b is a primary feeling or process of conceptual reproduction (i.e. a feeling associated with an eternal object as its source), and b' as a reverted feeling (i.e. one occasioned by proximate novelties that are felt through a prehension of relevant alternatives, though limited by the necessary inclusion of an element in feelings derived from an anterior stage), while c is a simple comparative or propositional feeling associated with proposition y (which operates as a datum for c), and d is a feeling

of contrast associated with z (itself, a contrast between a prehended nexus of entities and a proposition (in the particular case illustrated here, proposition y).[7]

A more cogent explanation of the process of concrescence, however, is afforded by Epperson (2004), who relates each stage to quantum physical developments. His arguments are summarized in what follows. The compatibility of quantum field and relativity theory with Process Philosophy is openly acknowledged by Whitehead (1968: Chpts 7 and 8). Epperson warns, however, against a reductionist interpretation that would seek to reduce philosophical concepts to those of the new physics:

> *Clearly, then, without a proper attention to the Whiteheadian distinctions between organic and inorganic, living and non-living, conscious and merely mental, the correlation of Whitehead's metaphysics with the physical sciences will be a needlessly uneasy one, likely to inspire either the complete excising of the mental pole on the grounds that it cannot be relevant to physics—or even worse, attempts to use quantum mechanics to "explain away" the human mind and other higher-order mentality (Epperson, 2004: 115).*

Epperson's (2004: 106-7) clearly stated goal is to demonstrate "how Whiteheadian metaphysics can be heuristically useful in understanding modern ontological interpretations of quantum mechanics, such that the physics can be interpreted logically, coherently, and empirically adequately as an exemplification of the metaphysics; but just as important is the converse demonstration that modern ontological interpretations of quantum mechanics can be heuristically useful to an understanding of Whiteheadian metaphysics".

Epperson (2004: 146-7) begins his explication with Whitehead's Category of Subjective Unity, which accounts for the fact that the many feelings which belong to an incomplete phase in the process of an actual entity, though unintegrated by reason of the incompleteness of the phase, are "compatible for synthesis by reason of the unity of their subject" (Whitehead, 1978: 26). Epperson contends that the evolution of the state of system obtains through alternative integrations of potential facts born of antecedent actual facts, including through negative prehensions. The next Category of Objective Identity accounts for the fact that there can be no duplication of any element in the objective datum of an actual entity, so far as concerns the function of that element in the satisfaction (Epperson, 2004: 147; citing Whitehead, 1978: 225). This principle establishes the uniqueness of any given actual entity. Epperson relates this category to the elimination of superpositions of interfering potentia in quantum mechanics. Next, Epperson (2004: 147; citing Whitehead, 1978: 225) introduces the Category of Objective Diversity, which accounts for the fact that there can be no "coalescence" of diverse elements in the objective datum of an actual entity, so far as concerns the function of those elements in that satisfaction. In other words, each potential must be as unique as the specific

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[7] For Whitehead, a nexus is a set of actual entities in the unity of relatedness constituted by their prehensions of one another; while a proposition is a unity of actual entities (logical subjects) in their potentiality for forming a nexus.

actuality from which it evolves.

The Second Stage—the Supplementary Stage—encompasses the Conceptual Phase, Comparative Phase, and Stage of Satisfaction, the first of which can be further subdivided into three sub-phases. Sub-phase I represents the actions relating to the Category of Conceptual Reproduction (Epperson, 1978: 140; citing Whitehead, 1978: 26) which requires that from each physical feeling there is a derivation of a purely conceptual feeling whose datum is the eternal object exemplified in the definiteness of the actual entity, or the nexus, physically felt. Epperson argues that under the action of this category the conditioned indetermination of real (pure) potentia provide conditioned (unconditioned) transcendental novelty to the evolving fact. This notion of novelty is crucial in Whitehead's metaphysics. Novelty must be a fully comprehended feature of the ingress of eternal objects into actual occasions. Sub-phase II represents the actions relating to the Category of Conceptual Reversion. Epperson (2004: 141; citing Whitehead, 1978: 249) argues that "as the category states, reversion is always limited by the necessary inclusion of elements identical with elements in feelings of the antecedent phase". Here, negative aversions or positive adversions are subsequently evaluated according to the probability valuations determined for each outcome state.

The Comparative Phase of the Supplementary Stage represents the action of the Category of Transmutation (Epperson, 2004: 148-150; citing Whitehead, 1978: 101):

> *in quantum mechanical terms we have the construction of the pure state density matrix determined by amplitudes. This integration achieved is via "…a massive average objectification of a nexus, while eliminating the detailed diversities of the various members of the nexus in question". Through the quantum mechanical "decoherence effect", it yields the mixed state reduced density matrix. This matrix is formally obtained through an application of the trace operation to the expression for probability amplitudes.*

The third Stage—that of Satisfaction—accounts for the actualization of the event based on subjective forms, which Epperson interprets as the probability valuated alternative potential outcome states. pperson asks exactly why these potential and probable outcomes are what they are, as a prelude to the completion of his analysis of Whitehead's categorical logic. his rhetorical question sets the scene for his discussion of the Categories of Subjective Harmony, Subjective Intensity, and Freedom and Determination.

Under the Category of Subjective Harmony the valuation of conceptual feelings are mutually determined by the adaptation of those feelings to be contrasted elements congruent with the subjective aim (Epperson, 2004: 156-7; citing Whitehead, 1978: 27). Under the Category of Subjective Intensity the subjective aim, through which there is the origination of conceptual feeling, is at an intensity of feeling both: (a) in the immediate subject; and, (b) in the relevant future. Finally, under the Category of Freedom and Determination the concrescence of each individual actual entity is conceived as being both intrinsically determined and externally free, thus generating a balance between

regularity and diversity, and between reproduction and reversion (Epperson, 2004: 157-8; citing Whitehead, 1978: 27-8).

Epperson (2004: 165-166) points out that the spatiotemporally extensive morphological structure of entities (conceived through coordinate division) is as crucial to concrescence as the intensive features (conceived through logical, historical, or genetic division). Both must be recognised as woven together in our efforts to overcome the bifurcation of nature. In the same way that extensive coordination requires prior genesis (in the form of a non-local causal affection of potentia by prior a actuality via genetic division), so does genesis requires prior coordination with respect to the ingress of eternal objects (in the form of a pairing between an actual-factual term and a potential-formal term (Epperson, 2004: 209).

4. WHICH VERSION OF COMPLEXITY THEORY DO DOPFER AND POTTS HAVE IN MIND?

Arguably, some of the most far-reaching changes in our understanding of probability theory and dynamics have come from the work of theorists such as Ilya Prigogine and Constantino Tsallis, who have each conducted research into the thermodynamic properties of complex systems. Significantly, Prigogine and Stengers argue that processes of emerging complexity and self-organization go some way towards explaining life-processes and what Whitehead termed the "creativity of nature" (Prigogine and Stengers, 1997: 62). They observe that Whitehead's "…ultimate goal was to reconcile permanence and change, to conceive of existence as a process (Prigogine and Stengers, 1997: 59).

While Prigogine and Petrovsky's (1996) work on resonance has profound implications for the interpretation of probability theory, related notions of thermodynamic entropy, and the phenomenon of symmetry-breaking, strictly economic interpretations of his findings are hard to find. However, this is certainly not the case for the work of Constantino Tsallis and his associates (see Tsallis bibliography for full listing of references).

In his research into the thermodynamic characteristics of chaotic and turbulent systems, Constantino Tsallis conjectured that a generalized version of entropy could be constructed by drawing on the mathematical properties of multifractal processes. Tsallis and his associates have elucidated the link between this generalized information measure, and the statistical mechanics of complex systems.

A q-generalized version of the standard central limit theorem is set out in Umarov et al., (2008), confirming the relevance of these q-Gaussian multifractal processes. Analogous to the classical Boltzmann-Gibbs thermodynamics, Tsallis conjectured a triplet of q-parameters (qstat, qsen, qrel) which characterise, respectively, the properties of the resulting meta- or quasi-stationary distribution, generalized exponential sensitivity to initial conditions, and generalized exponential relaxation of macroscopic quantities to thermal equilibrium. This conjecture about the q-triplet has now empirically confirmed for solar wind in

the distant heliosphere (Berlaga and Viñas, 2005)[8].

Constantino Tsallis's thermodynamically motivated work on the information measure that bears his name, has also given rise to a large number of economic applications, primarily in the field of quantitative finance (see Tsallis bibliography: references 1382-1395; 1413-1418; and 1413-1418 for insurance-related applications). The relevance of this literature to evolutionary conceptions of economics, however, should be demonstrated rather than merely assumed. Associates of Dopfer and Potts in the Economics Department of the University of Queensland, St. Lucia, such as John Foster, have urged economists to develop empirical techniques for the analysis of complex systems including: self-organizing systems characterized by logistic growth process, and 'symmetry breaking' phenomena associated with time irreversibility. While inferences about (i) changes in mean of stationary random process (jumps in mean position); (ii) intersecting or broken-line regressions (changes in slope); (iii) the significance of actual transitions (TAR and SETAR models) can be modelled and tested, Hinich et al. (2006: 137) warn that observed smooth transitions (mean shifts and slope changes) can be an artifact of the filtering process observing, in addition, that high levels of aggregation make it difficult to associate macro models with microeconomic (or even mesoeconomic) behaviour. They also complain that the conventional assumption of uniform agents effectively precludes study of structural change. They further note that a recognition of 'symmetry breaking' phenomena has lead to various tests of time irreversibility such as Hinich and Rothman's (1998) bi-spectrum test, this raises the obvious but unanswered question about what kinds of mechanisms are responsible for symmetry breaking within economic time series.[9]

5. CONCLUSION

This paper has implicitly argued that the interpretation of Whitehead's Process Philosophy advanced by Dopfer and Potts (2004) amounts to a travesty of the richness and depth of Process Philosophy, as a comparison of the categorical logic of Whitehead's Process ansd Reality, reviewed in the third section of this paper with Dopfer and Pott's' interpretation of three-fold axiomatic logic clearly reveals. In particular, the notion of association that Dopfer and Potts articulate fails to capture the complex nature of Whitehead's ontology. While the Principle of Concretion accounts for the existence of individual instances of order (objects), Whitehead's notion of association (described in terms of 'interconnectedness' or 'relation') pertains to both actual entities and eternal objects (events). As Whitehead (1985: Chapter 10 and 11) argues in Science and the Modern World, such interconnections are expressed in

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[8] Suyari and Wada (2008) provide an explanation for the q-triplet, which draws on the asymptotic and duality-related properties of a discrete two-parameter version of multinomial distribution.

[9] Here, cumulative processes that eventually break through capacity constraints must be recognised as only one of a diverse range of possible sources of symmetry-breaking in economics.

a two-fold manner. On one hand, a certain possibility is implicated in the actualisation of an event. This process of actualization, however, is an expression of both indeterminant and external relations. On the other hand, the event is distinguishable in its relationships from other events on the basis of determinate and internal relations. In other words, the systematic mutual relatedness of actual entities, which is accounted for by the general principle of relativity, must be reflected in a systematic mutual relatedness of potential entities (see Code, 1985: 170). From an ontological perspective, this two-fold process of interconnection, in turn, gives rise to differing levels of abstraction.

The philosophical differences between Kant and Whitehead, elided in the work of Dopfer and Potts, were also identified. In addition, it was revealed that Whitehead rejected Leibniz's theory of monads. At a foundational level these philosophical differences serve to question the underlying methodological individualism that Dopfer and Potts champion within their integrative framework. Significantly, although Epperson's Quantum Theoretic interpretation was deployed to highlight the materialist and realist aspects of Whitehead's metaphysics, Epperson's own warnings against reductionist readings of Process Philosophy were also heeded.

The final section of the paper reviewed research into far-from-equilibrium thermodynamics, which clearly seems to have informed Dopfer and Pott's preferred research agenda. However, this section also highlighted the fact that economic applications of this new thermodynamics are exceedingly rare. In fact, most applications of thermodynamic reasoning in the field of economic analysis (Foley, 1994; Smith and Foley; 2005; Liossatos, 2004; Hawkins and Freiden, 2004) draw on traditional rather than far-from-equilibrium interpretations.

When it comes to deployments of Process Philosophy in economic research, it would seem that macroeconomic applications currently afford the greatest scope for on-going collaboration! In particular, Post Keynesian approaches to the phenomena of decision making under uncertainty can both inform and be informed by non-equilibrium thermodynamics. Queirós, Anteneodo, and Tsallis (2005), and Queirós and Tsallis (2005), for example, highlight the link between the pseudo-additivity property of Tsallis entropy and Kahneman and Tversky's Cumulative Prospects Theory (CPT) (see Tversky and Kahnemann, 1992).[10]

While there are divergent views about the nature of Keynes's own views on the ontological basis for probabilistic inference (especially as his views are known to have changed notably between the 1928 publication of The Treatise on Probability and the 1936 publication of The General Theory), most Post Keynesians hold to the view that he rejected the Ramsey-de Finetti subjectivist interpretation of decision-making under uncertainty, opting instead for a more objectivist view. When it comes to specifying the ontological grounds for

[10] In applications of Cumulative Prospect Theory to decision-making under uncertainty, the decumlative distribution function is distorted by an S-shaped function that places more weight on the tales than the mid-points. In other words, more emphasis is placed on transitions from impossibility to possibility or from possibility to certainty than on those that merely make something that is likely even more likely. Similar distortions are occasioned by the q-parameter in the case of Tsallis entropy.

Keynesian notions of animal spirits, weight, confidence, and degrees of belief, opinions diverge ranging from intersubjective interpretations (Gillies, 2006), or a re-invigorated atomist approach (Davis, 1989), through to a fully-fledged organicist approach informed by the ethical constructs of G. E. Moore and the metaphysical principles of Alfred North Whitehead's Process Philosophy, the latter interwoven with insights from the Freudian psychoanalysis of Sandor Ferenzci and Ernest Jones (on organicism see Winslow, 1989; on Freud and Keynes see Winslow, 2005, 1986).

Once again, for those in the organicist camp, Whitehead's nested ontology underpinned the Keynesian distinction between short-run and long-run expectations and his notion that investors, to assuage their anxiety in the face of uncertainty, fall back on 'convention' rather than on 'caprice'. However, Keynes argued that the conventions of the "Benthamite probability calculus" would rapidly be abandoned during a financial crisis, as 'money-love' transformed away from its more sublime forms (such as the "lure of compound interest") into more regressive, cruder, and more pathological forms. For this particular author, it is these Keynesian and macroeconomic aspects of Organicism rather than Evolutionary Economic applications that seem to offer the richest lode to be mined.

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