QUANTUM DREAMING: THE RELEVANCE OF QUANTUM MECHANICS TO REGIONAL SCIENCE

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ABSTRACT: Regional scientists are familiar with such concepts as Wicked Problems and Social Messes, which describe a human world of great complexity and uncertainty. Both dramatically affect the accuracy and effectiveness of our analysis of regional economic process and policy prescription alike. This paper adds additional layers or dimensions to Wicked Problems and Social Messes via analogy with concepts derived from Quantum Mechanics, a branch of particle physics itself shrouded in great complexity and uncertainty. Heisenberg's (1930) uncertainty principle, for example, asserts the impossibility of stating accurately both the location and velocity of matter on account of its simultaneous wave- and particle-like behaviour, ideas that appear to apply to economic systems. Quantum mechanics also entertains the weird notions of entanglement and superposition, the latter of which led to Schrödinger's famous mind-game in which he proved a cat could be simultaneously alive and dead and Einstein's disparaging remarks about the entire field. Yet our spatial economic systems seem to embody elements of both entanglement and superposition. So Quantum Mechanics has potentially strange implications for theoretical development in regional science and ensuing public policy.

"I think I can safely say that nobody understands quantum theory"
(Feynman, 1965, p. 129).

"Perceptual and economic processes have no demonstrable
correlations with sub-atomic states ..."
(Campbell, 1995, p. 217).

"Doubt is not a pleasant condition, but certainty is absurd"
(Voltaire, *Candide*, 1759).

1. INTRODUCTION

This paper has three principal purposes. First, it rehearses briefly the already well-known arguments in favour of applying knowledge generated by the physical sciences analogously to studies of human economy and society. Secondly, we know that the social sciences have long had a fascination with, and perhaps admiration for, scientific laws and theories developed over the last 250 years or so. Ideas typically flow from the latter to the former, and it is interesting to note how the embrace of uncertainty by physical sciences a century or more ago took unexpectedly long to filter into social science consciousness, save some interesting exceptions. And finally we will explore the application of quantum concepts in geography and economics, an endeavour that has ebbed over the last decade after considerable interest in the last two decades of the twentieth century. In order to do this effectively, we will sketch both the general flavour and specific concepts of quantum physics.

2. THE ANALOGOUS USE OF SCIENTIFIC PRINCIPLES: A LONG FASCINATION

Studies of economy and society have long benefitted from adopting the analytical rigour of the physical sciences, including the:

- Formulation of testable hypotheses informed by existing, but maybe flawed, theoretical knowledge; and
- Collection of accurate and relevant data or information for that purpose; leading to
- Refinement of conceptual or statistical models with a high probability of accuracy.

But we can do more than just seek and explain order in human affairs *sui generis*. Another approach is to apply widely accepted physical processes analogously to social science subject matter. Massey (1999) and others believe that such use of analogy frequently extends and enlivens our understanding of social science processes or extends our own work in unexpected and imaginative ways, and helps to sell our findings or ideas as we bask in the reflected glory of rigorous and highly respected scientific processes. Thus Thurow (1998) uses geological imagery – for example, plate tectonics, subduction and earthquakes – to explain global macro-economic trends. Similarly, Richerson and Boyd (2005) explore the crucial importance of human culture in shaping people's adaptation to changing environments by melding images sourced from evolutionary biology, anthropology and psychology. One of the most powerful economic images coined in the twentieth century – *the gale of creative destruction* (Schumpeter, 1942) – in essence employs climatic analogy to explain a key process of capitalism. Equally powerful, but dating from almost 170 years earlier, was Adam Smith's rather metaphysical analogy of *the invisible hand* (see Kennedy, 2009). This idea is consonant with the physics of self-equilibrating systems using a variety of feedback mechanisms and of the laws of thermodynamics. In a similar league is Kondratieff's (1924) recourse to oceanography or light – take your pick – in developing the concept of long waves rising and breaking on economic shores.

In like vein, this writer has personally employed:

- *The Higgs boson,* which is the hypothetical fourth building block of the universe (after electromagnetism and the weak and strong nuclear forces). It is seen as the mass-bestowing agent in particle physics, giving mass to otherwise massless particles existing in the *quark-gluon plasma* post-big bang. Its economic analogy is the chance or contrived aligning of conditions favourable for the invention of new ideas and their implementation in commerce or public policy (Sorensen, 2005).
- *The double helix of DNA* (or spiral staircase structure; Watson and Crick, 1953). This image is reflected in the mutually entwined co-evolution of (i) human culture and (ii) the speed of invention and its adoption by producers (see Sorensen, 2009). Whereas the structure of DNA is largely stable, the spiral of mutual adaptation between culture and innovation accelerates in space-time and the concept of *stable adaptation* (Sorensen

and Epps, 2005) requires that the speed of both components – culture and innovation – accelerate at approximately the same rate. This concept was also inspired by notions of ecological resilience. Species survival under processes of natural selection requires stable adaptation in both environment and species' physical characteristics, including DNA. Sorensen and Epps also note, using another analogy taken from evolutionary biology, that stable adaptation in the highly complex and fast changing environments characterising industrialised human society requires a culture that is increasingly individualist or atomistic. In contrast, collective behaviours are less able to cope flexibly and rapidly with the rising pressure for change, a condition also noted by Richerson and Boyd (2005).

- *Superconductivity*, the notion of which was developed by Onnes in a Nobel Prize-winning paper in 1911. Sorensen (2009) points out that the transmission and adoption of innovation can be almost instantaneous under some communications conditions, just as an electric current flowing through wire at close to 0^{o}K encounters little impedance. What is needed is a fount of freely available innovation, ready receptors (or users of innovation) and impedance-free channels of communication and finance. In this case the receptors were, perhaps surprisingly, Australian farmers – known for their lightening fast adoption of farm technology.

Over a period of about 150 years from the middle of the eighteenth century, Newton, Boyle, Faraday, Darwin, Kelvin, Mendel, Einstein and many others constructed a majestic and surprisingly detailed natural world operating with unyielding precision akin to celestial clockwork. Even in the last half of the twentieth century, such people as Watson and Crick began to discover the complex, but highly regular, structures of genetic code. Such discoveries resonated with the many analysts who sought comparable order in the conduct of human affairs. It was assumed that possession of such knowledge could propel social engineering designed to: eliminate waste and inefficiency; rectify social injustice; defuse inter-personal conflict; enhance social stability; design better living spaces; accelerate human learning and understanding; or improve human and environmental resilience. The economists and geographers who adopted this paradigm bequeathed us such ideas as:

- Economic equilibrium, which resonates with the first law of thermodynamics (Samuelson, 1983);
- *Homo Economicus* (see Sen, 2008);
- The efficient market hypothesis (EMH) (Beechy *et al*, 2000);
- Rational expectations analysis (see Muth, 1961);
- Computable general equilibrium (CGE) models (Dixon and Rimmer, 2002);
- Game theory (von Neumann and Morgenstern, 1944);
- Central place theory (Christaller, 1933);
- Distance decay functions (Wilson, 1971);
- Regional multiplier analysis (ten Raa, 2005); and
- Innovation diffusion models (Hägerstrand, 1967).

And, in the world of urban design, town planners willingly applied such findings to the task of creating more efficient and socially equitable city-scapes.

Other social sciences – including political-economy, psychology and sociology – trod similar paths in attempting to discern persistent regularities among individual behaviours or social relationships. In the mid 19th century, Marx conceived the *perfect* society in tune with irrefutable laws of social evolution, building on a century or more of French philosophy. But it was not until the last three decades of the 20th that his geographical disciples misguidedly attempted to seize the intellectual high ground. They revelled in Marxian eschatology about the contradictions, crises and death of capitalism, and proclaimed the inevitable superiority of rational and perfectible socialism over the chaos of the market place. In sociology, the idea of structural functionalism took hold over much the same period (see for example the work of Parsons, 1951, and Merton, 1957). They conceived society as a structure based on a set of interrelated components including norms, customs, traditions and institutions, all mediated by issues of power and conflict. So, the use of scientific analogy to enhance our understanding of social science processes is common.

But sometime about the start of the twentieth century, the physical sciences became aware that exceptions to Newtonian celestial clockwork might be common for a host of reasons. Following the work of Onnes (superconductivity) and Planck (the inventor of quantum mechanics), scientists became aware that atomic structures often behave very differently at temperature extremes – hot in the case of the plasma conditions following the big bang, or cold (close to 0^o Kelvin). Einstein’s special and general relativity introduced light waves that bent under gravitational pull and the notion that people age at different rates according their speed of travel. Bohr and Heisenberg gave us the *Copenhagen interpretation* of quantum mechanics, whose weirdness shocked Einstein. Astronomers observed cosmic chaos in the form of black holes; while atomic structures and DNA were unravelled only to leave a trail of unanswered questions as major perturbations were often found in matter thought stable.

Our planet itself evolves perpetually through cycles of oscillating climates, continental drift, variable speciation, and the scramble of organisms to adapt to changing circumstances. The process of evolution has proved ever more chaotic through non-linearity, random – but deterministic – mutations, sensitivity of speciation to initial conditions, and fractal patterning (Bennett, 2010). Einstein’s linking of space and time in 1915, in the general theory of relativity, may require a divorce if Hořava is correct that they operate independently of each other (Hořava, 2009). And alpha, previously one of the fundamental constants of nature (the fine-structure constant is set at 1/137), now appears to be variable in space, if not time (Brooks, 2010). For example, it is smaller on one side of the universe than on the other, and if alpha became just 4% larger, the universe would be completely different to what we see and carbon-based life as known on earth would not exist. Chaos theory, which was formalised in the second half of the twentieth century by the likes of Lorentz (1963) and Mandelbrot (1963), sees many environmental and economic processes as being largely indeterminate – subject to a high level of chance. Uncertainty, it seems, is everywhere and it partly reflects our previous inability to understand the complexities of process, the increasing recognition of randomness or non-linearity, and acceptance that processes are often spatially variable rather than ubiquitous.

The social sciences have also begun to appreciate the importance of uncertainty, though to be fair some early practitioners in geography and economics understood the issue well. Regional geography, now largely dead, was founded on the idea of regional differentiation – the idea that places are hugely variable in socio-economic and environment conditions and processes. And market economics, in an unbroken line from Adam Smith through to the Austrian and Chicago Schools and on to Public Choice Theory (associated with Buchanan and Tulloch), sees the market place as an essential discovery mechanism to cope with myriads of actors each with their own motivations and preference sets. In a formal sense, chaos theory has been joined by its social science counterpart – complexity theory (Beinhocker, 2006), to augment nicely our ideas about wicked problems (Rittel and Weber, 1973), super wicked problems (Lazarus, 2009) and social messes (Horn and Weber, 2007). Table 1 enlarges on the complexities creating social science uncertainty and mitigating against remedial public policy (Sorensen, 2010). Further, to complexity theory we might add the notion of social tipping points of the kinds identified by Gladwell (2000) and Diamond (2005). Students of market economics will have observed by now that their work has a foot in both camps. The processes of self-equilibration and discovery under complex, if not chaotic, conditions are compatible if we recognise that the former is not a path returning to some *status quo ante*, but an attempt at *stable adjustment* within changing bounds imposed by new technologies or opportunities.

There is considerable overlap between these definitions and Arthur et al's (1997) diagnosis that economic systems are extremely difficult to model mathematically, and perhaps increasingly so, on account of six inter-connected conditions. They have dispersed interaction, no global controller, cross-cutting hierarchical organisation, continual adaptation, perpetual novelty niches, and out-of-equilibrium dynamics. Prigogine (1997) goes further and notes that the non-deterministic nature of complex systems make forecasting extremely hazardous. Such messes reflect (i) process uncertainty. (ii) the absence of timely and relevant data, (iii) the surprise impact of new technologies, and (iv) the vagaries of global competition among countries, themselves managed with varying degrees of competence by both luck and judgement. These components are, in turn, mediated by a large raft of behaviours, knowledge, and imagination on the part of individuals, organisations, institutions and government, all changing in the light of technology and the independence created by rising wealth. Sorensen (2010) lists over 40 such behaviours. Although subject to a variety laws, customs and behavioural norms, which are themselves in a state of constant modification, all actors exert a degree of independence to play the game as they see fit and thereby invent new processes. Much in both the physical and social sciences therefore resemble Critias's world of becoming and increasingly little the world of being (Plato, 1965). Hayek (1974), it seems was right to question the accuracy of modelling in the social sciences, but wrong about the ease with which simple systems could be handled in physics.

Table 1. Composition of Wicked Problems and Social Messes

A. Rittel and Webber's (1973) Original Formulation		**B. Horn's Guide to Social Messes**	
1	There is no definitive formulation of a wicked problem.	1	No unique "correct" view of the problem.
2	Wicked problems have no stopping rule.	2	Different views of the problem and contradictory solutions.
3	Solutions to wicked problems are not true-or-false, but better or worse.	3	Most problems are connected to other problems.
4	There is no immediate and no ultimate test of a solution to a wicked problem.	4	Data are often uncertain or missing.
5	Every solution to a wicked problem is a "one-shot operation"; because there is no opportunity to learn by trial and error, every attempt counts significantly.	5	Multiple value conflicts.
6	Wicked problems do not have an enumerable (or an exhaustively describable) set of potential solutions, nor is there a well-described set of permissible operations that may be incorporated into the plan.	6	Ideological and cultural constraints.
7	Every wicked problem is essentially unique.	7	Political constraints.
8	Every wicked problem can be considered to be a symptom of another problem.	8	Economic constraints.
9	The existence of a discrepancy representing a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the problem's resolution.	9	Often a-logical or illogical or multi-valued thinking.
10	The planner has no right to be wrong (planners are liable for the conse-quences of the actions they generate).	10	Numerous possible intervention points.
C. Lazarus (2009) Super			
11	Time is running out.	11	Consequences difficult to imagine.
12	No central authority.	12	Considerable uncertainty, ambiguity.
13	Those seeking to solve the problem are also causing it.	13	Great resistance to change.
14	Hyperbolic discounting occurs.	14	Problem solver(s) out of contact with the problems and potential solutions.

Source: http://en.wikipedia.org/wiki/Wicked_problem, accessed 9 July, 2011.

There is considerable overlap between these definitions and the diagnosis of Arthur *et al.* (1997) that economic systems are extremely difficult to model mathematically, and perhaps increasingly so, on account of six inter-connected conditions. They have dispersed interaction, no global controller, cross-cutting hierarchical organisation, continual adaptation, perpetual novelty niches, and out-of-equilibrium dynamics. Prigogine (1997) goes further and notes that the non-deterministic nature of complex systems make forecasting extremely hazardous. Such messes reflect (i) process uncertainty, (ii) the absence of timely and relevant data, (iii) the surprise impact of new technologies, and (iv) the vagaries of global competition among countries, themselves managed with varying degrees of competence by both luck and judgement. These components are, in turn, mediated by a large raft of behaviours, knowledge, and imagination on the part of individuals, organisations, institutions and government, all changing in the light of technology and the independence created by rising wealth. Sorensen (2010) lists over 40 such behaviours. Although subject to a variety of laws, customs and behavioural norms, which are themselves in a state of constant modification, all actors exert a degree of independence to play the game as they see fit and thereby invent new processes. Much in both the physical and social sciences therefore resemble Critias's world of becoming and increasingly little the world of being (Plato, 1965). Hayek (1974), it seems, was right to question the accuracy of modelling in the social sciences, but wrong about the ease with which simple systems could be handled in physics.

How, then, might quantum mechanics, a hot-bed of uncertainty and counter-intuitive processes, inform our understanding of wicked problems and social messes or other dimensions of uncertainty?

3. ON QUANTUM MECHANICS

Quantum Mechanics (QM) focuses mostly on matter at atomic and sub-atomic scales and seeks to explain the interactions of energy and matter, both of which possess particle and wave-like behaviours. Part of QM focuses on macro-scopic phenomena, but only at very high temperatures (plasmas) or at very cold temperatures at close to 0^{o}K. We are concerned here not with early formulations by Planck and Einstein, but with the later Copenhagen interpretation (Bohr, Heisenberg, and Pauli, mid 1920s) and its subsequent refinement by Dirac and von Neumann focusing on measurement issues, the nature of statistics and the role of the observer in about 1930. Although concerned with particle physics, quantum thinking has extended into many other branches of science (like chemistry, optics and electronics). We shall examine five key dimensions of QM: (i) wave-particle duality; (ii) the related uncertainty principle; (iii) quantum entanglement; (iv) superposition; and (v) decoherence. These are stated roughly in order of weirdness, and are described briefly before assessing their possible relevance for regional economics.

1. **Wave-Particle Duality** holds that all matter exhibits both wave and particle properties. For example, light comprises particles (photons) travelling at high speed in wave formation. A photon's position in space at any moment is a combination of forward velocity and position in the

wave cycle.

2. Under the *Copenhagen* interpretation, the **Uncertainty Principle** asserts that a phenomenon like light can be viewed accurately in one way or the other (as wave or particle), but not both simultaneously. The two dimensions are complementary, but the more accurately we measure say particle speed the less accurately we can measure its wave function.
3. **Quantum Entanglement** was described by a sceptical Einstein *as spooky action at a distance* and certainly it voids the idea of *local realism* in which every event has an immediate cause. Imagine a quantum system containing two or more distinct objects that are connected such that the measurement of one immediately alters the properties of the other even at arbitrary and large distances. QM has circumvented the problem of conventional causality by pointing out that during the sudden change in the properties of B following the measurement of A, no information is passed from A to B. Such events have been observed, but under extra-ordinary circumstances. There is one additional problem: if measuring A appears to affect B immediately and at great distance, the event many occur several times faster than the speed of light.
4. **Superposition** is another challenging concept about the nature or behaviour of matter at the sub-atomic scale. It amounts to the claim that, while we do not know what the state of any object is, it is actually in all possible states simultaneously, as long as we don't look to check. Measurement itself causes the object to be limited to a single possibility. This led to Schrödinger's famous proof in 1935 that a cat could be simultaneously alive and dead (for a gentle introduction to the topic, see http://en.wikipedia.org/wiki/Schr%C3%B6dinger's_cat). Note also the well-known two slit experiment in which it appears that a single photon fired at a screen can go through both vertical slits at the same time and interfere with itself in the process.
5. **Decoherence** related to the mystery of apparent wave-function collapse. A quantum particle is rarely completely isolated from its environment. Rather, the particle and the environment are bound together as one system – including any observer as part of the environment. For example, any measured object affects measuring devices in the environment, and vice versa. Such interaction with the macro-environment will lead to ebbing away of quantum states, leading to decoherence. Decoherence is not a mechanism for wave-function collapse; it provides a mechanism for the appearance of wave-function collapse.

This weird suite of processes is interconnected and mainly relevant to the behaviour of atoms and their components (quarks, neutrinos, photons, etc.). Quantum processes are largely indeterminate, and the related mathematics is heavily probabilistic.

4. TRANSLATION TO THE SOCIAL SCIENCES

QM concepts have been applied to such social sciences as geography, economics and regional science, especially during the 1990s (see for example, Wilson, 1971; Baker, 1983; Isard, 1986; Clark, 1994; Baker, 1994; Peterman, 1994; Macmillan, 1995; Popoff, 1997; Harrison and Dunham, 1998; Massey, 1999; Portugali, 2008; Juniper, 2008). A common theme in much of this work is that human behaviours are often probabilistic because they are analogous to quantum uncertainty, if not entirely random, and that our attempts to tease out regular patterns in such behaviours are often statistical constructs of dubious reliability.

Much of the literature also wrestles with a duality that is increasingly apparent in human affairs: the distinction between micro-scale individual action and macro-scale aggregate behaviours or norms. Some of the latter are regulated by institutions and laws, but some like distance decay functions have wide applicability. This discussion also wrestles with the extent to which micro- and macro-scales are congruent, and how they interact to shape each other. Bohm's (1980) idea of the *Implicate Order* considers that the identification of macro-scale regularity is a crucial task of both physical and human sciences and he warns that we should not be overly enthused by increasingly divergent behaviours at the micro-scale. Coming from a regional science perspective, Isard (1986) reaches a similar conclusion, arguing for a balance between empiricism and speculation and between detailed analysis of individual events and macro-modelling of economy and society – with an implied preference for the latter.

Both Bohm's and Isard's positions are potentially problematic in that there is clear evidence that all facets of economy and society are dissolving into a multiplicity of competing fractions. Marx's bi-polar focus on interactions of labour and capital as the fundamental dynamic of modern society has been replaced over the last 150 years by at least 10 interacting, and often competing, separate dynamics. These now include: capital-labour; young-old; male-female; passive-active (where active people are leaders, entrepreneurs and innovators); future-past; individual-collective; private-public; consumption-conservation; centre-periphery; local-global; and so on. Instead of occupying a kind of two-dimensional social space, each individual now occupies a dynamic niche in 10+-dimensional hyperspace. Even ethical and moral standards are fracturing.

If we examine some of the studies seeking to apply QM concepts, the intellectual stimulation they gain is readily apparent, although interestingly most engage only one of the five dimensions noted above. Popoff (1997), for example, engages quantum *entanglement* to explain people's decisions to migrate from, or stay at, a particular location. He explains how their decisions are connected to images of destinations partly formed by migration experiences of others – described as a band-wagon effect, which is influenced by wave-patterns linking origins and destinations. Baker (1994) explains that travel behaviour is partially connected to people's perceptions of place utility, which are themselves influenced by velocity of travel, which in turn affects the degree of uncertainty experienced by the traveller. This is clearly influenced by uncertainty connected with wave-particle duality. Meanwhile, Clark (1994) developed Bohr's (and QM's) concept of complementarity to come with a comprehensive interpretation of the process of gentrification and, just recently, Portugali (2008) argued that paradoxes of the kinds inherent in QM might be useful for prediction and planning in self-organising cities. Perhaps this is not far from Macmillan's (1995) conception of a fuzzy urban planning, with both sets of ideas revolving around uncertain urban futures in a world of rampant technology and conflicting ideals. About this time, Peterman (1994) saw the application of QM widely in human geography to help synthesise complex phenomena. Decoherence finally takes stage in the hands of Harrison and Dunham's (1998) assessment of its relevance to geomorphology.

All of this work employs QM metaphorically. It's the imagery that counts. For example, speed of travel induces uncertainty about the environment not because people personally travel in wave formation, but rather because of three interacting effects. One is the limited processing capacity of the brain to deal with ever increasing information created by rising velocity. The second concerns the decreasing quality of that information due to blurring effects of speed. Finally, spatial information is subject to a distance decay function the further one travels from home base. Perhaps information about destinations is received periodically in discreet packets, but these hardly take regular wave form and are subject to sifting, sorting and discard regimes by individual human receptors.

5. ON THE APPLICATION OF QM TO REGIONAL SCIENCE

During my long association with regional science, it has slowly dawned on me that we can draw some powerful analogies from QM. Let us start with wave-particle duality in which producers, consumers, suppliers, distributors, money etc. can all be considered as economic particles or quanta. Individually and collectively, all such quanta have mass (typically measured in dollar terms or maybe volume of output / inputs / consumption); exist in wave forms; have velocity; and demonstrate trajectory in both time and space. Examples of economic waves include:

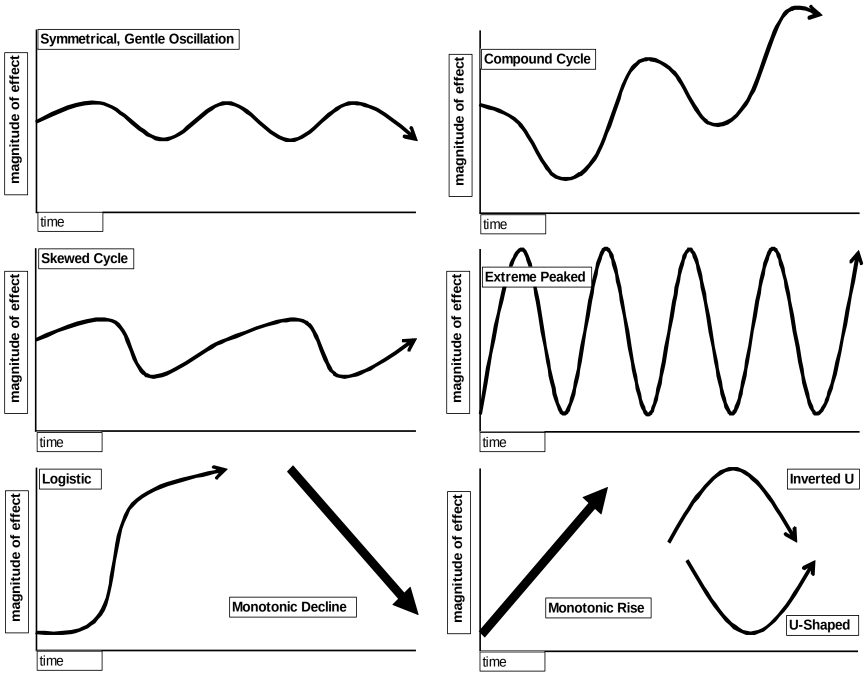
- Kondratieff (long waves);
- Periodic Schumpeterian gales of creative destruction, partially tied to the Kondratieff cycle;
- Semi-regular business cycles averaging, under Australian conditions, perhaps 6 years from peak to peak in terms of GDP growth;
- Business life-cycles from birth to demise or large-scale reinvention;
- Product life-cycles of hugely varying duration;
- Fluctuating currency and commodity values;
- Logistic curves in the case of many consumer staples; and even perhaps
- Moore's Law.

Such waves need not have regular pattern or amplitude, as shown in Figure 1.

Moore's Law is, despite its mathematical rigidity, in effect a wave as shown in Figure 2. Technological innovation does not pursue a uniform path, but is shaped by Kondratieff events, major scientific discoveries – themselves sometimes tied to wars, and the life-cycles of corporations.

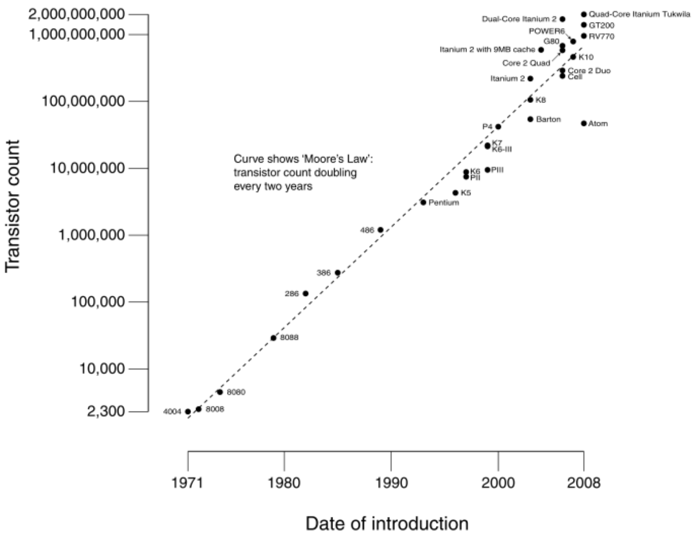
Economic quanta may, at any point in time, (i) be incommensurate, (ii) be variously discrete or overlapping in differing degrees (have different interaction paths), (iii) collide with, annihilate, organise, or reinforce each other, (iv) exhibit counter-cyclical trends (e.g. the Australian Reserve Bank's proclamation of a

Figure 1. Schematic Representation of Economic Waves



Source: Author.

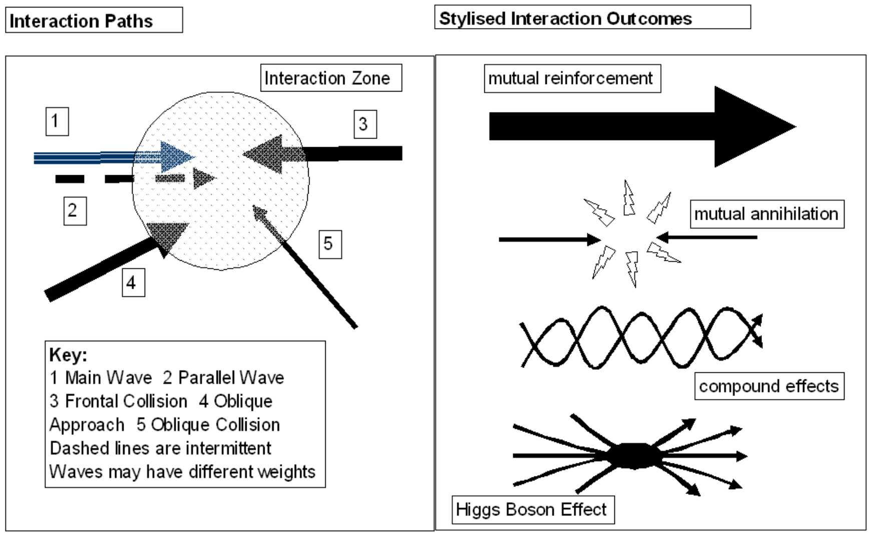
Figure 2. Graph of Computer Clock Speeds Illustrating Moore’s Law



Source:
http://en.wikipedia.org/wiki/File:Transistor_Count_and_Moore%27s_Law_-_2008.svg.

two speed economy – in reality, closer to 10 speed economy), (v) have spatial manifestation (although some may only exist at points), or (vi) exhibit different velocities. Items (i) and (ii) are portrayed schematically in the two parts of Figure 3.

Figure 3. The Dynamics of Economic Quanta



Source: Author.

The whole system of economic quanta is dynamic in terms of:

- spatial operation – the ebbing of power from local to global;
- wave trajectories – the shift from Europe and North America south to the likes of Brazil, or eastward to East and South Asia;
- wave amplitude (e.g. systemic instability like the GFC; but also a raft of transforming technologies: medical, energy and materials – like graphene nano-particles);
- cycle velocities (tendency towards shorter cycles aided by faster R&D; faster product invention and obsolescence);
- degree of complexity (a rising number of intersecting economic quanta and growing range of angles of intersection – or even mutual orbit);
- dominant exchange processes (from theft – which still exists in the world's kleptocracies – through to barter, command economies and on to market systems of different efficiencies);
- overlapping phase shifts: colonialism, mercantilism, free trade, socialism, globalisation;
- speed of adjustment to all these (slow to super-rapid); and
- interference from such aggressive new elements in the periodic table as politicum.

Sometimes the interactions of economic quanta are subject to the laws of physics. Commodity, currency and share trading is now highly automated to facilitate arbitrage between the world's financial capitals, for example, New York, London, Frankfurt, Mumbai, Tokyo and Shanghai. It has been suggested that Kazakhstan is the best place in the world to execute arbitrage because it is close to the epicentre of global trade, saving precious micro-seconds on transactions. Once Kazakhstan assumes that role – if it ever does – improved system speed will be curtailed by the limiting factor of the speed of light. Only superposition attached to quantum computing might expand such limits.

So economic systems exhibit endemic and highly complex wave-particle duality in time and space, but they are fast evolving through processes of discovery and adjustment which impart an element of decoherence to the wave effects. However, their entropic tendencies are simultaneously counter-balanced by frantic efforts by governments, businesses and institutions to rein in the degree of entropy through the establishment of effective rules, regulations and cultures. If we apply Heisenberg's uncertainty principle to individual economic quanta we have little idea as to where they exist in economic space, a problem becomes much worse at the level of regional and higher order spatial economies where quadrillions of economic quanta interact. Perhaps not even Lindblom-style disjointed incrementalism by actors and regulators can make sense of the system unless Bohm's implicate order is at least partially a reality. As noted earlier, individual actors operating in 10-dimensional space operate on the basis of private calculus, but they are constrained, unlike most physical particles, by laws, regulations, mutual agreements and custom. Economic quanta are also partially additive and entangled. We can sum local actors to describe regional economies, and regions into provinces, provinces into states, and states to trading blocks, and so on to the global economy. In short, economic uncertainty is not exponential, but constrained. The same might be said of the physical universe in the sense that particles form atoms, which make up the planets and stars, not to mention the biological world. Moreover, those are themselves constrained by the strong and weak nuclear forces, electromagnetism, and the still theoretical Higgs boson.

While in metaphorical mode, we should note that economic nodes generate gravitational fields whose intensity depends on the economic mass at the core. No economic black holes have yet been observed, though some were imagined during the GFC in the vicinity of Wall St or Detroit. Such fields distort the wave-particle duality of economic quanta, warp the flow of informational quanta (ideas, data), steer patterns of innovation, trap (to some extent) the flows of investment capital, mutually interact in complex ways (e.g. China and the US), and siphon resources from surrounding space. Regions are a bit like planets orbiting national suns, and collections of such suns form international galaxies. Economic nodes shine more brightly than cooler and darker locations, and economic dark matter may exist in the form of unrealised potential (resources, human talent) that currently has little or no economic value.

We end this analysis with a few words on entanglement, superposition and decoherence, processes that social scientists have difficulty integrating into their work. Can one have economic processes in which two (or more) *entangled* components – in the sense that change to one deliver immediate change to the other(s) without conventional cause-effect relationships? Many examples of remote reactions have been noted, but none that ultimately violates the concept of *local realism* that is the cornerstone of regional science. For me, it is always possible to link changes to component B to changes occurring with A elsewhere, even with six degrees of separation. Even coincident technological discoveries in spatially discrete locations and related investment or production decisions may ultimately have common causes in humanity's shared knowledge and the process known as *adjacent possible* (Kauffman, 1993) or in the notion of *exaptation* (Gould and Vrba, 1982; Dew *et al*, 2004), where the path of adaptation either hits a wall and sparks a phase shift in human ingenuity or two or more spatially separate individuals or teams have a Eureka moment. A case in point is Gutenberg's exaptation of the screw press used in wine-making to printing in c.1440.

Can economic quanta effectively exist in several states at once, in line with ideas about *superposition*? Remember that once we observe such quanta their state can be determined. Could, for example, a $5 bank-note simultaneously be a mechanism for acquiring – from a third party – specific assets or pleasures AND a store of wealth AND a toy (perhaps used to construct a paper airplane) AND a work of art to be hung on a wall? Perhaps it does exist in all those states until we observe exactly what it is being used for. However, such knowledge might have little relevance to the analysis of regional economies, except in the unlikely event that all $5 bills were suddenly withdrawn from circulation and used as works of art. Do economic quanta like labour, money, commodities, and even enterprise *decohere* with their environments? The answer is possibly yes in the sense that worth (or value) can ebb away and become more disordered over time in some entropic way, as we noted earlier. This is still only an analogy, not direct correspondence with particle behaviour.

6. CONCLUSION

How useful are such analogies? I find them highly useful in conceptualising the structure (or organisation) of regional economies, their interrelationships with other regions or nations, their evolution paths, their processes of transformation, the economic and social problems emerging from such processes, prospects for control and management, and the optimal means for doing so. Moreover, it appears that regional science is influenced simultaneously by several such analogies, each of which throws separate, but subtly interconnected, light on the nature of wicked problems and social messes. Chaos theory, complexity theory, tipping point ideas and quantum mechanics collectively help explain why so many economic and social conditions lie at the outer limits of human control. Some systems are highly sensitive to very small, but highly leveraged, perturbations in component settings. Some systems have massive numbers of variables interacting simultaneously and with a multiplicity of poorly specified feedback loops. If capital and labour are the only two operational variables, there are only two links to analyse: AB and BA. If we operate in ten-dimensional hyperspace, the number of potential links rises to 3,628,800, though statistically the number could be reduced using multivariate procedures to remove elements of autocorrelation. Complex systems often suffer from lack of relevant and timely information because actors are so decentralised and quarantine commercial-in-confidence knowledge. We should also add to this list of ingredients the slate of behavioural issues referred to earlier (Sorensen, 2010), since economic and spatial actions are highly susceptible to them and many behaviours are unstable on account of dramatic mood swings (Prechter, 2001).

Quantum mechanics adds to the mix. Economic quanta cannot be readily located in time and space, adding to measurement uncertainty through analogy with wave-particle duality. Moreover, each activity's wave amplitude and velocity will tend to differ. Information uncertainty is not just a question of quantity (high or low), but concerns (i) its accuracy and (ii) whether the measurement of some system properties will adversely affect the measurement of others – analogously with the Heisenberg's uncertainty principle. Moreover, such properties are never static and will be moulded by, or ebb or dissipate into, the wider environment in ways reminiscent of decoherence. Uncertainty about objects or resources is further heightened by knowing that they can serve multiple purposes, akin to superposition, but we may not know their current or future states. And finally, a crucial aspect of economic quanta from a public policy perspective is not their current state, but where they are headed. Alas, their wave-particle duality in economic space means that some quanta may be contracting, while others expand or remain static. Governors of reserve banks frequently talk about two-speed economies when they should perhaps be analysing several speeds and trajectories simultaneously. Of course, several of these considerations are either explicit or implicit in chaos and complexity approaches.

And so to the ultimate question: which of these elements of uncertainty are the most important? The more perceptive reader will have already guessed the answer. It is, of course, uncertain – depending on system attributes. These include size, internal and external complexity or connectivity, geographical location (core-periphery; local-global), the quality of leadership and entrepreneurship, internal diversity, speed of change, balance between market and state, magnitude of perturbations, ability to respond quickly to shocks, system leverage, individual and group psychologies, the quantity and quality of knowledge and information, and – finally – analysts' synthesising abilities and ability to command attention. To make matters worse, Shakespeare was right in at least two ways. He writes that "there is a tide in the affairs of men", and these words are appropriately uttered by Brutus (*Julius Caesar*, Act 4, scene 3). If we fast forward two Millennia, we find Prechter (2001) saying more or less the same thing as he develops the concept of *social mood*. Societies, and their component parts, are subject to sometimes violent mood swings, as in the current GFC.

Collectively, these elements fuel the uncertainty that underpins the wicked problems and social messes described in Table 1. Perhaps, too, they indicate that Bohm's *implicate order* is weaker than he estimates, and that regional science's traditional focus on spatial order may be excessive. If accepted, the endemic uncertainties hinted at here pose horrendous difficulties for both governments and corporations alike, but merely confirm the turbulent operating environments recognised and experienced by most small businesses. The problem is particularly serious for governments. They tend to be entrepreneurial laggards, hemmed in by conservative electorates, a glacial speed of collective decision-making and often out-dated knowledge. They are also less prone to Schumpeter's gale of creative destruction than the private sector. Worse, the political duopolies that bestride the democratic world seem ill-suited to decision-making in ten-dimensional hyperspace. They are, in essence, coalitions of the unwilling and even downright opposed. With some exception, the public service is losing its capacity to deliver advice that is simultaneously authoritative and realistic because of its lack of market discipline, insufficient relevant knowledge of complex, multi-disciplinary problem arenas, and weak future prognoses. Central banks are a partial exception to this characterisation, especially in Australia's case. And mystified electors, who perceive all this, are becoming dangerously disillusioned. Understanding the state of contemporary and likely future society is the key to reforming national governance, and knowledge of uncertainty is a core component.

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