Complexity, economics, and innovation policy: How two kinds of science lead to two kinds of economics and two kinds of policy

Author: Jason Potts

School of Economics, Finance and Marketing, RMIT University, Melbourne, Australia, E-mail Jason.potts@mit.edu.au

One interpretation of complexity science is that it distinguishes two types of science—an equilibrium science of forces, as begun by Newton, and a complexity science of rules, as exemplified by Wolfram (2002). If you accept that argument, then there are also two types of economics—an equilibrium economics in which forces move resources around the economy, and a complexity economics in which generic rules structure knowledge in an economy (Dopfer & Potts, 2008). However, this also implies two types of economic policy—a policy framework based on reallocating resources and a policy framework based on redesigning rules (Colander & Kupers, 2014). Modern economic policy generally engages in both, but we argue that this reflects the idea that modern economic policy has not caught up with complexity science. We illustrate how this difference plays out in the particular domain of innovation policy.

Keywords: Complexity science, evolutionary economics, rules, innovation policy

1. Pluralism in science and economics, and therefore in policy

A fundamental premise of the modern rational approach to economic policy is that it should be based on what, in the vernacular, is called 'proper science' or 'good economics'. The implicit case, robust against even the largest shock (Mirowski 2015), is that there is only one of these proper and true forms—variously called neoclassical economics, mainstream economics, textbook economics, or neoliberalism (by its critics)—and that the various other forms of economics, those of heterodox stripe for instance, such as post-Keynesian or Marxist economics, are weaker forms that are not based on 'proper science' and certainly do not constitute good economics. In this 'monotheistic' worldview there is only one fundamental truth, but we must ever be vigilant because many flawed imposters surround the one true way. In this worldview, good economic policy, as that which is rationally guided and scientifically defensible, is based on the 'one true economic model' and avoids the siren-song seductions and free-lunch promises of the false models. Good policy is based on good economics, which is based on good science. Bad policy is based on bad economics, which is based on bad science. That, in stylized essence, is the modern catechism of economic policy.

The question that this paper addresses concerns how evolutionary and complexity economics fits into this whole intellectual and technocratic exercise, and from there considers whether it is a proper and legitimate basis for policy. In essence, is it part of good economics and good science, and thus a valid and proper foundation for policy? Or is it not? Is it closer to Marxism—once thought by many to be proper and good, but now consigned to the bin of bad economics and bad science? Or is it closer to behavioural economics—once thought somewhat dubiously 'psychological', e.g. Herbert Simon's conceptions of bounded rationality (Simon, 1955) and its emphasis on non-standard lexicographic preferences (Earl, 1986), but now refurbished with

proper scientific methods and credentials (experiments, game-theoretic-foundations, Nobel prizes) and these days a respectable element of contemporary economic policy (e.g. 'nudge' policy, Thaler & Sunstein, 2008). When framed in this manner, the question would seem to be: is complexity economics canon? Is it part of the one true way? Because if it is indeed so, then and only then it is safe for policy use.

Yet I will argue that the monotheistic model—i.e. in which there in only one true *scientific model*, which begets the one true *economic model*, which begets the one true *policy model*, and about which all other models are false—is actually itself false (Maki, 2001). Rather, I want to argue for a pluralistic[i] or dualistic (polytheistic, in the metaphor) approach in which there are two distinct worldviews, both of which are true, and both of which range over the domains of good and proper science, economics and policy.

This isn't a compromised or accommodating position, but one that corresponds to two distinct ontological claims about the world: namely whether we are dealing with a closed system or an open system (Prigogine & Stengers, 1984; Dopfer & Potts, 2004). There is a true world of science, economics and policy for closed systems, and a different but equally true world of science, economics and policy for open systems. What we have come to think of as the 'proper science' and 'good economics', in the sense alluded to above, is an approach that is true in a closed world. This is tightly modeled on 19th century physics, which was also a science of a closed world (Mirowski, 1989; Potts, 2000). Much of our modern approach to economic policy is implicitly based on this manner of thinking.

However, a different approach holds in an open system—i.e. an evolutionary system in which novelty emerges from within and a dissipative system that operates far-from thermodynamic equilibrium to maintain various levels of internal complexity (Foster, 2005; Herrmann-Pillath, 2013). This requires a new kind of science, and a new approach to economics. It will also require a new approach to policy. The basic argument I make here is that the evolutionary and complexity approach to economics is true in the dualistic (polytheistic) sense of referring to an open system conception of the world in general and of the economy in particular (a different true system holds over a closed system worldview). The purpose of this paper, however, is to elaborate what this means for economic models and methods in general and to translate these into economic policy in particular.

The case for a pluralistic/polytheistic worldview has distinctly practical implications regarding the effective design and conduct of economic policy. It does so by highlighting the very different phenomena, in the respective closed and open system cases, that policy seeks to effect. The closed system world is essentially construed as a world of economic 'forces', and which eventually arrive at some equilibrium configuration. Policy is about shifting that equilibrium; i.e. a reallocation of resources. But the open system world is essentially construed as a world of economic 'rules', and from which emerge particular economic structures and processes. Policy is about the design of rules to achieve particular structural or process outcomes. An evolutionary-complexity approach does therefore imply a different economic policy perspective, but this is not a superficial distinction, even at the level of pluralistic economics. Rather, the origins of this more fundamentally trace from a different approach to science. This paper will outline this case, focusing on the different ways this manifests in two views of innovation economics—and the definition of the innovation problem as an economic problem—and the implications for innovation policy.

2. Two kinds of science

From the modern perspective of complex systems, it is becoming increasingly clear that an important, or at least plausible, distinction can be made between two kinds of science (Bertalanffy, 1968; Simon, 1996; Wolfram, 2002; Mitchell, 2009): the equilibrium sciences, and the complexity sciences (a.k.a. the science of complex systems). The equilibrium sciences are built on the study of forces, and are exemplified by the use of 'Newtonian' analytic methods based on algebra, topology and calculus. The complexity sciences are built on the study of rules, and are exemplified by analytic methods based on discrete, evolving, algorithmic systems. Now this distinction is rarely clean in practice, for it is certainly the case that discrete non-linear systems can be transformed into continuous linear approximations 'for the purpose of analysis', and there are domains of analysis with interwoven characteristics of both (e.g. Markov chain Monte Carlo, evolutionary game theory). And moreover, the claim for two kinds of science is far from unanimously acknowledged; indeed, it is only those who self-identify on the complexity side that seek to make this distinction, i.e. those affiliated with the likes of the Santa Fe Institute in New Mexico, or similar. Furthermore, this division does not neatly occur across subject domains (e.g. physics, chemistry, economics, anthropology, et cetera), or even across broader historical and methodological aggregates (e.g. natural sciences, social sciences, sciences of the artificial, et cetera), both of which are the sort of divisions that give rise to interdisciplinary resolutions. Rather, this difference occurs as a division about appropriate methods for the study of two broad classes of phenomena that correspond to closed systems and open systems (Bertalanffy, 1968; Prigogine & Stengers, 1984). At this stage it does not really matter what these systems are made of, or what they are specifically open or closed to for instance energy, matter-energy, information, ideas, and knowledge. What does matter is their analytic representation, which can be understood in terms of *solution concepts*.

By and large closed systems can be analytically represented with *equilibrium* solution concepts. Note that these can be static or dynamic, in which time is one dimension of analysis. The type of sciences that are based on equilibrium solution concepts are sciences defined by *forces*; i.e. a vector of forces, or force fields. Forces are conveniently represented mathematically in Real vector space (R^n) using algebra, topology and calculus. Most 19th and 20th century sciences are of this type, from modern physics to neoclassical economics. Methodologically, these sciences are reductionist and deductivist.

Open systems, however, have complexity solution concepts. I want to paint with a broad brush here and define complexity as a state-space at the edge-of-chaos (Kauffman, 1993; Mitchell, 2009) that refers to the study of self-organization processes and spontaneous and emergent order between the mutually interacting parts of a (complex) system (Mitchell, 2009). This conception of a new kind of science has been percolating for a while now (Hofstadter, 1979; Nicolis & Prigogine, 1989; Wolfram, 2002; Hendrickson & McKelvey, 2002), and has evolved along many different lines and approaches (e.g. dissipative systems, cellular automata, agent-based modeling, network analysis, genetic algorithms, and so on) and across effectively all scientific disciplines. This is increasingly indexed as 21st century science. However, what holds these together is not subject matter but a commitment to information-theoretic computable approaches that are best characterized as studying not *forces* (in vector-space), but *rules* (in computational space). Methodologically, these sciences are emergent and inductive.

Now good arguments can and indeed have been made against this claim: some directly, some obliquely. The universal 'Baconian' argument is that there is just the scientific method – that of conjecture and refutation (Popper, 1963) – and whatever analytic tools are brought to bear

on the questions of science are simply that: different tools used in science. Thus there is science and non-science, rather than different types of science. A different way of viewing the unified thesis is to argue that even the major distinctions between natural and social science will yield to a deeper model of the unity of knowledge, or consilience (Wilson, 1998), which is particularly associated with a unified evolutionary approach.

The argument advanced here is not inconsistent with these universalist or unified claims, but rather refers to different ways of knowing different types of systems, and reflect different trade-offs over different methods. Both natural and social sciences are amenable to closed and open system representations. Closed system representations have many advantages, not the least of which are highly developed underlying mathematical theory and tractable analytic solutions. But open system representations are naturally geared to study unfolding processes and to explain change and emergence, but come at the price of tractable analytic solutions.

But if we accept these trade-offs actually imply that from a practical perspective at the level of choosing methods and questions there are two types of science, then it can be reasonably noted that these choices align with a concept of the sciences of forces (broadly the 18th to 20th century sciences), and with an new and emerging sciences of rules (mid-20th century onwards). A science of forces sets up an analytical model of all major or relevant causal variables acting on the *explanandum* ('things to be explained'), and derives the equilibrium prediction of the state of the system once all these forces have worked their way through the system. The enormous benefit of this mode of science is that it is rich in well-understood tools and methods in which the objective is to discover how observed reality is explained by the interaction of forces. A science of rules works differently, seeking to understand how a small number of interacting rules can produce an emergent order that corresponds to an observed reality. While newer, the price you pay for adopting this approach is that the tools while in some sense far more powerful are also harder to work with, and less well-understood. The objective in this approach is also different, namely to discover the initial conditions and rules that generated the observed reality, and the principles by which the system transforms itself through time.

These different types of science have different solution concepts: equilibrium versus complexity. In consequence, these two types of science map to two different types of economics. Classical and neoclassical classical economics is based on equilibrium sciences and is analytically formulated in terms of (fields of) forces, and complexity and evolutionary economics is based on complexity sciences and is analytically formulated in terms of (systems of) rules. Two types of science imply two types of economics. That is the line of argument in section 2 above and in section 3 below. But the reason we make these arguments comes in section 4, when two types of economics implies two types of policy, which we illustrate with innovation policy. For it is here that we extract the core argument of this paper, reviewed in section 5, in which we run backwards through this same logic, that complexity policy *therefore* has its own foundation in not just economics, but in science. There exists, in other words, a distinct foundation for complexity-based economic policy.

3. Two types of economics? Two types of economic policy?

Economics is a curious type of science. The Classical economists—especially Ricardo, Mill and Marx—sought to develop a model of an institutionally rich and historically evolving but ultimately closed system, for example, theorizing about the notion of a long run stationary state (Dopfer & Potts, 2008, ch.1). The main economic policy implications that came from that era related to the logic and efficacy of broad policy settings, such as the debates about free trade.

During the twentieth century, a new model of economics emerged that took a more direct approach to maximizing aggregate social welfare. This built on the positivist approaches to economics as a science argued by Robbins (1932) and Friedman (1953). This newly professionalized model was led by the likes of Arthur Pigou, Paul Samuelson and Jan Tinbergen, who advocated an activist engineering approach of the sort that was in the ascendency at the time in respect of large scale economic planning, industry policy and Keynesian macroeconomics. This modern approach to economic policy was based around a theoretical conception of an economy as a system of *market forces* (the Arrow-Debreu general equilibrium paradigm) in which a policy approach (e.g. that based on aggregate demand management, industrial planning or market failure) was developed that sought to instrumentally control the economic system through the various policy levers and mechanisms that were available to governments through manipulation of market prices, incomes or spending.

But a different approach to economics can be read in the more heterodox schools of economic thought, particularly those associated with evolutionary economics, behavioural economics, institutional economics, agent-based computational economics and complexity economics (Arthur, et al., 1997; Velupillai, 2000; Holt, et al., 2011). These various schools of thought would at first seem to lack overarching commonalities, although Potts (2000) argues they are all characterized by analytic representation in non-integral space (*cf.* integral space in the field-theoretic equilibrium models (Mirowski, 1989)). But what they all share is that they are based on a theoretical conception of the economy as made of *generic rules* (Dopfer. et al., 2004; Dopfer & Potts, 2008). These heterodox schools of thought consistently argue that the economy is made of knowledge in the form of institutions, in the widest sense of that term (North, 1990; Loasby, 1999; Williamson, 2000), and that economic agents and firms alike are made of habits and routines as units of knowledge (Nelson & Winter, 1982). Economies are complex systems because knowledge is a complex system, and the process by which knowledge changes and grows is an evolutionary process (Ziman, 2000; Potts, 2000). Economies evolve because knowledge evolves.

Now there is of course a great deal of overlap between these two approaches and it is an almost cartoonish simplification to say that on one side lies an equilibrium model of forces allocating scarce economic resources, while on the other lies a complex systems model of evolving rules. Most obviously, institutional economics can be understood in both senses. But it is also interesting that institutional economics has significantly fractured down this line (Hodgson, 1998, 2007). This basic difference between two approaches to economics reveals itself in the different conceptions of what an economy is and what it is made of, and of the corresponding economic problem. In the mainstream equilibrium models an economy is made of (scarce) resources (i.e. commodities), which are allocated over an economic space that can be described by a vector of prices and quantities; i.e. the commodity space. Technologies and preferences parameterize that space and each point in the space represents a different configuration of allocations. Some of these are efficient. Within this positive analytic context, the purpose of policy is to artificially intervene in prices and quantities in order to achieve efficient or otherwise desirable allocations of resources. This is the physics approach to economics translated into the engineering approach to economic policy, which reached its apogee in the work of Paul Samuelson, an engineer turned economist, and broadly in the program of work of the Cowles Commission (Mirowsk,i 1989, 2001).

However, complexity and evolutionary models start from a different fundamental conception of what an economy is made of: namely that an economy is made of knowledge, not of resources. This knowledge has various forms, including: technical knowledge (technologies), social coordinating knowledge (institutions), organizational competence-carrying knowledge (firms), behavioural and cognitive knowledge (habits, routines), and so on. Patterns of economic

activity, and economic growth and dynamics, are a consequence of the structure of that knowledge and of changes in that knowledge. In this view, the knowledge base of an economy is a complex evolving system. The economic problem is centered about the effective discovery, coordination, use and replication of knowledge, as Joseph Schumpeter first clearly explained. It is this knowledge that enables the production of commodities and the exploitation of resources, and overall is what explains the wealth of nations (Beinhocker, 2006; McCloskey, 2016).

The essential point is that an evolutionary and complexity-based approach to economics expresses an underlying approach to science that seeks to explain economic reality in terms of complex interacting rules, not as a field of forces. The essential difference is that rules are structured as complex systems and evolve; forces are not and do not. An equivalent way to state this methodological proposition is that an evolutionary-complexity approach to economic analysis is a study of the growth of knowledge in which the constituent matter of an economic system is understood to be different forms of knowledge, ranging over technical knowledge, organizational knowledge, institutional knowledge, behavioural knowledge, and so on. It is this *generic knowledge* (which I have referred to here under the category of generic 'rules', following Dopfer and Potts (2008)) that makes possible economic operations such as production, consumption, coordination and exchange. This structure of knowledge forms a nested complex open system that evolves under the evolutionary mechanisms of variation, selection and differential replication (Loasby, 1999; Ziman, 2000). Rules are complex systems that evolve, forces do not. An economics of rules is thus fundamentally different from an economic of forces.

We may summarize our argument so far as follows: the complexity era has afforded us a new kind of science (Wolfram, 2002) that, when combined with evolutionary theory, has given us a new kind of economics (Potts, 2000; McKelvey, 2004; Foster, 2005, 2006; Beinhocker, 2006; Colander, et al., 2011; Kirman, 2011; Arthur, 2013; Elsner, et al., 2015; Kauffman, et al., 2015). But do we yet have a new kind of policy? I want to argue that this is indeed the next step. But our starting point is that there is, as yet, very little recognition of that imperative. Nevertheless, a new modern paradigm for public economic policy in the evolutionary and complexity science age is indeed emerging (Room, 2011; Dolphin & Nash, 2012; Durlauf, 2012; Colander & Kupers, 2014; Elsner, 2015). There are a number of nascent forms of a new type of policy approach that proceeds from a rules-based science and economics. This can be observed in aspects of the new institutional economics (Ostrom, 2005) and the economics of mechanism design and market design (Roth, 2015). But a particularly interesting aspect of this can be observed in the study of innovation economics. In this next section 4 we show how two distinct views on the nature of the innovation problem can be discerned that broadly line up with the two views of economics and two views of policy discussed in the above section.

4. The nature of policy: Two views of the innovation problem

The two views of economics—a scientific model of forces, and the corresponding equilibrium model; and a scientific model of rules, and the corresponding complexity model—can be observed in two distinct views of the innovation problem, variously as a market failure problem, i.e. forces, equilibrium allocation problem, and as a collective action problem, i.e. rules, complex coordination problem (Allen & Potts, 2016). These two distinct interpretations of the innovation problem translate into two distinct models of innovation policy: one corresponding to government intervention to reallocate resources, and thus solving a market failure problem; the other corresponding to governance in the discovery of effective rules (organizations and institutions) to coordinate collective action.

In the equilibrium view, the innovation problem is diagnosed as a misallocation of resources that is then corrected through innovation policy instruments to reallocate resources – indirectly via incentives, i.e. artificial rent creation, or directly via government coercion, i.e. tax and spend. But from the complexity perspective, the innovation problem is diagnosed as a collective action problem associated with coordinating distributed knowledge under conditions of high uncertainty. This sort of problem is resolved not by moving resources around, but by discovering effective rules that will enable coordination to occur and for new order to emerge (Potts, 2014). From the equilibrium perspective, what a policy solution looks like is a reallocation of resources. That is a surface rearrangement of an economy, leaving its deep structure unchanged. But from the complexity perspective, what a policy solution looks like is the discovery and adoption of new rules. That is a deeper change in the economic order, and these new rules will then cause subsequent changes in the surface level of the economy to unfold.

The innovation problem

The innovation problem was first clearly expressed by Nelson (1959) and Arrow (1962b) as a problem in the production of new information under competitive market institutions, diagnosed as a species of *market failure* in which "a free enterprise economy underinvests in invention and research (compared with an ideal) because it is risky, because the product can be appropriated only to a limited extent, and because of increasing returns" (Arrow, 1962a: 624).

The innovation problem has several distinct policy solutions (Davidson & Potts, 2016). It can take a Coasian form – attach property rights and bargain to equilibrium – which is the intellectual property approach; a Pigovian form – identify the externality and correct with subsidy – which is the R&D tax credit approach; a Marxian-Keynesian form through industry planning and targeted government spending to redirect existing organizations toward the innovation target; and Arrow-Nelson-Freeman form to create non-market research organizations, such as universities or public science institutes, and to assemble these into an effective innovation system. Innovation policy institutions range from decentralized and market focused – such as intellectual property rights, or regulatory support – that operate through the legislative and judicial branches, to mixed models operating through the tax system – such as R&D tax credits or targeted industry subsidies – to centralized and planning focused – such as public science institutes – that operate through government agencies (Flanagan, et al., 2011). While some are market-facing, these are all government mechanisms. Intellectual property is a state-sanctioned monopoly, and R&D tax credits work through the tax system. Public procurement models, for example in defense contracting or medical research, are often publically funded but delivered by private organizations, whereas public science is usually both public funded and publically produced.

Innovation is an economic problem because inputs into innovation have alternative uses. But the innovation problem is further confounded because the output is information produced under uncertainty (Arrow, 1962a). First, the output has fundamentally uncertain value *ex ante*. This makes it difficult to optimize on levels of input spending. It also incentivizes the rational agent to strategically wait for some other agent to reveal that information. Second, there are often significant fixed costs (indivisibilities) associated with research that are irrecoverable in a competitive market with marginal cost pricing. Again, this incentivizes the rational agent to wait. Third, ideas are appropriable, or non-excludable. Again, the first mover is at a competitive disadvantage. In the absence of significant first-mover advantages, such as learning-by-doing (Arrow, 1962b), the rational agent will underinvest in invention, as the production of new information, from the social welfare perspective, will experience market failure (Bleda & Del Rio,

2013). This is the standard diagnosis of the innovation problem (Martin & Scott, 2000). The innovation problem is a problem of the competitive production of information under uncertainty, giving rise to Pigovian externalities.[ii] It is equivalently a public goods problem (Lindsay & Dugan, 2013), or a problem of market structure (Aghion, et al., 2005). This connects the innovation problem to the economics of efficient and effective institutions (North, 1990; Acemoglu & Robinson, 2012), where we can clearly see the innovation problem and its solution expressed in terms of the discovery and design of effective rules.

Consider the institutions that facilitate innovation and economic growth and development. For instance, the Schumpeterian entrepreneur is a source of innovation in an economy, but that same behavior can be destructive of economic growth if channeled through political rather than market means (Baumol, 1990). The effectiveness of the rule of law predicts productive entrepreneurship, and therefore innovation. Innovation is also inhibited by extant regulation, much of which is actively sought by incumbent firms in order to protect their own interests against 'creative destruction' by new entrants. Regulation by-and-large inhibits innovation (Stigler, 1971; Thierer, 2014). Furthermore, the innovation problem also shows up as a design problem in the overall crafting of innovation institutions, both as a problem of designing and implementing an efficient institutional mix of innovation policies (Borras & Edquist, 2013), and in the assembly of an effective national innovation system (Freeman, 1995; Dodgson, et al., 2011; Potts, 2016).

The economics of innovation can be framed as a problem in microeconomic incentives that are consequence of the peculiar properties of the production of information in competitive markets, namely the existence of fixed costs in research and development, the appropriability of the resultant product, and its uncertain value. In a competitive market, this leads to private underinvestment. But the economics of innovation can also be framed as a problem in public goods provision because new ideas are non-rivalrous and non-excludable. This suggests public provision. However, the economics of innovation can also be framed as a problem in political economy, given that solutions to these problems involve the creation of new institutions with their own incentive problems, and the evolved institutions of a market economy will have their own effect on the allocation and intensity of entrepreneurial action. This covers neoclassical economics, evolutionary economics, institutional economics, and political economy. But a further angle on the innovation problem is to view it as a problem of collective action.

The innovation commons

Commons-type solutions to social dilemmas make use of effective governance rules to regulate access to the shared resource and to punish those who violate the rules (Ostrom, 1990). If we view the innovation problem from the perspective of 'who pays for the research and development?' then the collective action problem is to pool collective resources and to exclude free-riders. But the innovation problem is not necessarily a pooling of money to create a fund or indeed any pooling of fungible resources, say to create a laboratory. The innovation problem can also be formulated as a problem of pooling distributed information about the prospects, costs, risks, and opportunities of the new idea or technology. This information is distributed in the sense that different agents will have different parts of it, and these parts may not have much value or meaning in and of themselves. It is only when combined that these elements of information become of value in estimating the nature of the idea and the outlines of the opportunity it presents. This pooled information is the central valuable resource in an innovation commons because this is the information that entrepreneurs need in order to invest in the new idea, which is the origin of the process of innovation.

An innovation commons (Allen & Potts, 2015) is a further class of institutional solution to the innovation problem. But it is a solution that comes not from the state (government), but rather from civil society (governance). It is closer to a spontaneous order than a planned institutional system (Potts, 2014). For this reason, the innovation commons does not usually form part of the various instruments of innovation policy yet is a near pure example of a bottom-up institution to resolve the innovation problem as a collective action problem.[iii]

An innovation commons is both similar and different to other types of commons, encompassing natural resource commons (Ostrom, 1990) and the 'new commons' (Hess, 2008; Bertacchini, et al., 2012). The similarities accrue in the sense that an innovation commons is manifestly an institutionalized community with rules of governance. As Frischmann (2013) observes, a "commons is an institutionalized community practice, a form of community management or governance." In this definition, the "basic characteristic that distinguishes commons from non-commons is institutionalized sharing of resources among members of a community." (Madison, et al., 2010b, 841) The rules by which an innovation commons works are similar to the rules by which a natural resource commons works, as captured by Ostrom's well-known eight design principles for managing the commons (Poteete, et al., 2010). The value of the innovation commons comes from the value of the pool of information that is gathered there, and the basic problem is the same, namely seeking to resolve a social dilemma in contribution subject to free-riding. In an innovation commons, an individual can access new information about the uses and opportunities inherent in a new technology, or the meaning of the information that they already have in a way that would be costly or impossible in the absence of that institution. This combines with the natural human propensity to cooperate (Bowles & Gintis, 2011) to arrive at a new institutional watershed in the cooperative possibilities of the coordination of economic production.

At the surface level of analysis, in a field-of-forces model of the economy, the innovation problem presents as a problem of market failure in the production of new knowledge under competitive market conditions. From a policy perspective, the problem here is clearly diagnosed as a misallocation of resources that can be corrected with some intervention. But at a deeper level of analysis, in a rules-based model of the economy, the innovation problem presents in a different form, namely as a problem of coordination between agents in which distributed agents need to arrive at a system of rules that will enable effective cooperation in order to coordinate resources, including information, toward mutually satisfactory ends. The solution here involves the discovery and implementation of effective rules. And what the theory of the innovation commons highlights is that such rules will often emerge from the bottom-up, arising from the actions of a motivated and incentivized community. In other words, the sort of economy policy that emerges from a complexity perspective does not necessarily flow from government as top-down public policy, but will often emerge from community-level as civil-society instigated bottom-up discovery of effective rules.

5. Complexity policy follows from complexity economics, which is about rules

As complexity science emerged through the latter part of the twentieth century it soon became clear that it offered the prospect of a new kind of science (Wolfram, 2002), implying a new kind of economics (Colander, et al., 2011; Arthur, 2013). The latest phase of this unfolding development is recognition that it also seems to imply a new kind of economic policy (Durlauf, 2012; Colander & Kupers, 2014). A key claim made in this paper is that this policy bifurcation is deep, tracing to the distinction between a science of forces and a science of rules. The two

different types of policy follow from two types of economics, which follows from two types of science, namely a science of forces – exemplified in general equilibrium economics, and a science of rules – exemplified in complexity economics.

The approach to economic policy based on a science of market forces is one in which an equilibrium set of prices and allocation of resources can be displaced by the policy-maker, as a kind of chief-engineer, in order to achieve a preferred resource allocation. But the approach to economic policy based upon a conception of the economy as made of knowledge, and based on a science of rules (e.g. Dopfer & Potts, 2008), is substantially different because it occurs at a deeper level in the economy. The equilibrium approach to economic policy, as based on a field-of-forces model of the economy, seeks to intervene in the surface layers of an economy by redistributing resources towards a more efficient allocation. But the complexity approach to economic policy, as based on a generic rule model of the economy, seeks to change the deep structure of the economic order (see also Pelikan & Wegner, 2003). Douglass North (1990) identified this with institutional change; James Buchanan (1990), building on Brennan and Buchanan (1985) and Hayek (1960), called this constitutional economics; and Oliver Williamson (2000) identified it with four emergent levels of long run dynamics. Dopfer and Potts (2008) call it the generic level of analysis and argue that economic policy based on evolutionary-complexity approach is inherently generic policy, which is to say rules-based policy. Now while it is manifestly true that all economic policy as practiced by governments involves both modes – deep and surface, constitutional (change in rules and institutions) and operational (change in resources, distributions, prices) – the point here is that complexity policy emerges from complexity economics, which emerges from complexity science, which is fundamentally a science of rules. Complexity policy is *ipso facto* about rules.

An important but widely underappreciated implication of this rules-based approach is that policy does not exclusively or even necessarily come from, or work through, the standard democratic/technocratic model of the modern policy instruments of government. Colander and Kupers (2014) use the standard complexity theory trope to portray this as a top-down versus bottom-up distinction, but the radical implication here is that effective policy may emerge directly from civil society, arriving as an associational and community driven dynamic. We are, for example, starting to observe a lot of this emerging from the so-called 'sharing economy', about which top-down policy is variously playing catch-up, or seeking to formalize many norms and practices that have evolved spontaneously to address collective action problems in the affected communities. If policy means effective rules, then whatever makes effective rules is a policy-maker.

Innovation policy illustrates this. I outlined above two distinct formulations of the innovation problem. From the field of forces viewpoint, the innovation problem is diagnosed as an allocation problem where too little is invested in new knowledge, and is resolved with policy to reallocate resources toward innovation in order to maximize some social welfare function. However, from the complexity perspective the innovation problem is diagnosed as a collective action problem for dealing with the entrepreneurial uncertainty surrounding a new technology, and resolved with effective rules to enable agents to cooperate to pool resources and information to overcome that uncertainty. Government innovation policy transfers resources or creates rents, which is top-down by degrees. But a pure bottom-up innovation policy is the emergence of the 'innovation commons' when a community of enthusiasts for a new technology figure out rules to enable them to pool and share information and resources to explore and develop the new technology into exploitable opportunities, including what may eventually become firms, markets and industry organizations. These emergent coordinating rules form a solution to the innovation problem: they are, in effect, policy.

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There are two kinds of policy in economics because there are two kinds of economics, because there are two kinds of science. That has been the argument of this paper. The complexity perspective in economics implies that policy is the discovery of effective rules for collective action. This contrasts with the mid-20th century engineering inspired model in which policy is about reallocating resources across the surface of the economy. These rules are what the New Institutional Economists call 'the rules of the game'. But these are not necessarily at the macro level of the economy, and nor are they well-understood at the micro-level of analysis. Dopfer and Potts (2008) call these 'meso rules'—in that they are common to a population of micro-agents, and are the building blocks of the complex systems that compose the macro-economy. They are the proper target of economic policy from the complexity perspective. In the field-of-forces approach to economics, there is macro-economics and macro-policy, and micro-economics and micro-policy. But in the complexity approach to economics, which is based on a science of rules, there is just meso-policy, but which in turn has micro and macro consequences. Complexity economics therefore does not just suggest some new tweaks and riffs on the extant approach to economic policy. Instead it is far more revolutionary: a whole new meso-based rule-centered approach to economic policy because it is a whole new economics based on a whole new science.

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Endnotes

[i] Pluralism in economics (Davis, 2006) has been a recent touchstone for movements such as the post-autistic and Real World Economics (Fullbrook, 2003).

[ii] Davidson and Spong (2010) argue that this notion of externalities in innovation is widely confused with the Marshallian conception of an external economy.

[iii] The innovation commons overlaps with concepts from strategy such as von Hippel's (1986, 2005) 'user innovation' or 'democratized innovation' and Chesbrough's (2003) 'open innovation'. Economic historian Robert Allen (1983) explored this as 'collective invention' (also Nuvolari, 2004).