

Reflections on the Value of Systems Models for Regulation of Medical Research and Product Development

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INTRODUCTION¹

In a recent editorial in *Science*,² Bill Wulf used a systems ecology framework to construct a model for innovation in the life sciences. He defined an “innovation ecology” as the various “interrelated institutions, laws, regulations and policies” necessary to underwrite successful commercialization of publicly funded research through an “infrastructure that entails education, research, tax policy, and intellectual property protection, among others.”³ In this formulation, private intellectual property and regulatory (IPR) rights form the linchpin between innovative publicly funded medical research, reduction to practice of basic research by firms and university technology transfer offices, product approval and marketing by government and firms as well as public consumption of approved medical products. As such, ‘large scale’ IPR rights-intensive translational research and technology commercialization constitute important market push and pull levers for domestic governments and provide the legal and regulatory basis for the drug development cycle writ large. Even so, and as lamented by Wulf in his editorial, a narrow “one size fits all” IPR rights framework has the potential to stifle rather than encourage innovation.

Casting the innovation landscape as an open complex organic ecology rather than a closed historical linear model of basic-to-applied research⁴ is consistent with newer more open-ended analytical models such as complex adaptive systems,⁵ network dynamics⁶ and

systems dynamics.⁷ These ‘systems’ frameworks view and model systems as dynamic, adaptive and indeterminate networks where the behavior of the system as a whole is governed by the ever-changing and non-linear nature of the connections between actors and institutions rather than as a predictable sum of a set of linear deterministic nodes. At the heart of the functioning of a complex adaptive system is the number and nature of the interactions between network nodes, which produce novel and ever changing properties as the layers of complexity increase. This dynamic structure-function relationship of complex systems is nicely summed up by the phrase “more is different.”⁸

One implication of a systems view of IPR rights-intensive innovation in the medical and life sciences is that local innovation ecologies are collapsing globally.⁹ This is due, among other things, to the global reach of patent decisions of first instance such as that in *KSR International Co. v. Teleflex Inc.*,¹⁰ harmonization of regulatory processes and standards, such as those relating to biomedical product approval, marketing and patenting, adoption of international IPR rights-sensitive instruments such as the WTO’s Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) and, less obvious, the convergence of national science and technology (S&T) policies and normative behaviors aimed at commercialization of publicly funded medical research. Within the larger political and legal cultures of participating nations, there is an increasing



space being carved out for translational research and commercialization.

Indeed many nations, including Canada, are in the process of implementing strong IPR rights regimes that explicitly encompass publicly funded research efforts in order to reproduce the phenomenal success of university technology transfer and commercialization in the United States. This effort is hardly unique to Canada. Not only are other jurisdictions attempting to emulate U.S. translational research, but the United States itself, self-reflective after 25 years of Bayh-Dole,¹¹ is seeking to identify new and improved ways of commercializing public research in the context of its public health mandate. In the context of this debate, one hears increasingly vocal deliberation over the value of closed IPR rights models.

PURPOSIVE POLICY

Despite the growing visibility of network¹² and other “systems” theories,¹³ linear models of organizations and organizational change have and continue to dominate analyses of the behavior of individuals, groups and institutions and to provide the benchmarks by which both public and private ordering are gauged.¹⁴ One of the major differences of linear and non-linear models is the narrow range and simple nature of the assumptions and operating conditions that characterize linear models, including the desired outcome of maximizing certainty and predictability. The most important limitation of linear models is that, despite the good intentions behind them and the accrual of knowledge in relation to discrete silos, they often inhibit or even prevent the very thing they seek to facilitate through their unintended consequences. This outcome, referred to as “policy resistance” by Sterman,¹⁵ is only just getting onto the radar of key decision-makers. Opposition to the novel claims of systems frameworks may have occurred due in some part to the fact that experts are immersed (and therefore have a stake) in their own specialties and the fear that systems work lacks the required degree of scientific rigor in the face of “real life” complexity. A range of potential examples of policy resistance in the public health sphere include clinical trial design,¹⁶ disease management,¹⁷ responses to acute public health crises,¹⁸ as well as a host of broader state endeavors involving policies relating to health economics,¹⁹ innovation,²⁰ public health²¹ and drug regulation.²²

Nevertheless, there is growing acknowledgement of the drawback of these linear models, and the narrow range of assumptions that underpin them, due partly to a number of controversies surrounding therapeutic products,²³ food,²⁴ food containers,²⁵ and children’s toys²⁶ that have been approved for marketing then later found to be unsafe. In addition, a spate of popular books describing the emerging importance of complexity and networks in the realms of medicine and biology,²⁷ physics,²⁸ mathematics,²⁹ the Internet,³⁰ business organizations,³¹ branded products,³² public policy,³³ and economics³⁴ have raised the level of public discourse

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on systems models considerably. Decision-makers are coming closer to accepting that the cost of studying risk management using novel, albeit confusing systems tools far outweighs the costs to society of failing to understand them.³⁵ Tellingly, the problem of policy resistance, and the potential of novel systems-based approaches to answer it, has been the subject of recent editorials in prominent journals such as *Science*³⁶ and *Nature*.³⁷

As I will discuss today, a useful metaphor for a purposive systems-based policy development process is that of setting an Origami sculpture (representing purposive public policy) into a river and then “letting it go” without touching it versus letting it go then walking beside it with the intent of making sure it neither gets caught in various eddies and oxbows nor goes over Niagara Falls (system collapse or breakdown³⁸). In the former scenario, control is past-oriented and the performance of the system is seen to be at the mercy of future events which may be either exogenous or endogenous to the system and thus seen to be either outside or within control of the system. By contrast, control in the



“walking by” example is future-oriented in the context of certain system constraints (legal-democratic, economic, technological) and responsive to endogenous effects due among other things to various feedback loops, stocks and flows, time delays and non-linearities inherent to the system. Robust adaptive planning not only allows us to walk by our policy creations, but also helps us to be prepared no matter which way the river turns.

The goal of my research program is to determine how innovative therapeutic product development and regulation, and the national S&T policies that drive these processes, are linked and operate as part of a complex innovation ecology. We are particularly interested in the notion of a systems-based regulated Therapeutic Product Lifecycle (rTPL) as it is embedded within a larger public health discourse that in turn is constrained by prevailing legal and democratic norms. This presentation is intended to take a high level view of whether newer systems models, including network theories and complex adaptive systems theory, can be of use as a form of “alternative intellectual property” to policy-makers in their attempts to enhance translational research and technology commercialization.³⁹

THE REACH OF UNCERTAINTY

The implications of complex adaptive systems theory for law, particularly areas of law that are strongly contingent on science, was first recognized by J.B. Ruhl.⁴⁰ Reading this and related work from the perspective of someone having spent nearly 20 years at the bench⁴¹ prior to entering legal scholarship got me thinking about the value of systems approaches to the interface between medical science and the law. Particularly valuable areas of debate include the creative nature of breakthroughs in the life sciences and how these are parsed in innovation and litigation discourses, the methods and evidence with which novel therapeutic products are approved and regulated, how and why approval processes are becoming increasingly harmonized over time internationally, and the nature of national S&T policies being advanced for innovation and drug regulation in the context of globalization.

My own experience in the lab, likely little different from that of others, underscores the inherent uncertainty involved in “doing science.” As discussed in the context of evidence given by expert witnesses in pharmaceutical litigation,⁴² this uncertainty encompasses all phases

of experimentation no matter how planned the work may be from a grant application or project management perspective. A great deal of effort is required to accept and mitigate the “voodoo” inherent in conducting highly technical experiments and to maximize the quantitative, measurable, and predictable elements of science. It applies equally to the planning, conducting, troubleshooting, analysis and explicating of experimental science.

The tension between objective-subjective, certainty-uncertainty and determinism-indeterminism in various ways of framing science and its methodologies has particular resonance for the latest round of government-sponsored studies having as their objective policy recommendations aimed at enhancing domestic productivity and prosperity via commercialization of publicly funded life sciences research.⁴³ The reason is that these studies, and the expert panels drafting the reports, often single out biomedical and life sciences sectors as fertile policy targets.⁴⁴ These targets are identified in large part due the assumed quantitative and objective nature of work in these fields. The ‘scientific’ nature of the subject matter and methods in turn is seen to be conducive to arm’s length objective measurement and thus purposive policy-making. However, the strength of this nexus becomes increasingly tenuous as the distance between the experts and those who actually do and understand the normative strengths and weaknesses of benchwork increases. Hence the need for those who can comfortably straddle both divides from an experiential perspective. Happily, owing to the increasing emphasis of multi- and inter-disciplinary research, the number of these researchers and the reach of their work into scholarly and political arenas are increasing.

An important question arising from this new way of looking at public health systems is how to best handle the increased complexity and knowledge bandwidth⁴⁵ that results from global interdisciplinary studies, and to leverage it towards a “fit” rTPL innovation ecology in a manner that enhances national productivity *and* distributive prosperity. Do we increase the bandwidth and learn to accommodate a range of voices? Or, do we maintain it and attempt to employ increasingly “efficient” filters in order to identify what certain segments of the population deem to be correct information streams buried in a milieu of less relevant streams? In this light, one of the more intuitively acceptable aspects of complexity as a scientific, legal and regulatory tool is



that its broad generalizable rules are *not* cast in stone. Rather, the property of complexity *emanates from* all actors and evolves very slowly at the outer diameter of the sphere of human activity in spite of flurries of events at progressively more internal local scales. As such the broad generalized rules governing complex adaptive systems⁴⁶ are universal yet contextual. Like any good legal test,⁴⁷ policy,⁴⁸ or indeed philosophical system,⁴⁹ balance is key.

This bandwidth issue is often at play in workshops on innovation and drug regulation, where there are many voices and discourses typically at cross-purposes to one another. Worse yet, not only are the voices distinct and separate, but there is no shortage of judgment brought to bear on those with differing views. This is often the case when proponents of public and private rights face off against one another in the context of public health. One wonders however whether these groups may have more in common than first meets the eye,⁵⁰ and whether they can be ameliorated by reframing the debate in systems language.

The central problem, at least as I see it, is a lack of common goals and a lack of understanding of how these goals are part of the larger legal-political framework in which they operate. Too few participants in the process desire to engage in the hard work of identifying and working through the issue of common ground, in part because doing so requires the antecedent work of placing the narrower innovation discourse in the context of larger and considerably more complicated public health and democratic discourses. There is no avoiding the issue if we want to understand the complex processes of invention and innovation as they inform an rTPL innovation ecology.

INNOVATION ECOLOGY – A FIRST STEP FORWARD

So, do systems theories have anything meaningful to say about the tension between strong ‘closed’ IPR rights on the one hand, and ‘open’ systems of invention and knowledge spillover in an increasingly global product development environment on the other? A tentative answer is: a good deal, at least in theory. A legitimate starting point, owing to the vigor with which most domestic governments are pursuing the matter, is that of innovative product development in the medical and life sciences.

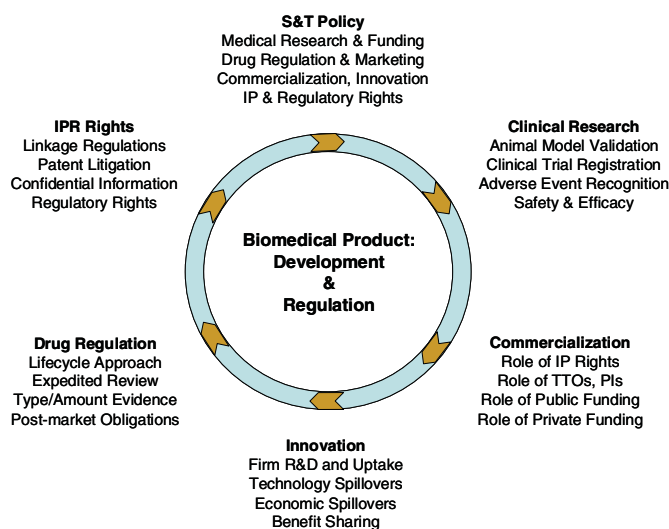


Fig. 1. Linear model of innovation in the medical sciences

Fig. 1 below illustrates a linear model of translational research and technology commercialization, typical of those used by most technology transfer offices, governments and funding agencies. As discussed by Stokes,⁵¹ and more recently Godin,⁵² the model focuses on translation of basic to applied research. The process begins with national S&T policies encompassing all aspects of an rTPL ecology, including the funding and prioritizing of medical research, the public health and economic goals of drug regulation, and the types of IPR rights associated with marketed products, and the legislative means by which those legal rights are expressed and enforced. The model continues on to encompass relevant steps in firm product development, regulatory approval, firm marketing of resulting products, subsequent litigation over IPR rights, and debates over the distribution of benefits from publicly funded private development activities.

Each structural and functional module, while covered by a host of related S&T policies and programs, is nevertheless seen to be reasonably independent of the functioning of other modules. The scheme is linear in the sense that each of these processes has a defined beginning and end point, including defined policy goals and economic outputs coupled to targeted translational research. The process is characterized by well defined economic metrics, which are seen to be (and indeed are modeled as) a linear function of system inputs and the



independent functioning of the set of institutions that supports the modules. The grist for the mill is rational (bounded or otherwise) decision-making, which permeates all steps in the linear process of technology commercialization in a narrow sense and which is deemed to connect individual self-interest to the collective interest in the broader sense.⁵³

The modular nature of linear models of innovation is best exemplified by the now familiar term “silos”. By their nature, silos are discrete, poorly connected and relatively independent; in a word, fragmented. This comports in an intuitive way with the two main economic levers used to enable innovation- law and business. Both of these endeavors deal with commercialization in a trade-oriented formulaic manner, largely owing to the fact that legal and management education privilege the related goals of certainty and predictability, though this is beginning to change (unfortunately much less so for law than management studies). The goal in both trades, including how many technology transfer offices work, is to chop up the process in order to maximize understanding of relevant structure-function relations and their related metrics. Recent examples pertaining to commercialization include the emphasis on return on investment (ROI), broad license terms and related revenue, the number of ensuing patents and prior art cites, and number of ensuing spin out firms. Little attempt is made to determine the components of the broader system relevant to effective public funding and commercialization of medical and life sciences research from a societal perspective. Both the ends and the means are focused on individual modules. In a linear framework, the highly iterative rTPL process is acknowledged to be complicated but not complex.⁵⁴

The pedigree of linear models in public health is difficult to trace, even within a relatively narrow innovation ecology framework.⁵⁵ Even so, it is now accepted that analytic models of this nature arose based on the notion that systems can be broken into constituent and determinative parts, understood as such with no other “value added” component (e.g., the whole is the sum of its parts), then reassembled and put back into motion. “Machine metaphors” of this nature have been privileged for centuries across the spectrum of human endeavor, particularly for organizations and organizational systems that emphasize objectivity and rationality.⁵⁶ Despite their wide use, however, the increase in cumulative knowledge as global borders

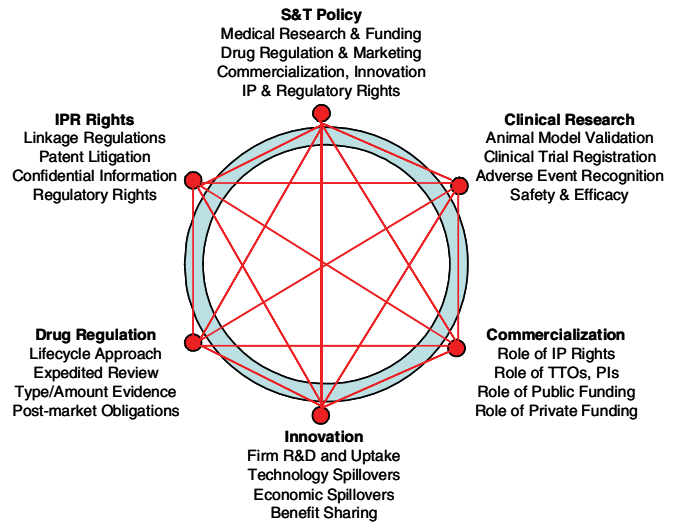


Fig. 2. Systems model of an integrated rTPL innovation ecology

dissolve⁵⁷ has yielded recognition of the limits of linear models privileging rational decision-making and determinism, particularly where maximization of certainty and predictability is the desired outcome of regulated social ordering.⁵⁸

Fig. 2 represents a highly simplified system ecology view of the *same* modules, but this time where the “whole is greater than the sum of its parts”. In common usage this phrase typically means that functioning of the system cannot be understood from analysis of the properties of modules *per se*;⁵⁹ rather, operation of the system is seen to be a function of the existence and nature of the interrelation and interdependence of modules, be they institutions or individual actors. In this simple scheme, not only is each hub directly dependent on the functioning of other hubs, but each of the modules within individual hubs are interconnected and interrelated to all other hubs in all other modules. The model is extended further as each of the individuals, groups and institutions within each of the hubs and modules are interconnected and interrelated to all other individuals, groups and institutions within the rTPL innovation network.⁶⁰ The totality of all actors, modules and hubs comprises the domestic innovation network, which in turn is connected to global innovation networks and constrained by local and international norms and values. The totality of all actors, modules and hubs comprises a single local innovation network, which



in turn is connected to other municipal, provincial, regional, and domestic innovation networks to comprise a global rTPL innovation ecology. The motivating force differs substantially from that in Fig. 1 and comprises some combination of rational decision-making plus the sum of reactions to and/or creation of chaotic or near-chaotic conditions and events in the form of emergent behavior, which propagates from the lower rungs of the organizational hierarchy upwards to shape the adaptive learning of the system.

A critical issue for the notion of an rTPL innovation ecology is that individuals working to create new products are largely found at the 'front lines' of innovation. In a complex system these people comprise that portion of the ecology the most immersed in and (potentially) responsive to chaotic or near-chaotic conditions. As we react, learn from and adapt to changing conditions, these lessons are propagated up the organizational hierarchy. When the system is working at or near a state of robust criticality, dynamic movement up the organizational hierarchy prompts further learning and adaptive behavior whereby the system as a whole becomes increasingly able to fulfill its fitness of purpose- here undertaking inventive and innovative commercialization activities that help individuals and nations prosper. Poorly adaptive systems, which neither learn through adaptation nor achieve strong levels of fitness, are those where individuals at the so-called higher rungs of command and control hierarchies do not take up and propagate the lessons of those seen to be below them (largely for reasons of power relations). Embedded within the model is the implicit assumption that anything which prevents or circumvents creative adaptation to changing conditions at the front lines, propagation of learning up the organizational chain or structural hierarchy, or the *de novo* expression of creative output of the system *per se*, ultimately leads to increasingly inefficient behavior of the system, which can, and often does, lead to system failure or collapse.⁶¹

Given that such a diverse range of public and private actors and institutions appear to be assembling themselves⁶² into novel forms of partnerships aimed at translational research and commercialization, it is pertinent to begin thinking critically about the value of new distributed and distributive models for analyzing risk-benefit and input-output relations, quality of life consideration and the social determinants of health. This is a relevant and potentially life-saving project in the context of an rTPL

ecology operating within a public health framework; particularly one in which health-related and economic risks are increasingly shifted on to the public. Indeed, using truly distributive platforms for policy development has the potential to engage market push *and* pull levers to an extent not seen before in government relations. This is largely because government has not taken a systems view of the problem to date, focusing instead on the function of individual institutions and processes and assuming that this will be sufficient both from the perspective of individual interests but also those of the system. This development is pertinent given the stance of prominent government advisors favoring a systems view of innovation linked to national productivity and prosperity.⁶³

Under conditions where private actors increasingly perform government functions either directly or via public-private partnerships,⁶⁴ it is reasonable to assume complimentary encroachment by public actors and institutions into the private spheres of profit and self-maximization. For example, assuming revenues and equity would be a first order approximation to those reported by AUTM,⁶⁵ a single distributive remedy, namely a compulsory government royalty on inventions successfully commercialized using substantial public funds,⁶⁶ has the potential to put \$4B and \$100M back into the coffers of public health agencies in the United States and Canada,⁶⁷ respectively. As a range of market push and pull mechanisms are engaged at various points in the medical product development cycle (cf. Fig. 2), distributive remedies of this nature are systemic in nature. Truly distributive policies and remedies operate on the assumption, minimized in linear innovation models, that the economy is one sphere of public life, not *vice versa*. What has not been appreciated by advocates of strong IPR rights is that by subtracting a certain fraction of "established" rights from one side of the push-pull equation, that the economy as a whole might ultimately gain more via recalibrated and revitalized inputs from a broader range of private *and* public actors.

MOVING FORWARD WITHOUT STEPPING BACK

It seems reasonable to say that the question is not *if* systems approaches can be useful in a public health context, but *how*. As usual, the devil is in the details; a notion further complicated by the interdisciplinary character of complexity-based systems models.⁶⁸



While it is still early days for an evidence-based systems innovation policy, it is not too soon to say that one of the major leverage points of complex adaptive systems and other systems-based approaches is the acceptance of uncertainty as an inherent, unavoidable and positive force, rather than something to be restrained and constrained. Acceptance of uncertainty has some reasonably straightforward implications for innovation in a public health context. The reason for this is because the *sine qua non* of innovation is invention.⁶⁹ Despite its potentially recursive nature,⁷⁰ invention is, at heart, a highly serendipitous process. Even if numerous

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elements of surrounding technologies and principles are known, including an unmet medical need, the idea (or series of ideas) that moves the process forward nevertheless emerges on its own accord. Invention is highly sensitive to initial starting conditions and the forward-looking nature of those participating in the process. As such, it is not amenable to being *strongly* quantified or controlled, especially using narrow metrics or narrowly circumscribed IPR rights-intensive S&T policies. Even so, there are things we can do within the prevailing constraints of the system in order to move things forward without losing historical advantages gained using silo-based linear models.

The first step is for governments, universities and capital sources to accept the prominent role of uncertainty when building models and best practices for technology commercialization. As correctly observed by Sterman,⁷¹ “all models are wrong.” Because of this, we must be leery of assuming that any one test or theory of innovation is correct and therefore that any one policy stone cast into the pond will solve an identifiable problem. Fluctuations and continual change are inevitable in our complex

system of layer upon layer of human behavior with the result that detailed predictability is simply not possible.⁷² Indeed, it is this very unpredictability that often leads to the most economically valuable inventions and scientific discoveries. We must ask whether it is socially responsible to build a \$300M infrastructure with an expectation of success (patents, licenses, spin outs) around something that is by nature random and unpredictable or whether there are other ways of stimulating invention. An alternative might be to concentrate resources on building new mental models of innovation that respect systems thinking and the potentially recursive nature of technological change, developing good filters for identifying, hiring, retaining, putting together and funding truly innovative personnel, and to identify and leverage innovative ideas in an adaptive manner when they do arise.

A related issue is one of commercialization-based funding of basic research by local and federal funding agencies. This is of course a topical issue. Not only have all major federal, state and provincial funding bodies in the United States and Canada made this a priority, but so have their parent public health agencies with regards to linking the approval process for drugs and biologics to innovation and transitional research in the life sciences.⁷³ An important point here is that almost all current funding models are silo-driven, even though economic diversification is often a stated goal as is stimulating innovative breakthrough inventions (Alberta being an excellent case in point). However, both diversification and the extension of knowledge and its reduction to practice in truly novel fields embrace the unknown.

You might ask: doesn't everyone know that? Absolutely not. To start with, contrary to established models of risk management and commercialization-based funding, diversification by definition means there will often be *no identified receptor targets*.⁷⁴ This raises the issue of how to fund commercialization-oriented research and development efforts effectively and efficiently from a perspective that embraces both uncertainty and risk over the long term rather than rejecting them for perceived short term gains. Answers to this problem will not come easily and will necessitate new ways of thinking through the issue of a common frame for public and private actors in a context that embraces rather than downplays risk. A second issue is that it will require a hard look into the types of individuals who have the potential to hit the desired home runs, which will



almost certainly entail new types of searches for people who are comfortable thinking outside the box. While this conclusion might seem obvious, it nevertheless runs afoul of the principle of “like attracts like”, cycling back to the importance of leadership values and styles. Tolerance of perceived differences and failure will be a focal point of this debate.

As discussed by Stokes⁷⁵ and Arthur,⁷⁶ history is replete with examples of successful innovation driven by (sometimes urgent) need. In each case there was a significant concentration of divergent intellectual, technological, administrative and financial resources brought to bear on numerous levels of recursive problem-solving that, and here is the key, went far beyond established silo-based models of “invention” and “innovation.” In each case, worries over risk were set aside (however reluctantly) and increased financial resources were poured into the task at hand. In each case the vista of creative options allowed to be addressed and grappled with by the people involved was open and expansive rather than closed and exclusive. As portrayed in an endless array of articles, literature, film and other art forms, mavericks, rogues and other personalities otherwise considered to be unfit for the task at hand were allowed membership in the group in order to attack a common problem – human, biological or technological.

We must, if we are to truly stimulate invention aimed at solving societal problems and enhancing domestic productivity, learn from these examples and bring lessons from them into commercialization practice. Important here is that risk tolerance, financial expenditures, scope of problem to be solved, and the horizon of creativity permitted in solving that problem by the relevant enabling institution are all interrelated in an *emergent* fashion. The potentially invaluable possibility exists that by expanding the boundaries for risk tolerance, financial expenditure and scope of creativity in problem-solving that the time scale for successful invention and innovation may be decreased by a significant, if not substantial, factor.

A related issue is the nature of communication between universities, PIs and firms. Indeed, several recent reports commissioned by provincial and federal governments on difficulties faced by innovators in Canada have pointed to the lack of firm research and development activities. The thing that distinguishes systems and

other network theories is that their structure-function relation is seen to *emanate from* the number and nature of interconnections between nodes. It is known, for example, that creation of novel technologies is a function of cumulative cultural and scientific knowledge and can be catalyzed within appropriate networks⁷⁷ or through establishment of so-called generative relationships.⁷⁸ As such, we not only need to help identify more receptor targets for university PIs in their commercialization efforts but also to (re)educate firms as to the breadth

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of potential new applications in their fields. This expansive approach differs fundamentally from currently accepted technology transfer, venture capital and marketing practices. Importantly, an increase in breadth of applications will not just be from directly related fields. Rather, it seems prudent to expand the horizons of firm leaders to look for applications in field “X” from apparently diverse fields “A”, “K” and “T”, as well as those in adjacent fields “W” and “Y”. Accepting the reality of this notion requires accepting the reach of uncertainty into all corners of the rTPL innovation ecology.

An expansive approach to recognizing the scope of prior art relevant to a given invention was recently taken by the U.S. Supreme Court in *KSR*.⁷⁹ In its reasons, the court stipulated that persons having skill in the relevant art were endowed with sufficient creative abilities to enable them to look not just at explicit prior art relative to the problem faced by the inventor (e.g., Problem “X”), but also to elements of the prior art designed implicitly to solve similar problems within the same industry (Problems “W and Y”) or parallel problems in different industries (Problems “A, K and T”). Opening up pipelines from firms to the public may therefore involve opening up those



from universities to firms, both in terms of unlogging existing pipes (finding common languages) but also expanding their number and diameter (increasing $X \rightarrow X$ flow and $W/Y \rightarrow X$ flows, but also $A/K/T \rightarrow X$ flows as well). Given the reach of IPR rights into all aspects of the rTPL innovation ecology, we ignore the direction of the US Supreme Court at our peril.

An important lesson learned from empirical studies of complex systems is that we must not gauge an individual's successes or failures too much by those of others. This has obvious implications for the normative practice of "benchmarking". While highly constrained local rules may for a time produce a cluster of related events, generally speaking causation in one set of circumstances is not likely to be causation in the next set. This will be particularly true the more one deviates in time and space from the local rules just mentioned. Each problem set has different set of initial starting conditions, different combinations of human and capital resources, technologies and considerations of use, and feedback loops, stocks, flows and non-linearities unique to those combinations. Rather than trying to narrowly reproduce the specific conditions that gave rise to earlier successes, effort may be better spent on identifying the unique aspects of the starting conditions, hiring massively creative people and allowing them the freedom to operate, funding them in the context of risk tolerance, keeping the linkages as open as possible, and refraining from over-regulating or otherwise suffocating them (including allowing for smooth transduction of adaptation from lower to higher rungs of the organizational hierarchy). This will permit as much emergent behavior as possible to occur within local innovation ecologies. The trick is to encourage innovation within narrow frames of identifiable problems but also to understand that, because novel technologies are made of building blocks of previous and future elements, long-term national success depends on setting up the system of invention to produce as many useful and creative building blocks as possible for future participants in the invention-innovation process.

At the other end of the invention-marketing spectrum we have the issue of narrowly circumscribed and over-regulation by local and national governments. As discussed in detail elsewhere,⁸⁰ an ironic outcome of closed legal and regulatory schemes is that they may stifle the very thing they seek to facilitate. Inventive translational research is known to be dependent on

open systems of knowledge sharing and tacit and focal knowledge, which represents a point of obvious tension in the context of an innovation system which privileges closed IPR rights. For example, product development in the pharmaceutical (and increasingly biotechnology) sector is dependent on strong IPR rights. Yet, linkage regulations tying patent protection to drug approval have created a narrow "escape" pathway for market entry which privileges low-level line-extension products. While regulatory rights under TRIPS were well intended to help provide extended market exclusivity to drug products given long regulatory approval times, they only compound the problem for obvious reasons.

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As discussed by Arthur in the context of "lock-in" and increasing returns, once the decision has been made to exploit a new niche (such as that created by strong IPR rights), industry leaders have substantial incentives to support maintenance of the regime. More importantly, they become increasingly locked in to the unintended consequences of the loophole as opposed to exploring other potentially more innovative paths.⁸¹ A similar problem has been recognized in studies of complex political systems, where "yardsticks" designed to measure progress tend to reorient actors' behavior narrowly towards fulfillment of the yardsticks.⁸² There is no question that the cultivation and then leveraging by multinationals of strong IPR rights for biomedical inventions constitutes a superb form of innovation. The question is however: is it one that society wants to keep funding?

As debated in the workshop, an innovation system that respects the boundaries and constraints of a complex adaptive system may precipitate a move towards



some mix of conventional IPR rights and open source. This may allow 'blue sky' and upstream research to continue to feed into the commons to inspire further research and to be reduced to practice by firms. In theory, a move towards a hybrid system may present a valuable opportunity to traverse the difficult border of stimulating and rewarding those responsible for true breakthrough inventions while inhibiting or at least providing partial disincentives for "investment by portfolio" strategies⁸³ that privilege less socially desirable forms of innovation.

However, it is not yet clear what technological or economic advantages an open source or hybrid open source-closed IPR rights regime would offer if it is predicated on the acquisition of traditional strong IPR rights. A graded regulatory rights scheme such as that described by Eisenberg here and elsewhere,⁸⁴ balanced by policies targeted specifically at reducing the conflict of interest involved in drug development and regulation and egalitarian distribution of the benefits of a public health system, may be particularly useful for biomedical inventions owing to long approval times and comparatively shorter patent lifetimes.

Finally, under conditions where government continues to push the supply side and to move in the direction of public-private partnerships in funding and prioritizing research, product approval and product marketing, then it should accept that the public needs to understand and partake in the distribution of benefits to an extent greater than currently on offer. As argued in the context of complex equality⁸⁵ and complex social ordering,⁸⁶ the market is one zone of democratic society, not the whole of it. Therefore, to the degree that we allow private actors to encroach on historic public and government functions,⁸⁷ the principle of balance, if not that of distributive fitness, requires complimentary encroachment by public actors and institutions into the traditional private spheres of bargaining, profit and self-maximization. Extending complexity theory to its logical conclusion, we might argue that the fitness, or desired goal, of an rTPL innovation ecology is the production of safe and efficacious therapeutic products in a manner that is constrained by prevailing legal and democratic norms. In this regard, movement by some technology transfer offices⁸⁸ and industry associations⁸⁹ towards trying to identify and measure the social benefits of translational research and commercialization is a step in the right direction.

rTPL SUBSYSTEMS

Despite difficulties in figuring out how to best move forward with some type of a hybrid closed-open IPR rights regime, it seems reasonable to say that our current system of innovation, while it has had successes in time and space, is currently presenting just as many roadblocks as stimuli in the broader biomedical community. An analogous conclusion applies to the legal regime underpinning drug approval and regulation. Happily, as discussed earlier, domestic drug approval agencies are currently undergoing considerable evolution in order to become more responsive to future contextual challenges. By contrast, privileging strong IPR rights appears to be making the innovation system less and less responsive to environmental challenges. In this context, a "one size fits all" IPR rights regime may be too much of a blunt instrument to maximize the ability of different industries to respond to different market push and pull demands. Indeed, this issue led Wulf to invoke the concept of an open innovation ecology in the first place.⁹⁰

In this light, one might say the two rTPL subsystems of drug regulation and innovative medical product development occupy different positions in a regulated space characterized by punctuated equilibrium.⁹¹ The evolution of numerous domestic drug agencies towards a back-loaded life-cycle approach to drug regulation suggests that the "avalanche" of events characterizing movement into a robust state of criticality has already begun.⁹² Here, the emphasis is not on explicating or even rendering adaptive policy. Rather, it is on doing our best to manage the potential benefits and harms to human health by being vigilant, displaying strong leadership and commitment to first principles and allowing the system to be as adaptive as possible. By contrast, the innovation subsystem is well behind in that we are aggressively trying to initiate a phase transition in order to bring innovation in the life sciences into a state of robust criticality. It is plausible that the longer we privilege a closed IPR rights regime that rejects risk, difference and uncertainty in favour of safe short term gains the longer we will wait for our phase transition in this sphere.

FINAL NOTE

Our research group is just at the beginning stages of determining whether the *distributed* nature of complex adaptive systems has practical relevance for a *distributive* legal analysis of a regulated therapeutic product lifecycle, or rTPL. Hence, the caution in putting forward targeted



recommendations for technology transfer practice at this time. Obviously, a rigorous theory and methodology must be developed in order to empirically test the utility of systems models for innovation and drug regulation. While, “false theories” have some utility in the context of untested assumptions that are valid for a so-called high level policy debate,⁹³ one nevertheless desires to take this more than a small step forward into developing truly pragmatic models. The hope is that these models will enable us to be more responsive to environmental challenges and stimulate innovative medical research while ensuring the products of that research are enjoyed equally by all members of the public. Until then, applications of systems paradigms to the topic at hand are speculative: interestingly so, but speculative nonetheless.

ACKNOWLEDGEMENTS

I thank Ed Levy, Emily Marden, and the participants at the UBC “Alternative Intellectual Property and Technology Transfer Offices: Exploring the Evolving Landscape” workshop held in Vancouver May 8-9th, 2008, for lively comments and discussion on several points of interest over which many disagreed. I’m also grateful to the members of my research lab, Jacob Foster, Monika Sawicka, Stuart Shaw and Nav Vashistha, for valuable comments and corrections. All errors and opinions are solely those of the author. This work was supported by a career establishment award from the Alberta Heritage Foundation for Medical Research (AHFMR).

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Endnotes

- 1 To steal a line from Mark Lemley (“Are Universities Patent Trolls?” (2008) 18 Fordham I.P. Media & Ent. L.J. 611), this is an edited version (and a substantially edited one at that) of a conference presentation and is intended to read like it. I’m aware that a talk like this can be frustrating for presenter and audience alike as it raises more questions than it answers. Even so, one needs to

start a new dialogue somewhere. In this sense, the presentation is as an extension and clarification of previous work (Ron A. Bouchard, “KSR v. Teleflex Part 2: Impact of U.S Supreme Court Patent Law on Canadian and Global Systems-Based Innovation Ecologies” (2008) 15 Health L.J. 247 [Bouchard, “KSR 2”]).

- 2 William Wulf, “Changes in Innovation Ecology” (2007) 316 Science 1253 [Wulf].
- 3 *Ibid.* at 1253.
- 4 Donald E. Stokes, *Pasteur’s Quadrant: Basic Science and Technological Innovation* (Washington, D.C.: Brookings Institution Press, 1997) [Stokes].
- 5 Per Bak & Ken Chen, “Self-Organized Criticality” *Scientific American* 264:1 (January 1991) 46; Nicolis Grégoire & Ilya Prigogine, *Exploring Complexity* (New York: W.H. Freeman, 1990); M. Mitchell Waldrop, *Complexity: The Emerging Science At The Edge Of Order And Chaos* (New York: Simon and Schuster, 1992) [Waldrop]; Stuart Kauffman, *At Home In The Universe: The Search For The Laws Of Self-Organization And Complexity* (New York: Oxford University Press, 1995); Steven Johnson, *Emergence: The Connected Lives of Ants, Brains, Cities and Software* (New York: Scribner, 2001) [Johnson].
- 6 Albert-László Barabási, *Linked: the new science of networks* (Cambridge, Mass: Perseus Publications, 2002).
- 7 Jay W. Forrester, “Learning through systems dynamics as preparation for the 21st century” (Keynote Address delivered at the Systems Thinking and Dynamics Modeling Conference, Concord Academy, Concord Me., 27-29 June 1994) [unpublished]; John D. Sterman, *Business Dynamics: Systems Thinking and Modeling for a Complex World* (Boston, Mass.: Irwin/ McGraw-Hill, 2000) [Sterman, *Systems*]; John D. Sterman, “All models are wrong: Reflections on becoming a systems scientist” (2002) 18 Systems Dynamics Review 501 [Sterman, “Models”]; John D. Sterman, “Learning from evidence in a complex world” (2006) 96 American Journal of Public Health 505 [Sterman, “Learning”]; Yanner Bar-Yam, “Improving the effectiveness of health care and public health: A multiscale complex systems analysis” (2006) 96 American Journal of Public Health 459 [Bar-Yam]; Jack B. Homer & Gary B. Hirsch, “Systems dynamics modeling for public health: Background and opportunities” (2006) 96 American Journal of Public Health 452 [Homer & Hirsch].



- 8 P. W. Anderson, "More is different" (1972) 177 *Science* 393. Having said this, one has to acknowledge that Anderson was skeptical of the parallels between understanding complex systems in physics and chemistry and applying this seamlessly to cultural or even biological systems (at 396). However, this has not stopped a number of scientists from doing just that; assuming a stance that systems theories are universal and can be used to explicate "everything that is and becomes complex." See, for example, criticisms of claims of this nature by Frigg: Roman Frigg, "Self-organized criticality – What it is and what it isn't" (2003) 34 *Studies in History and Philosophy of Science* 613 [Frigg].
- 9 Not to be confused with convergence of the political and social systems in which global innovation ecologies are embedded (though, as argued below, there is relevant evidence for this as well).
- 10 127 S. Ct. 1727 (2007) [KSR].
- 11 For a review of the extensive literature in this field, see Ron A. Bouchard, "Balancing public and private interests in the commercialization of publicly funded medical research: Is there a role for compulsory government royalty fees?" (2007) 13 *B.U.J. Sci. & Tech. L.* 120 [Bouchard, "Balancing"].
- 12 A social network is a social structure composed of nodes (individuals or organizations) that are "tied by one or more specific types of interdependency, such as values, visions, ideas, financial exchange, friendship, kinship, dislike, conflict or trade. The resulting structures are often very complex" and "display substantial non-trivial topological features, with patterns of connection between their elements that are neither purely regular nor purely random": *Social Network*, online: Wikipedia <http://www.en.wikipedia.org/wiki/Social_network>; *Complex Network*, online: Wikipedia <http://en.wikipedia.org/wiki/Complex_network>.
- 13 Systems theory is "an interdisciplinary field of science and the study of the nature of complex systems in nature, society, and science": *Systems Theory*, online: Wikipedia <http://en.wikipedia.org/wiki/Systems_theory>.
- 14 Benoît Godin, "The Linear Model of Innovation: The Historical Construction of an Analytical Framework" (2006) 31 *Science, Technology & Human Values* 639 [Godin].
- 15 Sterman, *Systems*, *supra* note 7; Sterman, "Models", *supra* note 7.
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- 17 Tim Wilson & Tim Holt, "Complexity and clinical care" (2001) 323 *British Medical Journal* 685; A.G. Matlow *et al.*, "How can the principles of complexity science be applied to improve the coordination of care for complex pediatric patients" (2006) 15 *Quality and Safety in Health Care* 88.
- 18 Sterman, "Learning," *supra* note 7; Bar-Yam, *supra* note 7; Homer & Hirsch, *supra* note 7.
- 19 "Econophysicists matter" (2006) 441 *Nature* 667; Robert M. May, Simon A. Levin & George Sugihara, "Ecology for Bankers" (2008) 451 *Nature* 893 [May *et al.*].
- 20 Stokes, *supra* note 4; Godin, *supra* note 14.
- 21 James Begun, Brenda Zimmerman & Kevin Dooley, "Health Care Organizations as Complex Adaptive Systems" in Stephen M. Mick & Mindy E. Wyttenback, eds., *Advances in Health Care Organization Theory* (San Francisco, Cal.: Jossey-Bass, 2003) 253 [Begun *et al.*]; Paul E. Plsek & Trisha Greenhalgh, "The challenge of complexity in health care" (2001) 323 *British Medical Journal* 625; Sterman, "Models," *supra* note 7; Sholom Glouberman & Brenda Zimmerman, *Complicated and Complex Systems: What Would Successful Reform of Medicare Look Like?*, Working Paper No. 8 (Saskatoon: Commission on the Future of Health Care in Canada, 2002); Patricia L. Mabry *et al.*, "Interdisciplinarity and Systems Science to Improve Population Health: A View from the NIH Office of Behavioral and Social Sciences Research" (2008) 35 *American Journal of Preventative Medicine* S211.
- 22 Ron A. Bouchard, "Should scientific research in the lead-up to invention vitiate obviousness under the Patented Medicines (Notice of Compliance) Regulations: To test or not to test?" (2007) 6 *C.J.L.T.* 1 [Bouchard, "Test"]; Ron A. Bouchard, "Living separate and apart is never easy: Inventive capacity of the PHOSITA as the tie that binds obviousness and inventiveness" (2007) 4 *University of Ottawa Law & Technology Journal* 1 [Bouchard, "Living"].
- 23 Marcia Angell, *The Truth About the Drug Companies: How They Deceive Us and What To Do About It* (New York: Random House, 2004); John Abramson, *Overdo\$ed America: The Broken Promise of American Medicine* (New York: Harper Collins, 2004); Jerry Avorn, *Powerful Medicines: The Benefits, Risks, and*



- Costs of Prescription Drugs* (New York: Knopf, 2004); Philip J. Hilts, *Protecting America's Health: The FDA, Business, and One Hundred Years of Regulation* (New York: Alfred A. Knopf, 2003); Trudo Lemmens & Ron A. Bouchard, "Regulations of Pharmaceuticals in Canada" in Jocelyn Downie, Timothy Caulfield, & Colleen Flood, eds., *Canadian Health Law and Policy*, 3rd ed. (Toronto: Lexis Nexis, 2007) 311.
- 24 Richard Mackie, "Walkerton final report urges fast action to safeguard water" *The Globe and Mail* (24 May 2002) A1; Carly Weeks, "Clone appetit" *The Globe and Mail* (16 January 2008) L1; Tu Thanh Ha, Bill Curry & Anne McIlroy, "Inspectors failed to adopt more rigorous U.S. measures: New rules pulled lone watchdog off floor of contaminated meat plant, union says" *The Globe and Mail* (27 August 2008) A1; Sheryl Ubelacker, "Irradiation is the most effective way to kill bacteria lurking in salad greens" *The Globe and Mail* (15 April 2008) L6; Matthew Campbell, "Nationwide outbreak spurs massive meat recall" *The Globe and Mail* (20 August 2008) A1.
- 25 Zoe Cormier, "Is plastic killing us? It's a chemical controversy" *The Globe and Mail* (5 November 2005) F6; Martin Mittelstaedt, "Bisphenol A most harmful to infants, study says" *The Globe and Mail* (11 January 2008) A4.
- 26 Marcus Gee, "Five Things" *The Globe and Mail* (7 September 2007) B2; Carly Weeks, "Mega Brands issues new toy recall" *The Globe and Mail* (18 March 2008) L1.
- 27 Fritof Capra, *The Web of Life* (New York: Anchor Books, 1996); Stuart Kauffman, *At Home In The Universe: The Search For The Laws Of Self-Organization And Complexity* (New York: Oxford University Press, 1995).
- 28 Fritof Capra, *The Tao of Physics* (Berkley, CA.: Shambala, 1975); James Gleick, *Chaos: Making a New science* (New York: Viking, 1987); M. Mitchell Waldrop, *Complexity: The Emerging Science At The Edge Of Order And Chaos* (New York: Simon and Schuster, 1992) [Waldrop].
- 29 John L. Casti, *Searching for Certainty: What Scientists Can Know About the Future* (New York: W. Morrow, 1990); John L. Casti, *Complexification: Explaining the Paradoxical World Through the Science of Surprises* (New York: Harper Collins, 1994); Nassim Nicholas Taleb, *The Black Swan: The Impact of the Highly Improbable* (New York: Random House, 2007).
- 30 Johnson, *supra* note 5.
- 31 Peter M. Senge, *The Fifth Discipline: The Art and Practice of the Learning Organization* (New York: Doubleday, 1990).
- 32 Naomi Klein, *No Logo: Taking Aim at the brand bullies* (Toronto: Knopf Canada, 2000).
- 33 Janice Gross Stein, *The Cult of Efficiency* (Toronto: House of Anansi Press, 2001) [Stein].
- 34 Steven D. Levitt & Stephen J. Dubner, *Freakonomics: A Rogue Economist Explores the Hidden Side of Everything* (New York: Morrow, 2005); Naomi Klein, *The Shock Doctrine: The Rise of Disaster Capitalism* (New York: Henry Holt and Company Inc., 2007).
- 35 May *et al.*, *supra* note 19.
- 36 Wulf, *supra* note 2.
- 37 "A Case for Nurture: Innovation is a complex ecosystem that requires careful cultivation" (2008) 454 *Nature* 918.
- 38 May *et al.*, *supra* note 19.
- 39 An important caveat for the use of systems theories and complex adaptive systems here is that no claim is being made to the universality of these models or their inevitable applicability to human behavior. Rather, the claim is that these models offer a new and useful "way of seeing" the levels of complexity and interdependencies involved in the regulation of medical research and product development. As such it is hoped that "trying on" the lens of systems theories will offer valuable insight in terms of how complex and strongly interrelated processes work when embedded within larger local and global public health systems, and to provide a platform (or prelude if you will) for discussion of the relation of empirically demonstrable distributed networks and distributive theories of justice and complex equality.
- 40 For a small sample, see: J.B. Ruhl, "The Fitness of Law: Using Complexity Theory to Describe the Evolution of Law and Society and Its Practical Meaning for Democracy" (1996) 49 *Vand. L. Rev.* 1407; J.B. Ruhl, "Regulation by adaptive management: Is it possible?" (2005) 7 *Minnesota Journal of Law, Science and Technology* 21.
- 41 Largely doing voltage-clamp, current clamp and gating current studies of Na⁺, Ca⁺, and K⁺ channels, wild-type and cloned Na⁺/Ca⁺ exchangers, cell shortening and intracellular Ca⁺ imaging at the single cell and giant sarcolemmal patch level, but also some whole muscle and whole heart studies involving force measurements, rapid cooling



- contractures and Fourier transforms of scattered laser light intensity fluctuations.
- 42 Bouchard, "Living" *supra* note 22.
- 43 Institute for Competitiveness & Prosperity, *Reinventing Innovation and Commercialization Policy in Ontario*, Working Paper 6 (Toronto: Institute for Competitiveness & Prosperity, 2004), online: Institute for Competitiveness & Prosperity <<http://www.competeprosper.ca>> [*Reinventing Innovation*]; Brian Guthrie & Trefor Munn-Venn, *Six Quick Hits for Canadian Commercialization: Leaders' Roundtable on Commercialization* (Ottawa: Conference Board of Canada, 2005); Expert Panel on Commercialization, *People and Excellence: The Heart of Successful Commercialization* vol. 1 (Ottawa: Public Works and Government Services Canada, 2006), online: Expert Panel on Commercialization <<http://www.strategis.ic.gc.ca/commercialization>> [*People and Excellence*]; Erika Fitzpatrick, *Innovation America: A Final Report*, (Washington, D.C.: National Governors Association, 2002), online: National Governors Association <<http://www.nga.org>>; The Council on Competitiveness, *Innovate America: Thriving in a World of Challenge and Change* (Washington, D.C.: The Council on Competitiveness, 2005), online: The Council for Competitiveness <<http://www.compete.org>>; The Council on Competitiveness, *Five for the Future* (Washington, D.C.: The Council on Competitiveness, 2007), online: The Council for Competitiveness <<http://www.compete.org>>.
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- 45 C. F. Kurtz & D. J. Snowden, "The new dynamics of strategy: Sense-making in a complex and complicated world" (2003) 42 *IBM Systems Journal* 462
- 46 Murray Gell-Mann, *The Quark and the Jaguar: Adventures in the Simple and the Complex* (New York: W.H. Freeman, 1994); Murray Gell-Mann, "Beauty and Truth in Physics" (Lecture delivered as a videocast on TED.com, March 2007), online: TED.com <http://www.ted.com/index.php/talks/murray_gell_mann_on_beauty_and_truth_in_physics.html>.
- 47 See generally, William A. Galston, *Justice and the Human Good* (Chicago, Ill.: University of Chicago Press, 1980); Philip Plowden & Kevin Kerrigan, *Advocacy and Human Rights: Using the Convention in Courts and Tribunals* (London: Cavendish Publishing, 2002).
- 48 Bouchard, "Balancing" *supra* note 11; Ron A. Bouchard & Trudo Lemmens, "Privatizing Biomedical Research – A 'Third Way'" (2008) 26 *Nature Biotechnology* 31 [Bouchard & Lemmens, "Privatizing"].
- 49 Plato noted, "If we disregard due proportion by giving anything what is too much for it; too much canvas to a boat, too much nutriment to a body, too much authority to a soul, the consequence is always shipwreck." Similarly, Aristotle wrote that "the psychology of the soul and its virtues" is based on the "golden mean", or the desirable middle between the two extremes of excess and deficiency. While attempts have been made recently to co-opt the concept for ideological purposes (cf. The Third Way), the notion of balance conducing to "fitness" in a complex adaptive social system resonates strongly with the balancing of cooperation and competition in biological systems necessary for fitness under conditions of uncertainty and scarce resources, the balancing of individual and state legal rights in service of national constitutional goals, the balance of self-interest and collective interests in models of the economy, utility and justice, again in service of system goals, and the relevance of all these balancing acts to finding the right mix of so-called public and private interests in commercializing publicly funded medical research.
- 50 Bouchard, "Balancing", *supra* note 11.
- 51 Stokes, *supra* note 4.
- 52 Godin, *supra* note 14.
- 53 See Neil Harrison, "Complex Systems and the Practice of World Politics" in Neil Harrison, ed., *Complexity in World Politics: Concepts and Methods of a New Paradigm* (Albany, N.Y.: State University of New York Press, 1997) 183 at 183 [Harrison,



- “Complexity”] (Arguing that rationality based decision making in politics renders maximization of self interest the normatively acceptable standard of behavior).
- 54 As Noted by Miller & Page (John H. Miller & Scott E. Page, *Complex Adaptive Systems: An Introduction to Computational Models of Social Life* (Princeton, N.J.: Princeton University Press, 2007)) at 9: “In a complicated world, the various elements that make up the system maintain a degree of independence from one another. Thus, removing one such element (which reduces the level of complication) does not fundamentally alter the system’s behavior apart from that which directly resulted from the piece that was removed. Complexity arises when the dependencies among the elements become important. In such a system, removing one such element destroys system behavior to an extent that goes well beyond what is embodied by the particular element that is removed.... Complexity is a deep property of a system, whereas complication is not.”
- 55 Godin, *supra* note 14.
- 56 Steven G. Morgan *et al.*, “‘Breakthrough’ drugs and growth in expenditure on prescription drugs in Canada” (2005) 331 *British Medical Journal* 815; Begun *et al. supra* note 21; Beverly Sibthorpe, Nicholas Glasgow & Duncan Longstaff, *Complex adaptive systems: A different way of thinking about health care systems*, online: Australian National University <http://www.anu.edu.au/aphcri/Publications/Background_paper_stream1.pdf>.
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- 59 Dean Rickles, Penelope Hawe & Alan Shiell, “A simple guide to chaos and complexity” (2007) 61 *Journal of Epidemiology and Community* 933 [Rickles *et al.*].
- 60 Bruno Latour, *Science in Action: How to Follow Scientists and Engineers Through Society* (Cambridge, Mass.: Harvard University Press, 1987) [Latour].
- 61 Examples of the collapse of economic systems include the Wall Street Crashes of 1929 and 1987, the Great Depression, and Russian loan default of 1998 (see May *et al.*, *supra* note 19; For examples in natural systems, see: Per Bak & Maya Paczuski, “Complexity, contingency, and criticality” (1995) 92 *Proceedings of the National Academy of Sciences United States of America* 6689 [Bak & Paczuski], for examples in political systems, see Jervis, *supra* note 58, Harrison, “Complexity”, *supra* note 53 . For examples of “policy failure,” see Barry Bozeman, “Public-Value Failure: When Efficient Markets May Not Do” (2002) 62 *Public Administration Review* 145; Barry Bozeman & Daniel Sarewitz, “Public values and public failure in US science policy” (2005) 32 *Science & Public Policy* 119.
- 62 I use the terminology of “self assembly” with relevant caveats pertaining to the universality of self-organized criticalities: Frigg, *supra* note 8.
- 63 Institute for Competitiveness & Prosperity, *Realizing Canada’s Prosperity Potential* (Toronto: Institute for Competitiveness & Prosperity, 2005), online: Institute for Competitiveness & Prosperity <<http://www.competeprosper.ca>>; *Reinventing Innovation*, *supra* note 43; *People and Excellence*, *supra* note 43.
- 64 Stein, *supra* note 33.
- 65 Association of University Technology Transfer Managers, online <<http://www.autm.net>>
- 66 Described in: Bouchard, “Balancing”, *supra* note 11; Bouchard & Lemmens, “Privatizing”, *supra* note 48.
- 67 Assessment of the potential effectiveness of a compulsory government royalty (CGR) can be gained by survey data from the Association of University Technology Managers (AUTM) (Association of University Technology Transfer Managers Licensing Surveys, online: <http://www.autm.net/about/dsp.licensing_surveys.cfm>. In FY2004, U.S. IPOs raised \$4.98B, M&A transactions \$22.4B, licensing income \$1.4B and running royalties on marketed products \$1.22B, for a total of \$30B US. A CGR should yield figures similar to those for licensing income and running royalties plus an additional 5% of IPO and M&A activity, amounting to approximately \$4B in royalty fees to U.S. government. In FY2004, Canadian license income was \$54.23M and running royalties on product sales \$29.43M. Unfortunately, Canadian survey does not report M&A and IPO data. Given FY2004 data, this would amount to a maximum of \$84M CN in fees to Canadian



- government plus 5% of M&A and IPO transactions. Emphasis on translational research, technology transfer, commercialization, and public-private partnerships is growing strongly over time. As commercialization-based programs become more entrenched within North American universities, one might reasonably expect continued or elevated revenues in all four streams in upcoming years.
- 68 So, to some extent one piles speculation on speculation- but you have to start somewhere.
- 69 For example, according to the established Neo-Schumpeterian view, technological change can be divided into three phases: invention (creation), innovation (commercialization) and diffusion. See generally, Godin, *supra* note 14.
- 70 W. Brian Arthur, "The structure of invention" (2007) 36 *Research Policy* 274 [Arthur].
- 71 Sterman, "Models", *supra* note 7 at 521 and 525.
- 72 Bak & Paczuski, *supra* note 62 at 6690; Desmond Saunders-Newton, "When worlds collide: Reflections on the credible use of agent-based models in international and global studies" in Harrison, *supra* note 53, 165 [Saunders-Newton] at 170-173.
- 73 See generally, Bouchard, "Living", *supra* note 22 and Bouchard, "Test", *supra* note 22.
- 74 That is not to say there never will be; only that one need embrace the possibility that work in completely novel fields requires a relatively open time frame in order time to identify practice areas relevant to the prospective invention from the perspective of university-firm knowledge transfer. The discussion also includes the necessity of open channels of communication from the firm-university perspective with the potential (understood *ex ante* or otherwise) to assist university researchers and firms in their reduction-to-practice activities. The latter process is seen to encompass targets that are identified or understood from an *ex ante* perspective and those that may only have potential relevance at the front-end of the invention-innovation process.
- 75 Stokes, *supra* note 4.
- 76 Arthur, *supra* note 70.
- 77 Joel Mokyr, *The Gifts of Athena* (Princeton, N.J.: Princeton University Press, 2002); David Lane & Robert Maxfield, "Foresight, Complexity, and Strategy" in W. Brian Arthur, Steven N. Durlauf & David A. Lane, eds., *The Economy as a Complex Adaptive System II* (Reading, Mass.: Addison-Wesley, 1997) 169.
- 78 For example, the "invention sessions" facilitated by Nathan Myhrvold at Intellectual Ventures: see Malcolm Gladwell, "In the Air" *The New Yorker* 84:13 (May 12, 2008) 50. On "innovative thinking" more generally, see Malcolm Gladwell, *Outliers: The Story of Success* (New York: Little Braun and Company, 2008); Guy Claxton, *Hare Brain: Tortoise Mind: How Intelligence Increases when you Think Less* (London: Fourth Estate, 1997).
- 79 Bouchard, "KSR 2", *supra* note 1.
- 80 *Ibid.*
- 81 For a discussion of Arthur's work, see Waldrop, *supra* note 5 at 119
- 82 Jervis, *supra* note 58 at 68-87.
- 83 William Kingston, "Intellectual Property's Problems: How Far is the U.S. Constitution to Blame?" (2002) 4 *Intellectual Property Quarterly* 315.
- 84 Rebecca S. Eisenberg, "The Role of the FDA in Innovation Policy" (2007) 13 *Michigan Telecomm. & Tech. L. Rev.* 345.
- 85 Michael Walzer, *Spheres of Justice: A Defense of Pluralism and Equality* (New York: Basic Books, 1983) [Walzer].
- 86 Waldrop, *supra* note 5 at 332. See also Jervis, *supra* note 58; Harrison, *supra* note 53
- 87 Stein, *supra* note 32.
- 88 Angus Livingston, "Alternative TTO Metrics" (Lecture delivered at the Alternative Intellectual Property and Technology Transfer Offices: Exploring the Evolving Landscape Workshop, Vancouver, 8-9 May 2008) [unpublished] [Livingston].
- 89 Association of University Technology Transfer Better World Project, online: <<http://www.betterworldproject.net>>.
- 90 Wulf, *supra* note 2 at 1253; See also Burk and Lemley's discussion of technology-specific patenting (Dan L. Burk & Mark A. Lemley, "Is Patent Law Technology-Specific?" (2002) 17 *Berkeley Tech. L.J.* 1155).
- 91 Steven Jay Gould & Niles Eldredge, "Punctuated Equilibrium Comes of Age" (1993) 366 *Nature* 223.
- 92 Bouchard, "KSR 2", *supra* note 1
- 93 Frigg, *supra* note 8.

