Complexity and Financial Regulation

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The world's financial systems may seem complex, but they don't hold a candle to the natural world. The biosphere contains approximately 8 million species, not including those that have come and gone. There are, however, similarities between financial systems and the biosphere—both are *complex adaptive systems* in which individual agents act to enhance their own selfish objectives. The collective consequences of the selfish actions of countless numbers of such individual agents have often-unpredictable consequences at the level of the entire system, and those consequences can feed back to affect and change individual actions. The resulting surprises should come as no surprise: *emergent* phenomena may lead to systemic crises and collapses, from atrial fibrillation to stock-market meltdowns, from the desertification of rich landscapes to the disappearance of species and cultures. Individuals—whether they be tumor cells or market investors—generally act in their own self-interest, without concern for possible longer-term damage to the systems to which they belong. By studying how evolution has made biological systems more robust, we may be able to develop new approaches to financial regulation.

Life began on the planet nearly 4 billion years ago, and despite these systemic challenges, we are still here (at least for the moment). Charles Darwin was similarly impressed by the "tangled bank" that emerged from evolution working at much lower levels of organization, and his brilliant insights revolutionized our understanding of the world about us. Through continuous innovation—via mutation and sexual recombination, for example—coupled with a deceptively and brilliantly simple filter called natural selection, the characteristics of species change in response to changing environments. Even the very mechanisms of evolution, including those that generate new variants, are subject to constant modification. Mutation rates are subject to selection, and sexual recombination itself evolved—and became more pleasurable—to provide new genetic material on which selection could act. The interplay between exploration, by which new solutions are tested, and exploitation, by which the best solutions are implemented, is characteristic not only of evolution via natural selection, but also of the way people, companies, universities, and other institutions must divide their time and effort to survive and thrive.

Evolution is not about optimization in the abstract; it is about optimization relative to other genomes within and across species. While we are evolving, so too are our enemies (like the influenza virus) and our friends (including the microbiomes within us). To a large extent, evolution is about preparing for the unknown, because the scope of possible changes in our environments is so immense. We know that we will be assaulted with a variety of pathogens, many of them hiding out in our bodies waiting for any sign of weakness. New threats can emerge, mutants of beneficial microbes that live peacefully in symbiosis with us. And we also encounter novel pathogens through direct and indirect interactions with friends, families, pets, and farm animals. Predictably, we will be challenged by these pathogens; but what is not predictable is what the specific pathogens will be—influenza A, for example, comes in thousands of forms—or when they will attack. So vertebrates have evolved a contingency plan in the form of our immune systems and barriers to invasion. Those systems combine early warning indicators, generalized first lines of defense that buy time while we populate our immune repertoire with more specialized antibodies tuned to the specific threats, and archive them in memory in case those threats return.

We can learn much from the evolution of natural systems to aid in the design of financial regulatory systems, as well as systems to protect us against bio- or cyber-terrorism, and other challenges to the robustness of systems on which we depend (1-5). A robust and sustainable system depends on homeostasis (maintenance of a stable state) or, more generally, homeorhesis (maintenance of a stable dynamic trajectory). Homeostasis and homeorhesis require feedback mechanisms strong enough to sustain desired patterns, but not so strong as to create endless oscillations. Human physiological functions normally are maintained by processes that correct deviations from the norm, on appropriate time scales. When the feedback loops are too weak or too slow, pathologies arise, as in Cheyne-Stokes breathing (an abnormal breathing pattern that alternates between rapid breaths and apnea). When the feedback loops are too strong, we also observe pathologies, as in allergies and auto-immune responses. Similarly, when the time scale of financial innovation outstrips regulation, the financial system can break down. However, feedback (including regulatory) responses that are too strong can lead to increased uncertainty and economic recessions that are equally undesirable.

These implications underscore the importance of maintaining diversity and heterogeneity in financial markets, and allowing enough exploration, i.e., financial innovation, to produce the requisite diversity. But what is the right amount? Evolution has dealt with such challenges by regulating mutation rates and sexual recombination. But all complex systems, including natural ecosystems and business ecosystems, also exhibit self-organized emergent patterns that are not *per se* selected. Robustness depends upon adequate variation, and systems that suppress or lose it are prone to collapse.

We tend to think of evolutionary change primarily in terms of natural selection based on differential fitness, but *transformational* evolution of systems can also engender change. The galaxies represent one example, but a simpler one is an old truck being driven down a pot-hole-ridden road, losing parts as it goes. Ultimately, if the truck is to keep moving, it develops a more robust and streamlined form in which parts stop falling off. Likewise, financial and other systems can experience such transformational evolution, sometimes becoming more robust as a result (but not always—the truck can also break down). Hence, the systems that persist, and that we observe, tend to have properties that make them more robust. This is not the same as saying that selection has shaped individual behaviors to enhance group properties, but it is obviously related in that non-robust systems disappear. However, self-organization need not lead to robust systems, but may also contain the seeds of system collapse. The potential for collapse means that attention to developing early-warning indicators of critical transitions is crucial, as is designing for robustness.

One crucial aspect of robustness is redundancy, which provides insurance against loss. In part this is related to the modularity of the system, since isolation of related elements leads to redundancy. Redundancy does not require identical elements, but rather elements that can perform the same or equivalent functions. Modularity is equally important. Modularity is the inverse of connectedness, limiting systemic risk (7) and providing building blocks for rapid adaptation (2–4). Organism performance is related to size (8), and hence to the mechanisms that regulate size. Breakdowns of the regulation of size, whether in terms of gigantism or tumor growth, are unhealthy for biological organisms. Similarly, unchecked growth can lead to financial institutions that are "too big to fail," which can threaten global financial stability as the recent financial crisis demonstrated.

These challenges highlight the importance of recognizing the multi-scale nature of financial and other complex adaptive systems. Most regulatory levers depend upon influencing agent (micro-) behaviors in ways that may lead to collective (macro-) benefits. Sustaining such collective benefits are difficult however, in part because of conflicts between individual and collective interests (9, 10).

Finally, any view of financial systems must recognize that they are ecosystems, linking agents, stocks and flows. And just as ecosystem ecology is focused on the cycling of crucial elements like carbon, nitrogen and phosphorus, financial systems ecology should be focused on the sustainable cycling of crucial elements like capital, labor, and financial innovation. Regulations that focus on just parts of such systems can miss the big picture, for example compromising liquidity as we saw in the recent crisis. Management of ecological systems in the past has often missed this point, opting for more simplistic views; but failures have led to calls for ecosystem approaches for example in the management of fisheries, forestry and even infectious diseases. If anything, the interconnectedness of global financial systems is even greater (9), and a holistic approach is essential.

There are great similarities between natural and financial systems, and hope that we can learn from billions of years of evolution how to deal with the challenges of financial regulation, and the regulation of many other systems crucial to our societies.

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