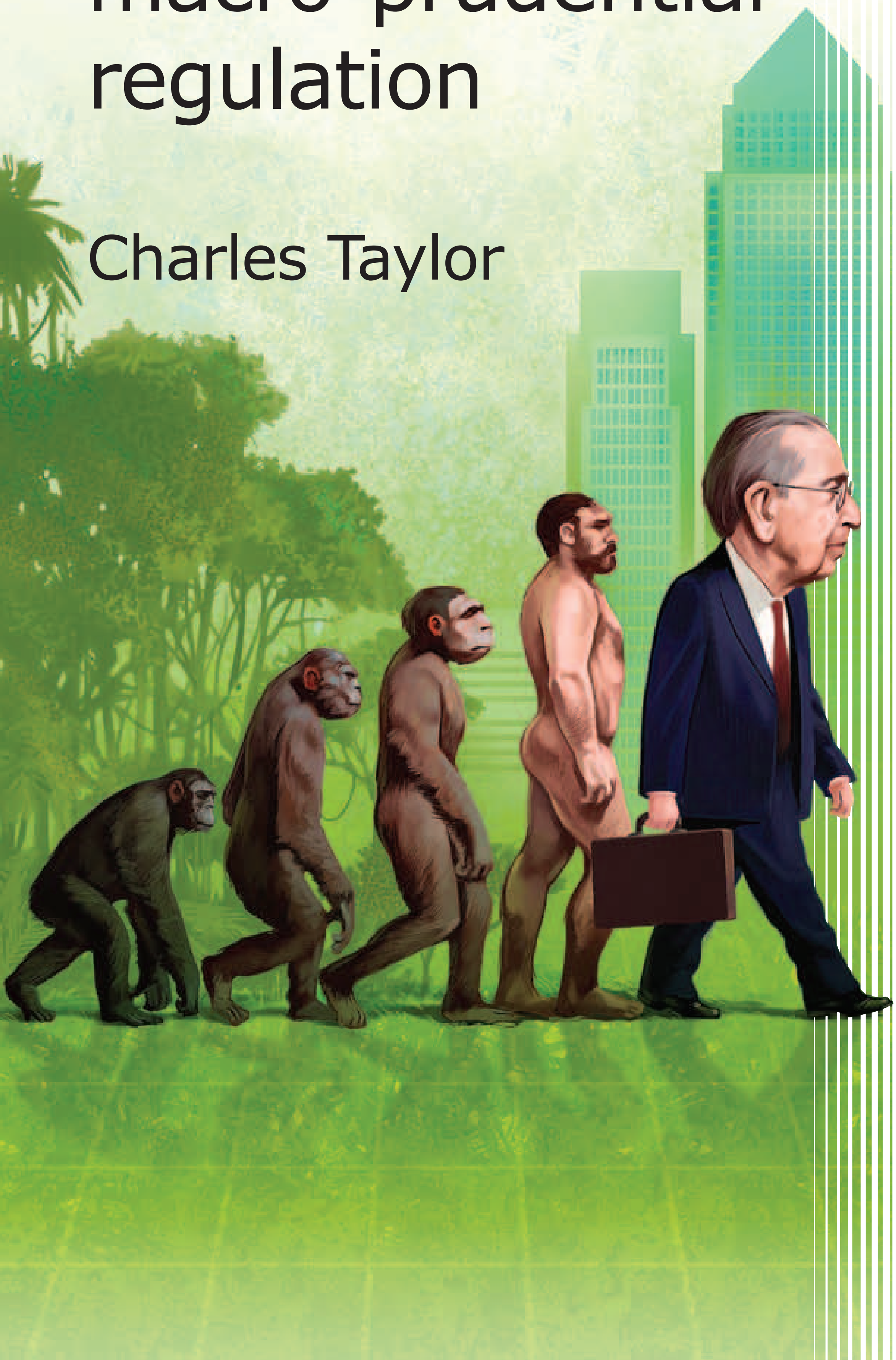
Evolution and macro-prudential regulation

Charles Taylor



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By Charles Taylor

Foreword

I have known Charles Taylor for many years. We joined the World Bank on the same day (as dewey-eyed Young Professionals) – and left on the same day five years later. He has always been one of the most innovative thinkers I have known – on development economics (he may not want to be reminded of an article he once wrote on putting out development to private-sector tender), on risk (he wrote an important paper for the CSFI building on the work that the Federal Reserve was doing on "pre-commitment") and on derivatives regulation (where he was responsible for the Group of 30's so-called Green Book).

Now, he has turned his hand to macro-prudential regulation – very much the buzz-word *de nos jours*. But his approach is typically quirky. Charles's initial academic training was as a mathematician – and it is the (relatively simple) mathematics behind the theory of evolution that appeals to him.

This is not a totally unploughed field; indeed, the article (in *Nature*) by Andy Haldane and Lord May earlier this year got a good deal of attention in the broadsheets – even it if wasn't obvious that commentators had always understood (or even read) the original. But I *think* (and I acknowledge the need for humility in this area) Charles goes well beyond their argument – at least in the implications for regulators. For him, evolution is not just an allegory; it is a (relatively simple) algorithm that generates the kinds of co-evolving populations that we see in financial services today – and that provides powerful lessons for those who seek to manage the risks that finance throws up.

In some sense, Charles's conclusions are pretty obvious – in one or two cases, blindingly so. But they are also extremely important, especially at a time when the underlying philosophy of financial regulation is under some stress (not least, with regard to implementation of Basel 3). Accept that the financial system is an evolutionary system (for which I believe Charles makes a strong case), and it follows:

- that regulators should encourage greater diversity – of institutions, of processes, of strategies – in the financial sector;
- that failure of individual institutions can be positively embraced as a protection against failure of the system – just as (individual) death in human populations is eminently compatible with the health and well-ness of the population as a whole;
- that crises will rarely be simple, since complex self-critical systems may suffer simultaneous failures – often around crucial nodes;

- that regulators, must, therefore, hold regulated institutions to high and sustainable standards – and must enforce laws against fraud and negligence with some zeal;

- that the danger of contagion within networks justifies super-intensive regulation of key nodes - as well as support for diversification and looser ties altogether; and (perhaps most contentious)

- that "unpalatable as it may be, temporary regulation or court control may be prreferable to yet further concentration" within the financial industry.

I hope that Charles's paper will provoke a lively discussion within the regulatory community – and among the banks. In Darwinian (or Lamarkian) terms, may the most powerful – and fittest – argument prevail.

Andrew Hilton
Director, CSFI

1. Introduction[1]

The financial and economic disaster that reached its climax in September 2008 was not just a failure of Wall Street ethics or regulatory oversight, but also of traditional economic theory. The dominant free-market paradigm that is centered on ideas of efficiency, optimality and equilibrium failed to guide policymakers and practitioners in the crunch. It had little to say about the multi-faceted decay and ultimate collapse at the very core of the global financial system, and that is cause for concern.

Evolution theory as an aid for policy-makers

This paper makes the case that evolution is a theory that can help meet policymakers' needs. Important macro-prudential policy implications flow from viewing the financial system as a set of co-evolving populations of institutions, products, strategies and processes. Through this lens, macro-prudential regulation relies less on policing and more on 'shepherding', less on constraining those populations with rules and more on 'nudging' them with incentives away from places where there are signs of heightened systemic risk.

An example of an important evolutionary insight is how death can be a healthy phenomenon. Some seven million people die each year in North America and Europe and yet, by historical standards, wellness and life expectancy are extraordinarily high. Applying that idea to the financial system, fairly steady rates of institutional failure (and new charters) might be one sensible objective for macro-prudential policy. "Living wills" for systemically important financial institutions are not just an expedient preparation for possible calamity; rather they are plans that should be used with some regularity.[2]

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1. Charles Taylor is Deputy Comptroller for Regulatory Policy at the Office of the Comptroller of the Currency. This paper reflects his own thoughts on macro-prudential regulation and does not necessarily reflect the views of the Office of the Comptroller of the Currency or the United States Government. It is based on a speech given by Mr. Taylor prior to becoming Deputy Comptroller at the Chicago Federal Reserve/IMF 2010 international banking conference and a presentation given in London at the CSFI in January 2011.

"Thanks are due to all three organizations for providing the opportunity to test out these ideas. Thanks are also due to Tony Peccia, Chief Risk Officer of Citibank Canada, for stimulating much of my interest in this subject and to Eric Beinhocker for his wonderful book, "The Origin of Wealth". I also want to acknowledge many other influences and sources of encouragement, some recent and some going back several years – Brian Arthur, Marcus Brunnermeier, Andrew Crockett, Christine Cumming, Doyne Farmer, John Geanakoplos, Charles Goodhart, Andrew Haldane, David Levermore, Simon Levin, Avi Persaud, Til Schuermann, George Shugihara, Scott Weidman and Sidney Winter." (CT)

2. Raghuram Rajan described the concept of living wills in Senate testimony in 2009. Richard Herring then developed it further and in June 2010, the G-20 Toronto Summit Communiqué endorsed the idea that resolution regimes for systemic financial institutions should include living wills. The Dodd-Frank Act, Title II, Section 165(d) built this concept into US law.

The rest of this paper is organized into three sections:

- *Evolution and the financial system*, which defines evolution as a general algorithm of which financial system evolution is a specific example. Differences from nature and some general implications are explored.

- *Evolution and instability*, which delves into the ways in which evolution is an especially useful framework for thinking about financial instability.

- *Implications for policy*.

"Evolution" is not just a metaphor...

One point to make at the outset is that "evolution" has often been used as a metaphor in discussing finance and other areas of economics.[3] That is not the way the term is used here. Evolution is not just a fancy word for "change". The financial system isn't "like" an evolutionary system. It is an evolutionary system - and important consequences flow from that fact.

BOX 1: WHAT'S NEW?

There are several implications for macro-prudential policy from evolutionary theory. Perhaps the three most novel injunctions would be:

- encourage as much diversity as possible across the financial system;

- monitor the diversity and fitness of financial sector processes, business models and strategies - as well as institutions, products and functions; and

- while encouraging high general levels of fitness, get rid of minimum standards wherever possible and create an environment in which virtually any population member can "die" without disrupting the system as a whole.

Unfettered evolution tends to cause periodic collapse in systems as tightly integrated as the financial system. That means there are strong grounds for rejecting naïve laissez-faire policies. On the other hand, because evolution is such a good mechanism for population change, policies should not undermine it. The objective should be to 'nudge' financial populations away from areas of heightened systemic risk, while in other respects letting evolution have a free hand.

Evolution is a relatively comprehensive explanation of financial system change. Most other theories fit "inside" evolution. For example, evolutionary theory explains networks and complexity. Complexity theory does not explain evolution. There will always be some black swans flying below the radar, but looking at the financial system from an evolutionary perspective should allow regulators to spot and tame more potential black swans - the ones that would have flown through the gaps between narrower theories.

3. In an address he gave in the mid-1990s, Paul Krugman referred to "the attractiveness of an evolutionary metaphor". However, his defense of neoclassical economics against evolutionary theory was more subtle. He argued that (a) you don't have to subscribe to the extreme neoclassical view to get great value from the ideas of equilibria and maximization as tools for thinking through lots of interesting problems and (b) mathematical evolutionary theorists use equilibria and maximization too. In other words, it doesn't make much difference. These two observations may be valid, but they do not add up to a good counter-argument to the case for evolution that is made here.

2. Evolution and the financial system

Criteria for an evolutionary approach

Evolution is a specific family of algorithms for changing populations. These can be populations in nature, the social sciences or in a computer simulation. They can be of almost any conceivable kind. An algorithm is a continuously repeated process that generates change - a loop of processes that can be automatic or expressed mathematically, but doesn't have to be. In nature, algorithms are usually automatic. In the social sciences, they can involve deliberate thoughtfulness.

The environment for evolution: Evolutionary algorithms have very particular properties and work only when the environment in which they operate meets two basic conditions:[4]

- *Limited resources*: the resources needed for population survival are in short supply; and

- *Change*: there is continuing unpredictable change in the environment itself.

Success for a population is that it survives and grows. Resource constraints in the environment mean that the members of any successful population are likely to compete against one another - if they do not first end up competing with other populations that share their habitat. Either way, competition is a consequence of evolution when resources are limited.

Continuing unpredictable change in an environment is not strictly necessary for evolution to work - although, without it, evolution may eventually slow up and stop. The prevalence in many systems of co-evolution – two or more populations sharing an environment and affecting each other - means that much of the environmental change for one population often comes from changes in other populations.

Evolution defined: There are four features that characterize evolutionary algorithms:

- *Local copying*: whereby individuals or small clusters of individuals create new population members, allowing population numbers to increase;

- *Local change*: whereby individuals or small clusters of individuals change themselves or their descendants with some degree of randomness.

4. The term "evolutionary algorithm" is often used to describe automatic numerical optimization techniques such as genetic algorithms. The term is used differently and more broadly in this paper. John Holland, in Chapter 2 of "Hidden Order: How Adaptation Builds Complexity", describes evolution as just one of the "acceptable procedures" that can affect change in a complex adaptive system (CAS). In saying that the financial system is an evolutionary system, this paper is making a more specific claim than those who say it is a CAS.

- *History matters*: while change can occasionally be radical, what follows usually resembles what went before; and

- *Selection*: competition leads to selection based on fitness, whereby members and traits that are less successful die out.

These four features capture the essence of evolution. Note, in particular, that there is nothing here about mechanisms. So, for example, local change could come about through mutation at the time of reproduction, as it does in nature - Darwinian evolution - or it could come about through adaptation by population members during their lifetimes – Lamarckian evolution.[5]

As an aside, Lamarck was a 19th century French biologist who published his ideas some fifty years before Darwin. He thought, for example, that when giraffes stretched their necks in search of food during their lifetime, they would pass on longer necks to their children. He was wrong about the local change mechanism in nature but, in the social sciences, changes often occur in the behavior of a person or an institution during their lives and are passed on this way via social interactions. In social systems, local Darwinian and Lamarckian change co-exist.[6]

The ability of a population member and its copies to survive depends on its fitness. Fitness measures are a forward-looking estimate of how well individuals are likely to fare in the face of local competition and environmental changes. For policymaking purposes, estimates of average fitness and the distribution of fitness about the average are useful indications of a population's prospects.

The financial system <u>is</u> an evolutionary system

According to this definition of evolution – local copying, local change, history matters and selection - <u>the financial system is indeed an evolutionary system operating in a changing and resource-constrained environment</u>. Among the population of financial institutions, human and financial resources are constrained. The technological, economic and social environment changes unpredictably, shifting the demand for and the possible forms of financial services. Copying via transfers of skills, technology or people is predominantly local. Change is also local as a rule, initiated by teams of individuals within institutions or small groups of institutions joining together. History obviously does matter: even new institutions are usually

5. Eric Beinhocker in "The Origins of Wealth" focuses on mechanisms, and gives a generalized account of how Darwinian evolution works. He suggests that evolution needs (1) a design space; (2) a way to code designs into a schema; (3) a schema reader to decode them and render them into interactors (alive things); (4) interactors to be made up of modules coded for by building blocks in the schemata (roughly what we call traits); (5) a constraining environment, whose constraints change over time; and (6) a "fitness function", so that some interactors are fitter than others. Obviously, (1) to (4) are one way of achieving automatic copying; (5) is our environmental condition; and (6) is a consequence of (5). (pp215, 216).

6. Lamarck published his theory of inheritance of acquired characteristics in 1809, the year Darwin was born. Darwin published "On the Origin of Species" fifty years later in 1859. Darwin argued (rightly) that change in natural populations occurred during reproduction and then was subject to natural selection, although he had no real idea of how these changes were effected. He either didn't know about Mendel's genetic experiments on peas, that were conducted from 1856 to 1863, or he didn't recognize their importance.

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colored by their founders' experience, and older institutions usually have a hard time changing themselves, even when leadership changes. And, finally, there certainly is selection based on fitness - as long as governments don't intervene.

True, evolving populations sometimes do die out. However, as a rule, evolution does a good job of adapting populations to new circumstances, not only when environmental changes are small but often when they are large too. That is because different local changes across a largish population put different eggs in many baskets, so to speak. Selection means that resources are quickly freed up for the best adapted variants by the death of population members who, in the new circumstances, are the least fit. It is hard to imagine a way that is better for changing populations than evolution when environmental changes are unpredictable, quite frequent, usually small and sometimes large.[7]

Positive, self-reinforcing change

Emergent characteristics: I suggest these areas where evolution creates positive, self-reinforcing characteristics:

- Cooperation: In any evolutionary system, great advantages can accrue to any sub-population that learns to cooperate. Cooperation brings the weight of numbers to bear on a threat or an opportunity. Individuals can specialize, thus increasing group capability. In nature, herds protect children, predators hunt together and symbiosis stretches across quite distinct branches of the evolutionary tree. In finance, markets are examples of cooperation among institutions, and financial institutions themselves are examples of long-term complex cooperative arrangements for the populations of their shareholders, officers, employees and suppliers. Evolution explains why cooperation arises so often.

- Diversity and standardization: Local change in evolutionary algorithms creates diversity across a population and, at the same time, a diverse population is necessary for selection to be an effective means of increasing fitness. Diversity usually waxes and wanes through time. Low levels pose a risk, because selective pressures are then more likely to threaten the entire population all at once. On the other hand, high levels of diversity generally improve the chances for survival and growth.

  While diversity brings survival benefits at one level, standardization can be beneficial at another. In nature, the interchangeability of worker bees or soldier ants adds to the strength of the hive or the colony, even while the global populations of bees and ants are extraordinarily diverse. In economics, product commoditization and market conventions create substitutability, contestability, liquidity and transparency even while there is an enormous variety of markets for goods and services. Think of those catalogues with

7. Stuart Kaufmann gives a slightly more formal argument about the superiority of evolution as an adaptive algorithm for populations faced with what he describes as a rough fitness landscape.

their standardized reference systems used by garage mechanics when ordering a part – extraordinary variety organized in a standard way. Successful technical standards deliver institutional and systemic benefits. That is the objective, for example, of the new efforts to create a common language for legal entities and transactions by the US Office of Financial Research and the European Central Bank.[8]

However, standardization carries risks. Recent financial reforms have included measures to promote central clearing of derivatives. These may improve transparency and reduce some kinds of risk, but not only do central counterparties concentrate operational risk, they may also constrain future developments. When power is concentrated in a single institution, standards management becomes something shaped by committees rather than evolution.[9]

- Structures: In addition to diversification, standardization, cooperation and specialization it is likely that, given enough time, any evolving population of sufficient size will:

    - *Create networks*, ie create lasting relationships of interaction and interdependency, not just between individuals but between specialized sub-groups;

    - *Become complex*, ie create complexity, in the sense that these relationships can multiply and grow stronger, deepening interdependencies; and

    - *Create secondary evolving populations*, with networks, traits, strategies, processes and services (or products, where both are defined as outputs that members of the initial population deliver to one another) – all of which can themselves co-evolve, ie form populations where copying and change are local, history matters, selection rules, the environment changes and resources are limited.

If it seems odd to talk about inanimate and abstract things like processes or strategies 'evolving', think of them as bearing a relationship to agents – individuals and

8. Early in 2011, the Office of Financial Research in the US Treasury issued its first policy statement on legal entity identifiers, and since then has moved ahead to contract out their management and maintenance.

9. Central counterparties (CCPs) are likely to become what some authors have referred to as an evolutionary "frozen accident". Nature is scattered with features that work after a fashion, but not as well as they might. One wonderful example is the optic nerve in humans that is connected to the retina by strands that run in front of it and not behind.

When the paperwork crisis hit Wall Street and the City of London in the early 1970s, CCPs were the solution - and they made use of the available mainframe technology to automate clearing and settlement. Had today's distributed technologies been available at the time, a more flexible and less vulnerable multimodal system might have been favored. Expanding the reach of CCPs today, as the Dodd-Frank legislation does in the United States, cements this "frozen accident" of evolution into more places.

organizations – that is similar to the relationship between genes and living things in nature. The idea of a "selfish gene" is that populations of plants and animals only do what serves the interests of their genes. The same might be said of individuals and institutions in the financial system. They only do what is useful for the effective development of processes or strategies. [10] Evolution of processes and strategies is through the agency of individuals and institutions.

Limited intelligence: The intelligence of individuals and institutions is an important aspect of the evolution of financial systems that can affect systemic stability.

The role of intelligence

First of all, we should acknowledge that intelligence must always be limited in any evolving population. In contrast with mainstream neo-classical economics (where it is convenient to assume that groups of individuals often behave as though their knowledge was perfect and complete), the randomness of local change and the unpredictability of environmental change in an evolutionary framework mean knowledge and intelligence must necessarily be incomplete. Besides, if knowledge of the present and the future were close to perfect, what need would there be for evolution? Evolution is necessarily myopic.

What is intelligence? It is the ability of an individual to develop a mental model of its peers, its past and its environment and use that understanding to develop social relationships, make (imperfect) predictions about the future and devise strategies to improve its chances of survival. In nature, intelligence took tens of thousands of years to evolve. In financial systems, the capacity for intelligent decision-making can evolve in a matter of days and weeks as new insights, technology, processes and strategies take hold.

As well as being a product of evolution, intelligence drives evolution in social and economic systems. It is the key facilitator of innovation. In thought experiments, intelligent individuals or institutions can combine traits of existing products, processes or strategies to produce new designs and assess their fitness against a mental model of the world. Combinatorial innovation is the economic equivalent of mutation in nature. Mental testing and then physical prototyping are efficient and quick alternatives to the marketplace as selection mechanisms.[11]

Intelligence also allows individuals and institutions to demonstrate, teach, imitate and learn. Good ideas can be disseminated from person to person and institution to institution. It is this capacity of intelligence to act as the innards of a social copying machine, together with its power to drive innovation, that facilitates Lamarckian evolution and thereby accelerates change so extraordinarily.

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10. See, of course, Richard Dawkins's 1976 classic, "The Selfish Gene" (OUP)

11. The concept of combinatorial innovation comes from Brian Arthur's "The Nature of Technology", where he looks at the evolution of technology and its implications for economic progress. Here, we follow Beinhocker and others and extend the concept from scientific technology to social, organizational and, of course, financial ways of doing things.

Measuring, monitoring, and managing diversity...

Measuring diversity: From a policymaking viewpoint, it is all well and good to theorize about evolution. But, as the old adage goes, what isn't measured won't be managed. The core problem for macro-prudential regulation is to measure, monitor and manage diversity and fitness. We start by thinking about measurement and monitoring of diversity.

Starting with financial institutions, what are the traits that distinguish one from another? A preliminary list would include size, specialization, culture, compensation systems, quality of leadership and personnel, organization structure and governance, technological sophistication, business and portfolio diversification, investment portfolios and strategies, and growth and funding strategies.

Turning to processes, distinguishing traits include purpose, inputs, output, size (value-added), ownership, sub-process structure, information asymmetries, degree of automation, number of hand-offs, tolerance (of substandard inputs), resilience (the ability to recover), redundancy (the ability to substitute), flexibility (the ability to adapt) and so on. Mainstream economists and policymakers have had a tendency to focus on institutions and markets, and have neglected processes, both high and low level. Businessmen and business school academics on the other hand pay a great deal of attention to processes and worry about their ownership and effectiveness – but generally within organizations. In fact, however, processes that cut across institutions – such as liquidity relationships between markets, clearance and settlement processes and securitization - matter quite as much for financial system stability.

One might argue that functional regulation recognizes the importance of high-level processes, and indeed it does. But it does not recognize their *mutability* – the possibility of hybrid forms emerging for reasons of regulatory arbitrage or simple economic advantage. Functional regulation accords importance to high-level processes, but not to the sorts of possibilities that keep an evolving population healthy.

Market researchers have a variety of techniques for characterizing and measuring product traits that might be adapted to measuring diversity across financial institutions or processes. (Also, to the extent that any one of these can be decomposed into sub-elements, structures can be defined and translated into matrices and then into formal measures of difference.) Mathematical ecology can then provide clustering and diversity measures that are straightforward to apply, so that once a group of traits is selected (or a standard decomposition has been settled on), it will be possible to develop data collection strategies and start monitoring and measuring changes in average characteristics and in diversity over time.[12]

This discussion has only scratched the surface of the topic of diversity. It seems likely that the diversity of other financial populations will also be important to

12. Two well-known indices for measuring diversity are the Simpson and Shannon indices. With some straightforward extensions, they would adapt well to measuring financial population diversity.

financial stability – populations of portfolios, strategies, business models, products and services. Some of the key traits of each of these populations will be relatively straightforward to characterize and measure - provided data is collected - while others will present more of a challenge.

Measuring fitness: Along with measuring and monitoring diversity, macro-prudential regulators should be concerned with the fitness of financial system populations.

Profitability is, of course, a key measure of fitness, but it is backward-looking, narrow and subject to numerous distortions. Other traits, like inventiveness and adaptability, are also important indicators of institutional fitness. So too of course in financial institutions is capital adequacy.

The problem is that process fitness depends on robustness, resilience, redundancy, reliability and other traits not necessarily correlated positively with profitability. The fitness of products and strategies depends on other traits too. And in all of these cases, fitness measures should reflect a view about the future, dependent on some assessment of how the market (or the organizational, social, technological or regulatory environment) is likely to change.

Measuring fitness of a population means calculating some statistics of the distribution of individual fitness – average, lower limit, upper limit and so on, unweighted or weighted by size or type. What is important from a macro-prudential viewpoint is that average fitness should be maintained. So the recent and current average, the trend and the volatility of average fitness measures are all important.

3. Evolution and instability

Evolution can lead to instability...

While it is an effective change algorithm, evolution can also lead to instability.

Resource constraints: When populations grow steadily for an unusually long time, resources are eventually exhausted. If they can't then adjust to zero growth or if resources are not renewable, they will either break into sub-populations that compete, or bump along - or just die out. The recent extinction of large publicly-owned investment banks could be viewed that way: they had reached the limits to growth and begun to compete in ways that undermined their own resilience and reliability – sacrificing capital, liquidity and controls for profits.

Co-evolution: The standard credit cycle can be told as a story of co-evolution.

... and increasing recklessness

It starts with diverse populations of lenders and investors. Lenders lend to investors who are in the business of acquiring assets. The main trait for both investors and lenders that varies across their populations is their aggressiveness, or their willingness to bear risk. At the outset, investor funding is sufficient for them to be able to bid up asset prices and kick off a period of asset appreciation. It becomes very profitable to borrow, and investors who are more aggressive accumulate more wealth and attract more funds to manage. Less aggressive investors underperform and lose funds so that they go out of business, or they become more aggressive themselves – either Darwinian or Lamarckian selection catches up with them and, on average, the population becomes more aggressive. Likewise, lenders on average become more aggressive over time as an asset bubble gathers force. Moreover, because lender aggression increases investor opportunities and borrower aggression facilitates lender profitability, a positive feedback loop develops between the two changes in population composition, fueling asset price rises and increasing recklessness.

During this process, asset valuations are increasingly justified by expectations of future asset appreciation - and less and less by prudent expectations of actual earning power. As a result, a point comes when the slightest wobble in expectations of future appreciation can start a fall in prices. Then some lenders lose confidence in borrower solvency and withdraw funding. The most aggressive borrowers sell assets but are unable to cover their debts and go out of business - so that the remaining population of investors is now more conservative than it was. The most aggressive lenders, who lent to the most aggressive investors, are particularly chastened or themselves go out of business so that, either way, the lender population becomes more conservative too. And, because asset prices were driven down by the first round of fire sales, the positive feedback loop will cull aggressive borrowers and investors again and again.[13]

13. John Geanakopolos has explored the leverage cycle using the idea of diversity. The Geneva Report by Brunnermeier, Crocket, Goodhart, Persaud and Shin provides a subtle and precise macro-analysis of the credit, leverage and maturity cycles.

Diversity as a force for stability

By telling this story in terms of shifts in population diversity, two important points emerge. First, the more diverse are asset price expectations, investment strategies and lending strategies at the outset, the less likely it is that a group of aggressive borrowers will come to command a disproportionate amount of funds – and thereby be able to start up a bubble. Second, if a trend in behavior and prices does begin to emerge, sufficient differences in lending and investment strategies may well mean that reactions to the accelerating trend are a bit more stop-go than they would be otherwise, weakening positive feedback loops. Diversity can be a stabilizing force against endogenous change as well as exogenous shocks.

This short term co-evolution in lender and borrower populations describes the typical cycle of credit excess, speculation and collapse. But in the last decade or so, the environment for the credit cycle changed. In particular, risk management techniques became more quantitative, leading many lenders to demand more collateral as volatility measures increased in the downturn, adding fuel to the collapse of liquidity and prices. Fair market accounting may also have made the downturn worse. Certainly, uncertainty about accounting principles and practices didn't help and, among other things, many bankers worried that fair market accounting might force them to write down assets below their long term value, eroding their capital and therefore forcing them to sell off assets just as the bust was intensifying. In this way, environmental changes intensified the positive feedback loop between the co-evolving investor and lender populations.

As a general matter, feedback loops matter a lot for systemic stability. Loops can be decomposed into reaction functions that characterize how different populations react to changes in their environment – how they bat the ball back over the net, so to speak. Negative feedback loops - that pat the ball back – are associated with dampened volatility and better chances of stability. Positive ones – that smash it back – can lead to surges and collapses in activity and populations. Left to its own devices, evolution generates both sorts of feedback in complex evolutionary systems.

Limited intelligence again: By its very nature, intelligence gives members of any population the power to anticipate things – and whenever a common belief takes hold, herd behavior is the result. In a panic, the common expectation is that something essential is going to be in short supply. Seeing this, some individuals rush to acquire it, which of course heightens the appearance of shortage for everyone else and, in a very rapid positive feedback loop, justifies them rushing too. What's difficult for policymakers is that, if the shortage is real, anticipation is both individually rational and collectively destabilizing: individuals do better who anticipate first, but they pour oil on the fire as they do so.

But, beyond that, the fact that intelligence is always limited can add significantly to the instability of any social system. It means that two other evolutionary strategies - extrapolation and imitation – can be attractive. Extrapolation and imitation can protect individuals, especially below-average performers. US house price expectations before the peak in 2007 were the product of unthinking extrapolation, among other things. Over the same period, imitation led to widespread involvement in derivatives and securitizations by financial institution managers who didn't really understand what they were doing. Senior managers who are out of their depth, especially at large financial institutions where they may face extraordinary complexity both within and without, are fertile ground in which imitation as a strategy can flourish.

Extrapolation and imitation tend to produce homogeneity in placid times and herd reactions that amplify cycle dynamics in times of stress. Positive feedback loops are shortened and strengthened. And anticipation leads to congestion and panic, whether it is a stampede for the exit or a run on deposits. Via these three common strategies of anticipation, imitation and extrapolation, limited intelligence is destabilizing.

Key role of complexity...

Network structures, contagion and complexity: Network structures influence financial stability. Between institutions, linkages of direct credit exposure, liquidity supply, trading and overlapping business models, strategies and portfolios all create potential pathways for contagion. Most obviously, when an institution fails, any firm whose credit exposure is large enough in relation to its capital is likely to fail too, potentially starting a cascade of failure across the financial system. In the last crisis, similar portfolio strategies were important for propagating contagion: that is, when a failing institution started to sell assets at distressed prices, others who held similar portfolios often chose to (or were obliged to) sell too, reducing their solvency as well. There is more to bilateral exposure than credit.

Financial networks have grown more complex – more connections of increasing strength - over the past decade as transactions among financial institutions have grown relative to the transactions between the financial system and the real economy. Increasing connections without increasing the strength of connections can increase systemic stability by providing more routes across the network, thereby generating greater network redundancy. But when it is accompanied by increasing strength, then a complexity 'tipping point' can be reached when the network suddenly goes from stable to unstable.[14] This is true not only about networks of institutions but also about the population of products and processes. When derivatives markets approach completeness – that is, as derivatives products approach a state of interconnectedness where every financial risk can be priced and traded - they can also become unstable.[15, 16]

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14. Andrew Haldane has argued cogently that the financial system can usefully be viewed as an adaptive network that, over the last decade, has become increasingly complex and, at the same time, more homogeneous.

15. See Andrew Haldane's and Robert May's article, "Systemic Risk in Banking Systems" which draws on earlier work by Lord May on how, at a certain point, increasing strength and number of links between species destabilizes an ecology.

16. Caccioli, Marsili and Vivo have shown how pricing strategies for derivatives based on arbitrage pricing theory can destabilize markets as those markets approach completeness.

In addition, complexity obscures the past and the present and makes the future harder to predict. Particularly where evolution is accelerating and new complexities are emerging, it gets easier and easier to make mistakes. In many ways, the breakdown in the securitization process was due to the fact that it was rapidly evolving – becoming more complex, etiolated and very opaque. Few market practitioners and fewer regulators understood it from stem to stern soon enough to do anything about it.[17]

Stability is affected by network structure as well as complexity. For example, institutions that become super-nodes connected to large numbers of other institutions may create a good deal of efficiency for the network (and profits for themselves) in normal times by virtue of their network position. But super-nodes can become super-spreaders in times of stress if their network neighbors are overexposed.[18] Their failure is liable to start contagion; and, if they are themselves weak, they are far more likely than average to transmit it.

Problem of "super-nodes"

Moreover, as we noted in reference to central counterparties, oligopolistic or monopolistic super-nodes can slow or even stop evolution. We also noted that evolution is a peculiarly effective method for population adaptation. So, quite apart from acting as a super-spreader, super-nodes can threaten medium-term stability by inhibiting evolution.

Concentration: With or without much direct connectivity, economies of scale or scope, market power and the robustness borne of business and asset diversification can give an evolutionary edge to large institutions. Then high levels of industry concentration can result from and reduce the pressure for Lamarckian evolution. As time passes, if an institution maintains its domination and resists change through political and other anti-competitive means, its demise, though postponed, is more likely to be more disruptive. Fear of this disruption allows institutions to become "Too-Big-To-Fail".[19]

Some strategies available for adaptation in other concentrated industries are not available in finance. The reason is that there is an almost universal global regulatory

17. The importance for policy of the paper by Adam B. Ashcraft and Til Schuermann, "Understanding the Securitization of Subprime Mortgage Credit", was not recognized in time.

18. Sujit Kapadia drew a telling analogy about rumors at the 2011 Wharton Risk Roundtable. Consider how a rumor can spread across a network of friends. Suppose there is a 5% chance any person in the network who hears a rumor will pass it on to a friend. If the number of links between friends is gradually increasing over time, at 18 or 19 links, the rumor is very likely to die out. But by the time the number of links rises to 21, the rumor will be very likely to go viral. There is a tipping point is at around 20 links per friend.

A more academic treatment is in Gai, Kapadia and Haldane.

19. Simon Johnson's analysis goes back to the US Republic's founding fathers and emphasizes the pernicious effects of the concentration of economic and political power. He argues that President Jefferson, and later President Jackson, had a point. Even when large banks do not act collusively and when central banks relentlessly pursue the common good, the concentration of power in large banks is corrupting. Managing crises by selling failing banks to other banks has been counterproductive. Protecting the biggest banks from failure in any crisis may be an understandable disaster management practice but it fosters extraordinary moral hazard in the long run. These institutions influence the policymaking process directly through lobbying and indirectly through their substantial influence on how policymakers think about risk and finance. Johnson's analysis leads to the conclusion that today's systemically important institutions need to be broken up; anything else would be unconvincing and ineffective.

imperative to isolate finance from other sectors of the economy. Indeed, in the US, the Volcker rule further isolates subsectors of the financial system from one another. The Lamarckian survival option of totally redirecting a large firm's strategy (that, for example, Nokia and IBM exercised at different times in their histories) is unavailable to many financial institutions.[20]

Concentration undermines evolution. When population numbers diminish enough, competition becomes a game-theoretic problem and evolution stops. Survival of the population becomes indistinguishable from the survival of individuals.

Evolutionary systems are fragile

Self-criticality: Evolutionary systems have a tendency to be self-critical. They tend to evolve toward states in which they teeter on the edge of collapse. Evolution spurs competition and drives individuals toward the edge of their abilities, exhausting their reserves. General fitness can be eroded and across any network of interdependency, pools and filaments of fragility of uncertain size and length develop, generating periodic avalanches of failure from the slightest perturbation - avalanches that sometimes are large enough to threaten the entire population.

This tendency exists across the real economy, but it is muted to some extent by the looseness of logistical networks and the ever-changing diversity of the manufacturing and non-financial services sector. But the financial network provides multiple pathways for contagion that are tight, and the system naturally tends toward complexity. Moreover, finance deals in something that is inherently volatile – beliefs about contingent obligations and promises – in which the implicit faith in the future of the system must be held by a large majority of agents for it to continue to function. The financial system is inherently self-critical.[21]

Multiple causes: In complex systems and networks, collapse often has multiple contributory causes. Think back to the one way in which complexity adds to stability – by creating many routes between distant nodes. For one node to be cut off from another, many nodes and links have to fail simultaneously. For network connections to fail, a general decline in fitness of nodes and reliability of links is required – the sort of general decline that self-criticality can bring about through the relentless short-term pressures in economic networks to lower costs, increase speed, neglect maintenance and circumvent controls.

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20. Both Nokia and IBM went through transformations that took them from one industry to another at times when, had they not done so, they probably would have failed. Nokia began life as a lumber company in the 1860s, morphed into an industrial conglomerate for most of the 20th century and then specialized in mobile phones in the 1990s to great success – at least until now. Also in the 1990s, IBM was close to failing when its new CEO, Louis Gerstner, took it from being a hardware producer into software and systems integration.

21. This contrasts with cars. The car industry has been disrupted in the past four years by GM and Chrysler's near-failures and by an earthquake and a tsunami. Through it all, GM, Chrysler and Toyota cars were still on the road in many countries around the world - and they still continued to work. If the financial industry is systemically disrupted, household and business financial accounts cease to be useable. Drivers don't have to believe in Toyota to continue to use Toyota cars. They do have to believe in banks, brokers, insurance companies, asset managers and so on en masse for their financial accounts to continue to function.

One of the hallmarks of the 2008 crisis is how many things went wrong together – from accounting practices to credit rating practices, from derivatives to commercial paper to repos, from investment banks to commercial banks and mortgage brokers, from retail housing finance to wholesale financial markets, from risk management processes to securitization processes.

In the history of financial crises there are some common themes – leverage and bubbles go together and misguided public policy is often somewhere nearby. But in major crises, that is only a small part of the story. The pronounced tendency of the financial system towards self-criticality explains why, in contrast to more typical credit and leverage cycles, serious crises can have multiple causes.

BOX 2: EVOLUTION AND NEOCLASSICAL ECONOMICS

From time to time, evolution slows down. Sometimes for quite long periods, the environment is relatively stable and co-evolution between populations is dominated by interactions that have moderate negative feedbacks loops associated with them so that population dynamics tend to take the form of temporary and diminishing oscillations. Networks and other structures settle into patterns that inhibit contagion rather than promoting it, so that small local changes cannot go viral. The system can look stable for a protracted period.

At the beginning of such a period, an evolving market-based economic system might very well begin to look neoclassical, provided that populations are large enough and standardization dominates diversity. Neoclassical theory will then provide a good description of how the economy works until some external shock or a large local change kick-starts a more dynamic period. In this sense, neoclassical theory is a special case of evolutionary theory.

While some neoclassical ideas - like individual omniscience, population homogeneity and general optimization - do not generalize well outside periods of arrested evolution, many other central ideas of neoclassical economics are central to evolutionary theory. They include competition, limited resources, individual (albeit limited) intelligence and the pursuit of equilibrating marginal rates - as an example of a behavioral rule rather than a behavior that leads to actual equilibria. Concepts like price determination, public goods, externalities and welfare migrate effectively over to the more general theory too – provided we are talking about a hybrid theory of Lamarckian and Darwinian evolution, as we are.

Perhaps unsurprisingly, much of behavioral economics would fit very comfortably inside broader evolutionary theory. Game theory also fits into an evolutionary account, though not exactly as a special case. When populations shrink to the point where there are only a handful of members or when population diversity resolves itself into a handful of specific types, game theory kicks in and evolutionary theory ceases to apply. Local change becomes global change and there is, so to speak, no room for evolution to work until the population grows again or specific types break down and multiply.

4. Implications for policy

What are the main lessons for macro-prudential regulation?

Laissez-faire will not work

First of all, the evolutionary nature of the financial system gives us a strong reason to believe that laissez-faire policies will not work. Of course, not many people think they would, because of moral hazard and many other sources of market failure. But some libertarians and conservatives do argue that ridding the system of most forms of government oversight and interference would improve things.

The fact that the financial system is, in the strict sense, an evolutionary system is a strong reason to believe this is not true – even at the theoretical level. Evolution tends to push populations toward a self-critical state, where resources are stretched thin, sub-populations over-specialize and networks become complex and unstable. The tight linkages, complexity and opacity of the financial system, combined with the fact that it trades in promises that are vulnerable to doubt, means that, unattended, it is much more prone to self-criticality than the rest of the economy. This is not fundamentally about deposit insurance or moral hazard; it is just the way that completely unfettered financial system evolution would work.

Regulatory policy should allow the financial system as much room as possible to evolve. Because change is local in evolving populations, some part is likely to be able to adapt responsively to the next round of social, institutional and technical change and its adaptation is likely to spread across the population and take hold generally. Macro-prudential policy should 'nudge' financial sector populations away from possible areas of heightened systemic instability but, otherwise, it should give evolution free rein.

Monitoring the system: How do we characterize such areas of instability?

...checking response functions

These are states of financial populations where average fitness is low, diversity is low, and/or there is a high danger of contagion. We have discussed how fitness and diversity of different populations can be measured and monitored. Contagion risk can also be monitored because it arises from specific network configurations – from concentration, super-nodes and complexity – which are observable and measurable. Contagion risk also rises with the emergence of positive feedback loops between sub-populations, so that the modeling, analysis and monitoring of response functions – how different populations respond to changes in their environments - should be high on the list of tasks for monitoring systemic stability.

The key lesson for macro-prudential policy is to cast the net of measurement and monitoring wide: to identify, measure and monitor networks, institutions, processes, strategies, business models, products and services, and their various attributes – especially their diversity and fitness. If there is a place to concentrate attention, it is wherever growth, diversity or fitness seems to be accelerating or decelerating particularly quickly.

The dangers to the system caused by large complex interconnected institutions can be considerable – even if current policies aimed at doing away with Too-Big-To-Fail are implemented effectively. Their internal and external complexity makes many of them difficult to manage and potentially unstable. Their interconnectedness means they are potential super-spreaders for contagion. Their size makes them politically powerful.

Free entry/exit...

These institutions are well placed to arrest any kind of evolution that they find difficult to accommodate. Free entry into and exit from different financial sub-populations is critical for the long term health of the financial system. Regulators should insist that systemically important financial institutions (SIFIs) have credible, transparent and effective resolution plans, and that the exposures they create for other institutions are always small in relation to those institutions' capital. Regulators should be alert to the potentially stultifying effects of SIFIs on evolution.

... resolution plans

How can we expect regulators to foresee heightened risks that the private sector does not? The answer lies in one of the general aspects of evolution that we have discussed. Notwithstanding the power of evolutionary pressures to encourage intelligent agents to think ahead and to cooperate, there is no incentive for individual population members to think about systemic stability or the long term. Evolving populations tend to be myopic, concentrating on first round effects and not wasting much effort on what happens after that. Despite the interest of some larger firms today in managing systemic risks better, there is a danger that their attention will wane because either they become too busy "dancing while the music plays" or because their oligopolistic and political power will freeze evolution anyway.[22] Macro-prudential regulators do not have to be clairvoyant to add value; they simply have to focus on systemic and long term issues that may not command the sustained attention of the private sector.

Focus on the systemic...

Encouraging fitness and diversity: As a rule, fitness in institutions doesn't require too much encouragement. Institutions have strong incentives to adopt effective business models and to execute them judiciously, trading off capital, risk, return and investment in risk management.

The exceptions are where risks get mispriced or where there are major externalities – eg during the business cycle, with deposit insurance, and in systemically important financial institutions. In these instances, firms are likely to make choices that sacrifice gains in social fitness for gains in private fitness whenever the two conflict. Encouragement for banks and nonbank SIFIs to hold more capital than they would otherwise can improve alignment between the public and the private viewpoints on fitness.

22. "As long as the music is playing, you've got to get up and dance." Citigroup CEO Chuck Prince, in a comment to the Financial Times, July 10th 2007.

Where fitness may not be addressed at all by private interests is in processes that evolve quickly and cross institutional lines. Processes of this kind have no natural owner. If they become complex or opaque or if they develop information asymmetries, or if they harbor positive feedback loops that push practices toward extremes, they can become sources of systemic instability – as we know all too well from recent experience. So macro-prudential regulators need to encourage cross-institution process fitness.

Left unencumbered in a changing environment, evolution can create a good deal of diversity without much positive encouragement. Institutions (and processes, business strategies and so on) must be able to fail non-disruptively – hence the importance of planning for and provision for orderly resolution - and restrictive practices must be held in check so that new institutional structures, processes etc., can get a foothold. If diversity does begin to diminish, then there is a case for regulators to seek out ways to encourage innovation and new entry.

Micro-prudential policies must not be overly prescriptive or restrictive. Guidance and incentives aimed at encouraging fitness are preferable to rules and regulations that force uniform practices. Rules and regulations tend to inhibit diversity. When they are imposed for whatever reason, macro-prudential regulators should be alert to their potential cost.

Perhaps somewhat surprisingly, it follows that minimum standards come with a macro-prudential cost too. Minimum standards have a tendency to become maximum standards, stamping out diversity and meaning that when one population member gets into trouble, there is a better chance that many will. From a macro-prudential viewpoint, better to monitor the traits that comprise average fitness – such as the average capital in a population of institutions – and if it seems that the average is falling to the point where it represents a threat to systemic stability, let the weakest institutions fail – which will help the average. If that is not enough, then evolutionary theory would suggest policymakers put in place incentives to encourage average fitness traits to rise. In the case of capital, equilibrating effective tax rates of debt and equity issued by financial institutions would be a good place to start.[23] Macro-prudential considerations would then suggest that, if average capital still seemed to be heading downward to uncomfortable levels, raising the tax rate on debt and/or lowering it on equity for financial institutions would be the next logical step. Counter-cyclical capital policies become counter-cyclical tax policies and SIFI capital premia become SIFI tax premia. Keeping capital standards as a powerful and flexible tool of regulation doesn't logically have to depend on defining and enforcing minimum capital standards.

23. Politically, this may seem easy to dismiss as a non-starter. However, in the United States, in the wake of the housing finance debacle and in the heat of the deficit debate, we have begun to talk about reducing the mortgage interest rate deduction – something that was an impossible subject to raise even a year or two ago. Perhaps the time is coming for a more thoughtful general reconsideration of the tax code.

The other peculiar implication of nurturing evolution is that standardization can be a mixed blessing. Standardization that raises fitness and enhances local change, copying and selection is good, whereas standardization that adds to instability or inhibits population adaptation is bad. So, for example, standardization that increases transparency is going to be a positive force for many reasons. It may allow markets to discriminate better between superficially similar institutions, reducing the risk of contagion when one of them gets into trouble. However, as we have already noted, central counterparties that may seem like an elegant way to offset contagion risk, come at the cost of inhibiting evolution of clearance and settlement arrangements. Equally, the standardization of financial entity and instrument language should create a language like English that can still evolve over time, easily accommodating new concepts and networks of meaning. Heaven forbid that the day might come when an innovation was prohibited because the "words" did not exist to describe it. Standardization proposals should always be viewed skeptically – and, when they do actually make sense, they have to be subject to open, transparent and flexible governance.

The challenge for macro-prudential regulation: The goal remains, of course, to reduce the severity and frequency of future crises.

In a world of evolving social, technological and political conditions, the financial system must evolve too. So the challenge for macro-prudential regulation is to encourage steady, rather than fitful, financial system evolution in response. Regular earthquakes that register a 1 or a 2 on the Richter scale are far preferable to one or two that register 8 or 9. And once the nature of larger quakes is understood, some investment in strengthening structures to withstand them is likely to be worthwhile. We are just at the beginning of understanding the nature of the problem of financial system stability. With a bit of luck, evolutionary theory can help regulators work toward wise and effective policy.

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Charles Taylor has recently been appointed Deputy Comptroller for Regulatory Policy at the Office of the Comptroller of the Currency (OCC) in Washington. Prior to that, he was Director of the Financial Reform Project at the Pew Charitable Trusts, also in Washington.

Charles, who is married with three children (his wife, Mary-Ellen, is one of the leading experts on housing finance in the US), has been an American citizen for many years. However, he grew up primarily in the UK, and read mathematics at King's College, Cambridge before completing an MPhil in economics at St Antony's College, Oxford. He also has an MBA from the Wharton School. He spent five years at the World Bank, mainly as an economist in the South Asia department, before moving into the private sector. He has held senior positions at Anderson Consulting (Accenture), the DTCC and the Risk Management Association. He also spent several years as executive director of the Group of 30, when the Group did its ground-breaking work on derivatives regulation. He is the author of two previous CSFI papers. He is not related to the Liberian dictator or the Washington Redskins hall-of-famer, both of whom share his name.

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