5 S&T Challenges in the 21st Century: Strategy and Tempo

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All worldviews are built on a set of assumptions that are deeply embedded in people and organizations, rarely questioned, and difficult to "unlearn." Talk to a member of the Flat Earth Society if you want a demonstration of the power of hidden assumptions. In most organizations, we find a disconnect between reality and "wishful thinking" or, put another way, between what people say and what they do. As some organizational researchers have pointed out, people often hold two, quite contradictory, theories of action: one they espouse and one they actually use.[1] People who do the planning in government also live in an organizational milieu and are subject to the same set of constraints, logic traps, and conflicts that can give rise to inconsistent and anachronistic worldviews. If we examine the planning and budgeting techniques that have been institutionalized throughout most of the government, we find that they can work relatively well under the following conditions:

- Change is relatively predictable, i.e., linear with respect to cause and effect.

- The system is bounded and fits neatly into disciplines and departments.

- Unintended consequences are minimal (or can be controlled or effectively ignored).

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- Feedback is low or negative, so you have dampening effects and things do not spin out of control.

- The rate of change in the environment is not going to exceed the rate of change in the organization.

This world is almost unrecognizable to scientists, engineers, and bleeding heart techies but in the public sector, these assumptions remain largely unarticulated and unchallenged. Their implications for public policy are profound, especially for science and technology policy. What if our policymakers are increasingly confronting a world that does not obey this set of rules?

Time Matters

At closer examination, many of the phenomena that policymakers face no longer change in simple, predictable ways. Maybe they never did, but the world in the past was less complex, less interconnected, and more forgiving of mistakes and miscalculations. We now live in a world characterized by what the Organisation for Economic Co-operation and Development OECD has termed *emerging systemic risks* that arise through the interactions between complex social, technological, environmental, and economic systems.[2] We can differentiate at least four other types of emerging threats and challenges that operate at very different temporal rates in this new world and are of interest to government: slow threats, exponential change, step change, and tipping points (See Figure 1). These change scenarios are not mutually exclusive and we often find ourselves challenged by complex phenomena operating under multiple scenarios or find that one scenario transitions into another over time. For instance, many slow threats can also exhibit threshold effects and tipping points over time. Let us examine these in more detail.

Figure 1
Emerging Threats at Different Temporal Rates

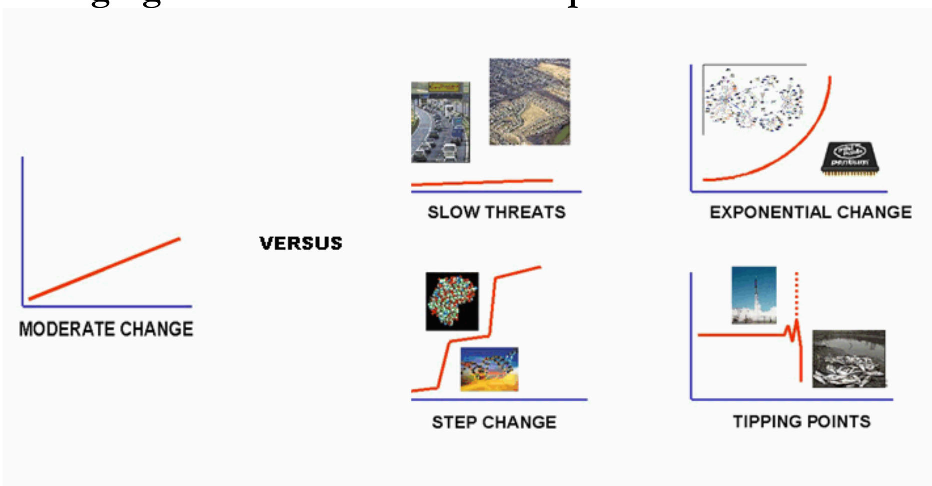
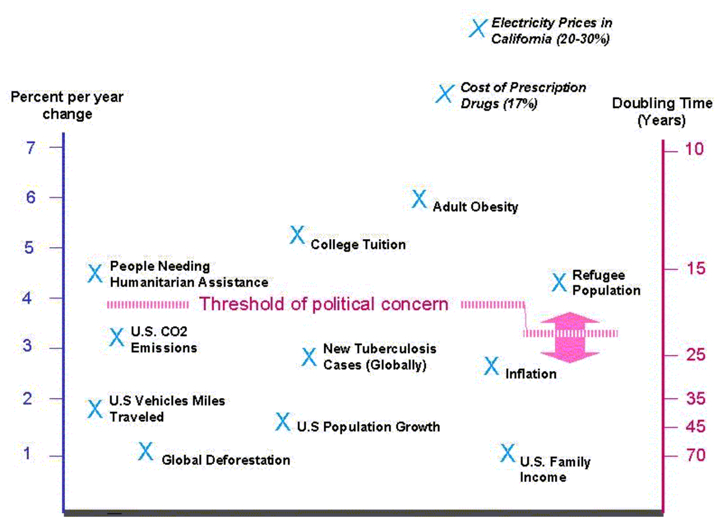


Figure 2
Slow Threats



Too Slow to Notice

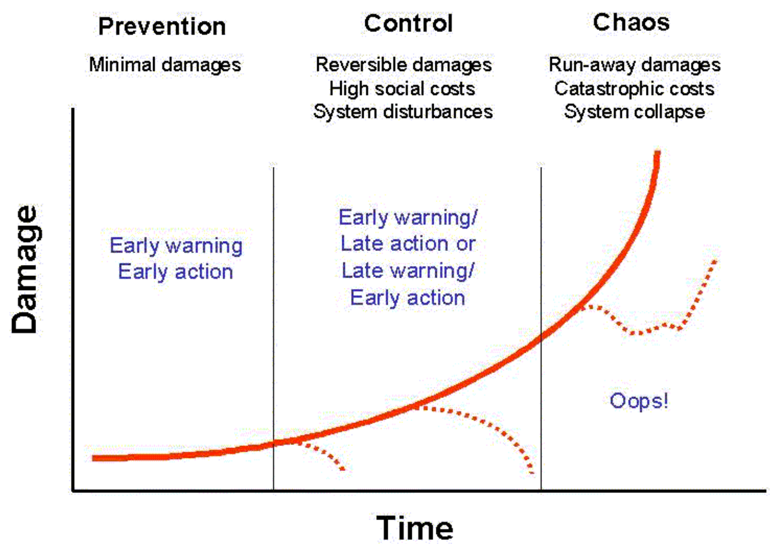
The first is the world of slow threats where change can take decades, hundreds of years, tens of thousands of years, even millions of years. This is the world that geologists, hydrologists, and social scientists are quite familiar with but one that does not correspond to the world where governments make budgets and do year-to-year planning. How fast do things have to change before someone takes notice and begins to mobilize the public or the politicians? Figure 2 shows some common rates of change for a variety of issues.

In 2001, electricity prices in California were rising at rate of 20-30 percent, which certainly focused people, policymakers, and the media on the problem. Prescription drug prices went up about 17 percent in 2001 and that increase grabbed the public's attention. The increase in adult obesity recently made the news. But there seems to be some threshold of concern (estimated here at approximately four percent per year) where important social, economic, technological, or demographic phenomena can change and remain under the political and public radar screen. In some cases, the public has become socially conditioned to pay attention to small change—in areas such as unemployment, inflation, and GDP—but in most areas small increases fail to catch our attention. Such changes, if they remain persistent, can degrade systems, stress the government's capacity to respond, and trigger threshold effects where change becomes difficult to reverse or systems fail catastrophically. Many slow changing problems never go away, though they may move geographically and affect another set of social and institutional actors (infectious diseases are one example). What is often not appreciated is that these slow changes can rapidly compound, at least in timeframes that are worrisome to many scientists. In fact, one of the least understood concepts in public policy is the rule of doubling, though the math underlying the concept is relatively simple.[3] The doubling time of a variable growing at a constant yearly rate is approximately equal to the number 70, divided by the annual percentage increase (this is sometimes called the Rule of 70). For example, U.S. carbon emissions are presently increasing at slightly over three percent per year. Not much to worry about it would seem, yet at this rate emissions will double in less than 25 years, a radical jump in climatological and geophysical time scales, though not political ones. In a government where political appointees remain on average for two years, such changes are psychologically imperceptible and often appear politically irrelevant.

Too Fast to Catch

Another temporal scenario, one of exponential change, has become familiar to us in the Information Age, starting with an obscure 1965 article entitled "Cramming More Components Onto Integrated Circuits" written by a young researcher at Fairchild Semiconductor named Gordon Moore. Moore's Law, which postulates that the performance of integrated circuits doubles every 18 to 24 months, has defined the exponential wave driving the Information Revolution. Moore's Law effects can also be found for displays, for storage (1.5 times Moore's Law), for bandwidth (two times Moore's Law), and for graphical processing units (now three to four times Moore's Law). If the law remains in effect for the next ten to twelve years, we will have 37 doublings in computational performance since 1965, a rate of change that has no precedent technologically. We can add to Moore's Law the law of network effects developed by Bob Metcalf, the inventor of the Ethernet. This states that the value of a network—be it a network of computers, telephones, or even cars—increases as the square of the number of nodes. And finally, there is Monsanto's Law, that the amount of useful genetic information is doubling every 18 to 24 months.[4] An economic infrastructure operating under such laws can exhibit very different behaviors than those commonly assumed in policymaking. Such differences may occur in the nature of economies of scale, rates of return (positive, rather than negative), rewards for first movers, and lock-in effects for technologies.[5] In addition, these laws interact and give rise to very rapidly change at the convergence points of various disciplines and sectors. One example would be DNA arrays that sit at the intersection of the biological and computational worlds. From a governance standpoint, as our world speeds up, a much higher premium is put on our ability to provide early warning and couple that with early and focused action. A failure in one or both of these areas—early warning and early action—can lead to significant and often irreversible social and economic consequences (see Figure 3).

Figure 3
Potential Damage-over-Time



Discontinuities

The third way things can change is step wise, where large gains in efficiency, knowledge, etc. occur in short time periods resulting in a rapid flood in new capabilities. Steps often occur when major discoveries or innovations occur that change the rules of the game for decision makers or create new possibilities or threats that have not existed before. These may be associated with discovery—we can think of the seminal articles by Otto Hahn and Fritz Strassmann in 1939, which ushered in the atomic age or Edwin Hubble's theory on the expanding universe. Another driver underlying step change is extremely rapid advance. This occurred recently when a combination of new robotic and computational capabilities effectively increased the sequencing rate of the genome by a factor of ten within a very short time period and led to the completion of the genome project almost four years ahead of schedule.

Thresholds

Finally, there is the world of tipping-points. This is a potentially very dangerous world in which very complicated systems—social, ecological, technological, and/or economic—reach a certain threshold and tip, often irreversibly and with significant consequences. As these tipping points are approached, systems can become very unstable and their behavior difficult to predict or control. Virtually all government agencies deal with threshold phenomena, ranging from ecosystem management, to traffic congestion, disease outbreaks, or state failure, yet our ability to detect approaching thresholds using the appropriate indicators is not very well developed. In some cases, changing the threshold of recognition of an impending tipping point by minutes or hours could radically reduce adverse impacts.

So the world where science operates is a world of complex tempos and complex systems, coupled in multiple ways, and often punctuated by surprises. But what does that mean for a government that must manage science and technology–in terms of its organizational structure, its work force, its conceptual models, and its analytical techniques?

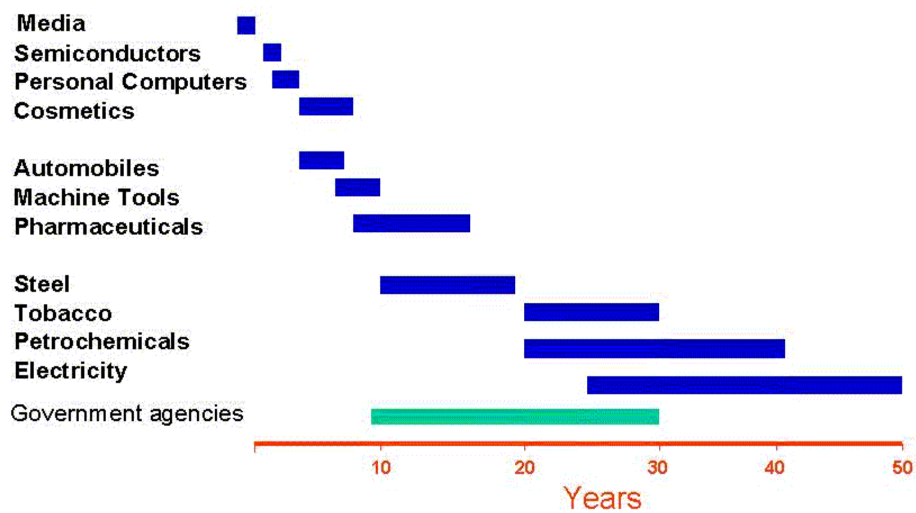
Tempo and Strategy

"We are moving from a world in which the big eat the small to a world in which the fast eat the slow."

-Karl Schwab, Head, World Economic Forum

Let us consider for a moment the implications of increasing the speed of knowledge generation and innovation and what this might mean for the public sector. Charles Fine at the Massachusetts Institute of Technology developed a concept know as *organizational clockspeed*, which refers to the rate at which organizations can change processes and products, reinvent mind-sets, and modify organizational structures in response to external threats or opportunities.[6] Figure 4 shows approximate clockspeeds for various sectors of the economy with the government added.

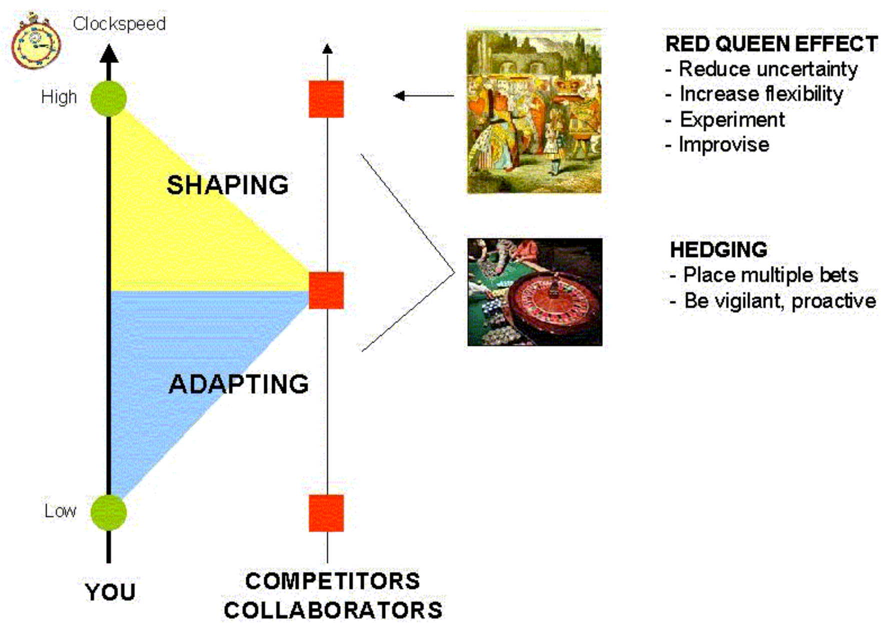
Figure 4
Organizational Clockspeeds



Thirty years ago there was greater clockspeed parity between the public sector and the sectors of the economy the government was interacting with around policy issues. Today, that parity has disappeared and many sectors are moving much faster than government, making it far more difficult to anticipate policy issues, build public-private partnerships, or avoid unintended social and ethical consequences of private sector actions.

This difference in clockspeed fundamentally affects the types of strategies government can use in relationship to various competitors, collaborators, or enemies. Falling behind the people you are trying to influence limits your strategic options. Simply put, the faster runners are in a better position to shape your world and you end up having to adapt. Recently, McKinsey & Company did a study of some of the most successful companies over the past 15 years.[7] About 80 percent of them are successful because they are capable of using shaping strategies. They were moving much faster than their competitors and they had the capacity to shape the world that their competitors live in (see Figure 5).

Figure 5
Shaping and Adapting



As the external environment speeds up, an organization can cover some of the potential outcomes through the use of *hedging* strategies. In this case, one does not seek an optimal strategy, but one that remains robust over a wide range of outcomes that you cannot predict. For instance, if you are building a new computer application you can hedge against three operating systems—Macintosh, Windows, and Linux. This is a knowable world.

The problem is when the rate of change accelerates even further. You then reach a point that University of Chicago paleontologist Lee van Valen described as the "Red Queen Effect," after the character in Lewis Carroll's *Through the Looking Glass* who remarked to Alice that she had to keep running faster and faster just to stay in the same place. Moving at ever-higher tempos, organizations or organisms reach a point of "persistent coevolution" where no one has comparative advantage very long.[8] This state of affairs is likely to characterize our war on terrorism into the perceivable future as well as the persistent dance between software and hardware developers.

The organizational strategies for this world are very different and require increasing flexibility, reducing uncertainty, rapid experimentation, and the ability to improvise. Because we have little experience in operating organizations at this pace, we need to approach the problem metaphorically. Organizations will need to operate more like white water canoeists or an improvisational jazz combo than mechanistic entities following prescribed rulesets.

One example of a high-clockspeed organizational model is In-Q-Tel, developed by the Central Intelligence Agency (CIA) to allow them to accelerate the development of information technologies by tapping into private sector capabilities and fast turn-around times. Operating like a venture capital firm (with an annual budget of $30 million and former private sector director), In-Q-Tel reviewed over 900 business plans and funded 23 companies in its first two and a half years.[9] The CIA has first dibs on products developed, which are showcased at a CIA-Internal Interface Center.

The other implication of living in a world of fast paced innovation and relentless change is that unintended consequences, spill-over and revenge effects may occur at a faster rate and be harder to anticipate or respond to.[10] In such a situation, more foresight in government is needed, not less. Yet we have systematically done away with institutional mechanisms that provided these functions, such as the Office of Technology Assessment and Congressional Clearinghouse on the Future.[11] In some instances, the federal government has created special programs to examine the ethical, social, and legal implications (ELSI) of scientific advance. The most visible is the ELSI program of the Human Genome Project. However, there are vast areas of the scientific enterprise that lack this systemic study of emerging public policy challenges, such as cognitive neuroscience. What we lack in terms of evaluating these long-term societal and policy implications is what Yale computer scientist David Gelernter referred to as *topsight*—the ability to see the entire system.[12] This capacity is more important today than in the past because many important advances may occur at the interstitial spaces between disciplines (for instance, between biology, informatics and nanotechnology). A focus that remains project, discipline, or organization specific will not provide society with an adequate early warning of impending social or policy impacts.

So the world of science demands from the public sector a new set of characteristics in the 21st century: more foresight, more topsight, and a greater sensitivity to change—its consequences (intended and unintended) and its implications for strategy. Speaking at the Woodrow Wilson Center in November, 2001, Dr. Rita Colwell, director of the National Science Foundation remarked that, "We need to develop a broader, more anticipatory perspective in our research. We need to increase our emphasis on envisioning future possibilities, good or ill, as a mechanism to predict." The sentiment is well taken. How the government responds to the challenge however, remains a question.

Endnotes

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3. Michael W. Klein. "Doubling Times and the Rule of 70." Mathematical Methods for Economics. Available at: http://www.aw.com/klein/mathecon/apps/ruleof70.htm.
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5. Brian Arthur. *Increasing Returns and Path Dependence in the Economy*, Ann Arbor, University of Michigan Press, 1994. Carl Shapiro & Hal Varian. *Information Rules: A Strategic Guide to the Network Economy*, Cambridge, MA, Harvard Business School Press, 1998.
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