**GOVERNANCE CHALLENGES OF 21ST CENTURY TECHNOLOGIES**

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**(Draft version)**

My professors taught me what they knew how to do. In the decade before I was born, the U.S. Congress enacted social security; the Social Security Administration mailed out the first monthly payment in 1940. My professors knew how to organize large social welfare programs. In the decade of my birth, the United States successfully concluded a massive war of logistics and attrition. My major professor (Paul P. Van Riper) served in the Army Quartermaster Corps, working as a logistics officer to supply Paris with goods needed after its post D-Day liberation. The Tennessee Valley Authority celebrated its twenty-fifth anniversary when I started my high school senior year; the Grand Coulee Dam has been powering the Pacific Northwest for nearly thirty years when I earned my PhD.

My professors knew how to do these things. For social welfare, they exposed me to Max Weber’s essay on bureaucracy, written in 1911 and translated into English in 1946. For industrial models of management, we had the administrative principles promulgated by Henri Fayol, Frederick Taylor, Luther Gulick, Lyndall Urwick, and James Mooney. Elton Mayo’s principles of human relations appeared in 1933. Philip Selznick had published his pioneering work on the politics of community relations *TVA and the Grass Roots* in 1949 and I knew a little bit about managing rural electrification and water resource projects in the American West.

We knew how to do these things. Management analysis essentially took the form of an aircraft crash investigation that blamed pilot error. Administrative accidents occurred because operators failed to follow known principles appropriately designed.

Unfortunately, when I arrived in Washington, D.C., in the mid-1960s, I was asked to work on activities for which I was wholly unprepared. My professors had taught me what they knew, not what I needed to know.

Instead of wars of logistics and attrition, we were asked to fight wars of counterinsurgency in Vietnam and a war on poverty at home. I understood the meaning of rural development, but I had no idea what the institutional basis of the anti-poverty crusade (community action) meant. I took a temporary appointment at the U.S. Bureau of the Budget. Nobody outside of the Defense Department knew how to do program budgeting, which the president instructed all federal departments to institute in 1965. I received an assignment to study the NASA space program. What little we knew about building dams and similar large projects proved totally inadequate for the demands of going to the Moon. A few Air Force officers understood large-scale systems management (NASA hired them), but I could not describe it. Subsequently, I turned my attention to natural resource management. What I knew about co-optation in the TVA wholly failed to explain the sagebrush rebellion. When I recovered from that inadequacy, someone dropped electronic government on my plate.

Much of the knowledge needed to address these challenges existed when I went to school. I just was not exposed to it. For the most part, it was new and I had to learn it on my own.

Today these matters are routinely taught in public policy schools. Citizen participation, street-level bureaucracy and stakeholder relations complement what we know about unity of command and span of control. Warren Bennis’ theory of adhocracy (the basis of project management) is taught alongside Weber’s theory of bureaucracy. Program budgeting may not have taken hold in all federal agencies, but today’s finance and budgeting professors know what it is. Privatization and lessons about the new public management have grown old. I even know what electronic government means. A new body of knowledge has taken its place alongside the relevant remains of earlier lessons.

Once again, however, the lessons we have come to know are in danger of proving inadequate for a new generation of students. The techniques we know may not be of much use for the challenges they face. Asymmetric conflicts are replacing wars of insurgency. Global concerns like climate change, immigration and trade are undercutting the relevance of the nation state and its principal methods of organization (notably the bureau). If futurists are correct, we may see machines capable of human thought (artificial intelligence) by the mid-point of the twenty-first century. They may be the last machines that humans invent. All future machines would be designed by other machines.

We do not have a great deal of time to devise appropriate methods of governance for these challenges. In a tribute to Moore’s law, the pace of change increases exponentially – along with the creation of new products and wealth.

Each age, I believe, develops its own characteristic forms of governance, largely in response to technology. The age of industrialization produced the factory and the social welfare state, along with principles of administration and the bureau. The post-industrial era (also known as the information age) produced privatization, electronic government and new forms of project management. The twenty-first century will produce equally distinctive forms. There is no reason to think otherwise.

This essay identifies the technologies reshaping human existence in the 21st century, the characteristics associated with them, and the governance challenges they pose. Alongside knowledge from the past, these are the lessons that a new generation of students will need to know to further their careers.

Twenty-first century technologies

Commentators generally agree that the 21st century will be reshaped by advances in GRN technologies. The acronym stands for genetics, robotics and nanotechnology. I prefer to substitute GRIN for GRN. The “I” stands for the information science leading to artificial intelligence.

Genetics, in the words of Ray Kurzweil, is “the intersection of information and biology.” (Kurzweil, 2005, 206) Humans are learning how to manipulate nature by understanding its information code. The technology has profound implications for life spans, retirement age, health expenditures and demographics, matters that currently consume a huge portion of federal expenditures.

Robotic science is creating a new servant class of machines. The word “roboti” means artificial person; the word servant means slave. The outcome of efforts to suppress servants and slaves is an old story. It usually does not turn out well.

Artificial intelligence consists of the human effort to create machines that are smarter than the people who invent them, with all the attendant risks that implies. It is especially worrisome when combined with advances in robotic mechanisms (androids) shaped like artificial people.

Nanotechnology is the science of learning how to do what nature does without much outside help – build things from the atomic and molecular level up instead of the machine level down. The science has the potential to create entities the size of mosquitoes (sometimes called nanobots) that can do the work of older machines the size of a tank.

Just as the steam engine encouraged the industrial age and the computer shaped the information age, GRIN technologies will produce their own social arrangements. The governance issues arising from those arrangements will be as distinctive as the jet engine is from the steam-driven locomotive. Understanding the distinctive features of these new technologies helps to illuminate the governance issues they contain.

Distinctive features of 21st century technologies

Governance methods that incorporate the characteristics of twenty-first century technologies will be far more robust than governance methods that do not. Just as information age technologies could not be effectively managed with machine age methods, so the new age technologies will require their own distinctive forms of governance. The principle characteristics of GRIN technologies follow.

 **Twenty-first century technologies are disruptive.**  When American engineers designed the Corona reconnaissance satellite to spy on the Soviet Union during the height of the Cold War, they installed film canisters to record the images taken. The satellites ejected the canisters, which parachuted into the atmosphere to be retrieved by special “skyhook” aircraft. Modern satellites utilize digital technology. No film is involved. The scientists that developed the digital camera worked for the Kodak Company, the world’s primary provider of twentieth century film. Kodak invented electronic film. Yet the company as a whole could not restructure its marketing and production processes to accommodate the new technology. The Kodak Company declared bankruptcy in 2012. Kodak’s history is famously employed by writers like Clay Christensen, author of *The Innovator’s Dilemma* (2011), to demonstrate the nature of disruptive technology. Disruptive innovation occurs when a product or service appears at the bottom of a market, initially in a simple form, then moves persistently up through the market until it displaces the old technology. Christensen insists that organizations improve old products faster than customer preferences evolve (hence the need for planned obsolescence). The organizations push more sophisticated or expensive versions of what has proved profitable in the past. Inexorably, this behavior provides an entry point for disruptive innovations at the bottom of the market. The disruptive innovation appeals to a new class of consumers weary of the complexity or cost of the old product. Established companies typically avoid the innovative product because in its initial stage it does not provide adequate sales or profit margins. Sometimes the organization is simply not well positioned to make or distribute the new product given the history or culture of the organization.

**Twenty-first century technologies are fast.** In his book *Flash Boys* (2014), Michael Lewis describes the financial practice known as high-frequency trading. Essentially, this practice allows stock market financiers to write computer programs that anticipate impending “buys” and “sells” and – at nearly the speed of light – place the financiers in a position to benefit from the anticipated transaction. The process is conducted entirely by machines, at speeds far too rapid for human cognition. It serves no socially useful purpose except to enlarge the wealth of people who know how to do it. When the practice started, it baffled regulators at the Securities and Exchange Commission. Congress created the SEC in 1934, during the apex of the industrial age. Market mechanisms commonly work faster than the regulatory institutions organized along bureaucratic lines. Electronic technologies work faster than traditional buy-and-sell markets organized through old-fashioned stock exchanges. The computers that did the flash trading were far more intelligent (and profitable) than Watson, the computer that used a very fast word-recognition program in 2011 to defeat two human masters and win $77,147 playing Jeopardy.

**Twenty-first century technologies are exponential.** In 2004, Mark Zuckerberg founded the social network service he had worked to develop while an undergraduate student at Harvard University. Membership grew not only fast; it grew exponentially. After four years of operation (2004-2008), Facebook had enlisted 100 million users. In the next four years (2008-2012), Facebook grew ten-fold, to one billion users. As of 2015, Zuckerberg was worth $39 billion. Compare this rate of change to the sales of an industrial-age item, the American automobile. In the 1950s the number of automobiles sold annually in the United States increased from 5 to 6 million. Sales rose to 10 million yearly in the 1970s, then fell back to 8 million in the 1990s. A slow-moving technology gives a better target for social and political control than one that moves exponentially. The latter situation characterizes twenty-first century technologies.

**Twenty-first century technologies are dispersed and accessible.** When editors at *Time* reviewed candidates for their person of the century award, they considered Martin Luther King, Franklin D. Roosevelt, and Mother Teresa. (*Time*, December 31, 1999) The editors settled on Albert Einstein, the century’s “preeminent scientist.” The two bombs that Einstein’s theories helped produce (Fat Man and Little Boy) cost the modern equivalent of $27 billion to fabricate. Realistically, no entity but a nation state could make an atom or hydrogen bomb. The technology was too complicated, the cost too prohibitive. You had to be a national government to join the atomic club. CRISPR is a gene splicer, a quintessential twenty-first century technology. A revolutionary genome engineering tool developed in 2012, the term means Clustered Regularly Interspaced Short Palindromic Repeats. The total cost to perform a CRISPR operation can total as little as $30. “That effectively democratized the technology,” observed one scientist. (Ledford, 2015, 7554) Anybody could do it. Genetic engineering follows a central trend of 21st century technologies. The technology is much more dispersed and accessible than a device like an atom bomb. The same can be said for drones relative to personal aircraft. Transportation experts predicted that Americans would purchase 700,000 drones in 2015 – just one year’s sales. That contrasts dramatically with the total number of all small aircraft owned and flown in the United States, estimated to be about 360,000 as whole. Similar predictions are being made for space flight and personal robots. They fulfill a central tendency set in motion by twentieth century technologies like the automobile and telephone: accessibility and dispersion. (Corn, 2002)

**Twenty-first century technologies are characteristically small.** Imagine a single atom expanded to the size of a modern football stadium. The atom’s nucleus would consist of an object the size of a marble on the fifty-yard line. Electrons the size of gnats would orbit in the vicinity of the flood lights. Now expand the human body to the same scale. If one of its atoms was the size of a football stadium, the human body would be the size of an object in the solar system that stretched from the sun to the orbit of Pluto. Physicists use these imaginary scales to express how much material exists at the nano-level and their optimism at the possibilities for manipulating it. As physicist Richard Feynman observed in a famous 1959 lecture, “there is plenty of room at the bottom.” (Feynman, 1959) Molecular assemblers, nanobots, and quantum computing all proceed from the hope that humans will learn how to manipulate objects at the scale of the very small.

**Twenty-first century technologies are characteristically smart.** Responding to horrific fatalities suffered by soldiers exposed to roadside bombs while driving military convoys over foreign terrain, officials at the U.S. Defense Advanced Research Projects Agency offered a $2 million grand challenge prize to any team that could successfully traverse a 142-mile course with a self-driving car. In 2004, the first year of the contest, all of the teams failed. The following year, 195 contestants arrived to try a 135-mile course. A research team from Stanford University shared the prize when their robot car “Stanley” finished first. In all, five self-driving cars finished the course. Executives at Google hired the Stanford team leader, associate professor Sebastian Thrun, and asked him to develop a self-driving mechanism for a conventional car. In 2012, Nevada became the first state to license a self-driving automobile. As will be seen, autonomous vehicle technologies have profound implications for a wide range of government policies, from traditional vehicle licensing and highway safety and urban land-use planning. The technology contains a central feature of 21st century technologies, a characteristic known as “smart systems.” The technology embodies the capability of non-human entities to operate at very high levels of predictability in a relatively autonomous fashion without the need for direct human control.

**Twenty-first century technologies are characteristically cheap.** In 2011, the National Aeronautics and Space Administration stopped flying America’s winged space shuttle. In preparation for the transition to a new launch vehicle, NASA engineers agreed to develop an Ares I launch vehicle that could transport astronauts and cargo to the International Space Station. In 2010, President Barack Obama cancelled the Ares I project, largely due to NASA’s inability to meet financial and technical goals. In its place, the administration encouraged commercial firms to build rockets and sell them to the government – first for the transport of cargo and then for astronaut crews. SpaceX, Orbital Sciences, and the Boeing Corporation qualified. Industry executives signed contracts promising to sell the rockets for a fraction of the cost of flying the discarded space shuttle and Ares I. Amplifying the doctrine of accessibly, twenty-first century technologies are supposed to be cheaper than their 20th century counterparts.

Summary observations. As these technologies suggest, the characteristics that typify twenty-first century innovations differ considerably from their twentieth century counterparts. Creating governance methods powerful enough to counteract the new characteristics is a major challenge.

* Twenty-first century technologies tend to be disruptive, fast, exponential, dispersed, accessible and small.
* Twenty-first century technologies tend to be “smart,” differing considerable in their modes of operation from the trial and error techniques that characterized early industrial design processes for products like the steam engine and railroad trestle. (Petroski, 1985)
* New century technologies are supposed to be cheap, which amplifies their accessibility.

The basic challenges

Three basic challenges dominate the governance challenges arising from twenty-first century technologies. They are innovation, regulation, and effective methods.

Public officials have a vested interest in encouraging innovation. Innovation is the engine that maintains political stability, promotes personal security and reduces the burden of national debt. Innovation keeps the wheels of progress running faster than the world demand for energy, food, resources, and material goods. In the early 1970s, the Club of Rome commissioned a study of the consequences of unlimited growth in the absence of strong technological innovation. A research team directed from the Massachusetts Institute of Technology provided a computer simulation of the results. In their World 3 standard run, population increased rapidly. Pollution followed. Food per capita declined. Natural resources likewise diminished. The simulation predicted a severe population crash at the mid-point of the twenty-first century, accompanied by starvation and consequential relief on resource consumption. In the computer runs, a steady dose of technological innovation delayed but did not deter the inevitably decline. Reviewers criticized the research team for not accepting the exponential nature of technological change. In any regard, both sides agreed that only technological innovation could stave off the Malthusian tendency for population to outstrip food production and resource consumption. The public officials who would be blamed during any global collapse have a strong incentive to avoid it, which accounts in large measure for the current political fascination with technological innovation.

The Earth was a considerably safer place for humans to live at the end of the twentieth century than at its start. World population rose from less than two billion in 1900 to six billion in 1999. Average life expectancy worldwide increased from 31 years in 1900 to over 60 years by 2000. improvements in areas such as sanitation, water quality, vaccinations, workplace safety, antibiotics, central heating, air conditioning, refrigeration and nutrition made life less painful and less short. Nonetheless, the twentieth century was not without its dangers. Abetted by technology, humans managed to kill millions of their fellow beings through wars and politically inspired slaughter. Estimates vary, but sources assign more than 30 million to military casualties, 50 million to civilian war dead and another 80 million to revolutions and other political movements. (Brzezinski, 1993) Motor vehicles in the United States alone killed three million people. The dangers of living during the twentieth century were considerable, but on the whole humans lived less risky lives in 1999 than in 1900. (Wildavsky, 1988) Public officials have an important responsibility in this respect. Through regulation and law, public officials often attempt to control technology’s nefarious effects. Given the history of conflict, officials have an equal responsibility to control themselves.

Understanding the nature of new technologies is a critical step in achieving regulation. Every age develops its own set of governance tools, largely in response to the nature of technology. Administrative controls change. The engineers that dispatched humans to the Moon in the second half of the 20th century discovered that they needed methods of project management that were far more robust than the methods used to organize massive public works projects in the first half of the 20th century. Twenty-first century technologies will present similar challenges. If humans are able to engage in atmospheric manipulation, the techniques they use will be radically different from the factory-based methods used to produce electric power from gas and coal. Understanding the nature of new technologies is a critical step in making government work.

These are the three great governance challenges: encouraging innovation, regulating its effects, and developing administrative methods powerful enough to do this work. The challenges manifest themselves in the specific issues that follow.

Meeting the challenges

**Can humans develop methods of organization that achieve their objectives without extensive human control?** A central characteristic of the development of new technologies is that they tend to happen automatically. As in a market, the advances contain incentives and practices that work to promote the desired outcomes without extensive human involvement. In a phrase, the methods once running operate on the principle of “nobody in charge.” (Cleveland) Human involvement is needed, but more for design than for enforcement.

An illustration may help to make the concept more concrete. Suppose that an elected official sought to reduce automobile accidents. The statistics on automobile accidents are horrific. Thirty thousand Americans each year die from injuries caused by auto mishaps. Over 1.5 million survive serious accidents but endure severe pain. The resulting casualties would never be tolerated for air or train transport.

The best efforts of traffic safety officials have reduced fatalities by only one-quarter, from 40,000 to 30,000 annually. Ironically, some of the best safety devices (such as seat belts and air bags) cause drivers to pilot their automobiles more recklessly, knowing that the devices improve their odds of survival should one lose control. Economists characterize this behavior as a “moral hazard.”

To reduce traffic fatalities, public officials could adopt the Scandinavian model and severely enforce traffic laws. They could hire more patrol officers, expand the use of traffic sobriety check points, install speed cameras, and generally expand the traffic safety bureaucracy. That would be a quintessential 20th century approach to the problem of traffic fatalities.

Alternatively, safety devices could be built into the car. Mechanisms in place already prevent rear end collisions, guide cars into parking spaces, and provide blind spot warnings. Devices have been installed that prevent impaired drivers from starting a car. Even more effective is the emerging technology of self-driving cars. So long as the occupants had the capacity to identify a destination, the automobile would take them safety there. The need for a broad-scale traffic safety bureaucracy that wrote tickets and enforced laws would largely disappear. Patrol officers would still be needed to investigate errors, but the officers’ traditional enforcement responsibilities would be supplanted by technology.

The technologies involved in self-driving cars have implications that extend well beyond traffic safety. It is truly a disruptive technology. It could allow people to drive (so to speak) who are currently incapable of piloting a vehicle, such as the elderly. It would have enormous consequences for drunk driving. It would revise the automobile insurance industry. It would affect urban land use planning. It could alter the tradition of car ownership and the need for multiple family cars.

A central feature of innovations like this is their ability to operate at higher levels of effectiveness than the capabilities of the individual parts that make them up. No one needs to control the whole system to make it work. When the individual components follow a set of common rules, the emerging system exhibits what might be considered intelligent behavior. This observation has its source in chaos theory. Behavior that appears chaotic at the individual level, as in a hive of bees searching for food, may be highly effective as collective action. Chaos theory proceeds from the observation that small changes in initial conditions produce large changes in long-term outcomes. Nature provides frequent examples of this process, from the butterfly effect to the willingness of species like meerkats to behave in what appears to be altruistic behavior.

To work effectively, the overall system must possess two central features: a relatively simple set of rules that the individual entitles follow and a set of effective incentives that prompt the entities to behave in the desired fashion.

Understanding how complex systems emerge from less intelligent entities lies at the heart of nobody-in-charge administration. In a prophetic short story, first published in 1941, science fiction writer Isaac Asimov dealt with the implications of this process. Two astronauts (Powell and Donovan) work on a space station that beams microwaves to Earth. Their robot, QT1 (Cutie) directs power perfectly during a disruptive solar storm – more capably than the astronauts could do. Cutie denies that humans as imperfect as Powell and Donovan could have created such a proficient machine and develops its own religion to explain its existence.

The spontaneous nature of nobody-in-charge systems raises a fascinating question – can humans (public officials) design systems that once set in motion produce additional systems that operate at even higher levels of intelligence than the original design?

**If technological improvements occur spontaneously, how can humans working through large institutions encourage innovation?** The answer, according to some observers of the process, is that humans cannot encourage innovation in traditional ways. That is, they cannot advance innovation by using large organizations that distribute funds through government grants and contracts. This observation is very controversial among persons who study innovation policy.

Innovative societies invest 3 to 4 percent of their gross domestic product in research and development. (The United States invests about 3 percent.) We do not know whether they invest that much because they are wealthy, or whether they become wealthy because they invest that much. Regardless, national wealth correlates strongly with investment in research and development. Rich countries invest more and are sources of innovation, while poor countries lag behind. The situation is probably self-reinforcing. The rich get richer while the poor languish in disorder and various shortages.

Having established a 3 to 4 percent goal for investments in research and development, national leaders in innovative societies are left with a set of important questions. To assess the answers to the questions, one needs to understand how innovation occurs.

* How much money should governmental bodies invest in research and development as compared funding sources in the private and philanthropic sectors? Put another way, what the most productive distribution of investments in activities that spur innovation? Should it be split 50/50 between government and industry or 25/75? How much of a supplement can non-profit organizations like foundations and private universities provide? Should the ratios vary by field, for example, a larger government presence for health research but a smaller one for transportation? Everyone wants innovation – that is a given. The funding options for that investment are numerous.
* How much money should the society as a whole set aside for basic research as opposed to applied research and development? Again, this is controversial. Some people believe that basic research drives innovation in a more-or-less linear fashion. According to this point of view, money invested in basic research produces scientific knowledge. Knowledge leads to applied research which in turn leads to product development. Others are not so sure.
* How should the government organize itself to distribute the funds it provides? Once again, the options vary with the ways in which people visualize the innovation process.

The argument for a hefty government presence goes this way. Society needs investments in technology to ward off the destructive forces of population growth, inequality, and resource depletion. In spite of the existence of industrial labs, market forces cause private firms to underinvest in basic and applied research. The basic cause of this shortcoming is known as the “spillover effect.” The firm making a new discovery cannot prevent knowledge about that discovery from spilling over to other firms that use the knowledge to develop new products without paying for it. The resulting market failure will prompt private underinvestment as firms wait for someone else to conduct the research. The failure can be corrected by tax-financed contributions to research and development.

The contrary argument has been articulated most forcefully by Terence Kealey, a British biochemist and university vice-chancellor (retired). Kealey wrote two books on the subject. One is a rather thick treatise titled *The Economic Laws of Scientific Research* (1997). The other is oddly called *Sex, Science, & Profits: How People Evolved to Make Money* (2008). It has nothing to do with reproductive activities, but Kealey thought it would sell more copies if he put a lurid word in the title.

Kealey’s argument evolves in the following manner. First, he says, the spillover effect is overrated. Competing firms that seek to steal new ideas need to invest in the knowledge needed to understand those ideas. So no market failure exists, or if one does, it is too small to justify massive public corrections. Second, he insists, public institutions are not sufficiently agile to promote real innovation. Removing money from the private sector to then finance government agencies that in turn provide research grants to the private sector in his view creates loses due to various frictions that would be corrected by simply leaving the funds in the private realm.

The third observation is very disruptive. According to Kealey and British journalist Matt Ridley, innovation is non-linear. Their argument appears most forcefully in Ridley’s *The Evolution of Everything: How New Ideas Emerge* (2015). Ridley casts the issue in the following manner. As in biology, some people believe in creationism – the argument that a guiding hand created the universe and the natural entities within in. Most biologists believe in evolution – the idea that individual entities emerged without any super-intelligent designer to create them. In biology, observations of the natural world favor the evolutionary principle.

Ridley applies the same argument to innovation. New ideas emerge spontaneously, he says, without a central creator. Among other examples, he offers the invention of the light bulb – commonly (and inaccurately) ascribed to Thomas Edison. From this point of view, efforts to spur innovation through directed research spending guided by large command-and-control institutions are essentially futile because they work against the natural world.

Sometimes the creationist approach works. When public officials committed the Unites States to race to the Moon, they created one large federal field center in Texas to develop spacecraft and converted a separate field center in Alabama to build rockets. With adequate funding, the rocket and spacecraft centers completed their work. When the U.S. National Institutes of Health attempted the biological equivalent of the Moon shot, they took an evolutionary approach. Instead of a massive field center staffed by government and contract workers, the officials established an information hub into which widely distributed scientists working to map the human genome could enter their findings. The scientists completed the work for a fraction of the cost of sending humans to the Moon.

The genome project and others like it suggest that government support for technological innovation works best when it creates incentives for scientists and engineers to work on the puzzles they are already motivated to solve. In policy circles, the process is called nudging. It can take the form of information hubs (as in the human genome project), competitive grants (as in the NASA Discovery program), prizes (as in the DARPA autonomous vehicle program) and innovative patent policies.

People in Kealey’s camp offer cases such as energy subsidies and the Japanese space program as examples of failed government investment. His opponents (writers like Mariana Mazzucato) offer contrary examples such as tax-supported research on health and the Internet, which began its history as a defense project.

The stakes are not insignificant. The United States invests roughly $150 billion each year on basic and applied research, split almost evenly between the two categories. That includes all sources, from industrial firms to government agencies and various foundations. Governments contribute more than half of the funds devoted to basic research. Public officials contribute a lesser share to applied research, where industry is the dominant contributor.

Basic research is research without a product in mind. It provides information and understanding. Applied research and development leads to new products or improvements in existing ones.

Are these amounts sufficient to keep the innovation engine running at the appropriate speed? In practical terms, is that enough to stay ahead of population growth, resource depletion, and global climate change? The issue resolves itself into the forms noted above. It is sufficient – if it is wisely spent.

**Should public officials limit the development of new technologies in troublesome areas until their consequences are more fully known?** In addition to funding basic and applied research, governments also set the rules by which much innovation occurs. The rules apply to a wide range of issues, from mundane concerns like patent policy to larger issues such as the ethical implications of genetic engineering.

Some people worry that the innovation movement will accelerate inequality, both biological and economic. In biology, the concern attaches itself to what is known as transhumanism – the effort to radically extend life spans through computer science and genetic engineering. The economics of innovation conjures images of a society consisting of very wealthy entrepreneurs and a vast population of lower class drones.

No single issue within the transhumanist movement raises more concerns than artificial intelligence. In 2000, Sun Microsystems founder Bill Joy wrote an article in *Wired* magazine titled “Why the Future Doesn’t Need Us.” He quoted from the Unabomber to make the point that AI could be the most dangerous invention that humans have ever attempted to make. An AI computer may be the last invention that humans ever develop, since every subsequent innovation would be made by machines. AI would eliminate the need for engineers, programmers, chemists, physicians and stockbrokers. (There will still be plenty of jobs for fast food cooks, gardeners, and nurses’ aides at the lower end of the wage scale.) In 2014, Stephen Hawking warned that “the development of full artificial intelligence could spell the end of the human race.” The warning was echoed by Elon Musk and Bill Gates. History suggests that technologically inferior civilizations rarely survive encounters with technologically superior ones. AI could prove to be the last devastating example of that observation.

Ray Kurzweil and Hans Moravec are more optimistic, through in a twisted way. Kurzweil believes that AI will allow humans to “live forever.” They will not live as biological humans, however, but in an electronic and cybernetic form. Hans Moravec (2000) predicts that intelligent machines will become our evolutionary heirs.

**Will these lessons be applied to a wide range of fields?** Narrowly defined, science policy concerns a limited number of fields like health research and space exploration in which science and technology play a substantial role. The governance challenges created by science and technology are much more broadly applied.

See how many of the following applications you can envision. Keep in mind the principal characteristics of 21st century technologies and their associated governance methods. The technologies tend to be disruptive, distributed, widely accessible, small, smart, fast, and often cheaper than their previous counterparts. The new governance methods tend to be automatic and fashioned in such a manner as to reflect the principal characteristics of the underlying technology.

Air traffic control. Rather than rely mainly upon human controllers working on the ground, aircraft of the future will be equipped with robotic devices that communicate aircraft position to other commercial vessels in the skies. The technique allows far more aircraft in a given air space than the current system of ground control. The technique is known as “smart skies” and in its current form combines ground and air systems.

Energy. The world needs a plentiful supply of cheap, non-polluting forms of energy. Traditionally, public officials have addressed this need through the creation of public utilities, large government-regulated monopolies and other production strategies. Energy policies of the future will be much more distributed. Imagine an energy governance system that employs automated electric power grids (“smart grids”), household electrical production sources, two-way distribution systems, and very low voltage electronic appliances.

Bioterrorism. Humans survived the dangers posed by atomic and hydrogen bombs through nuclear deterrence policies and nation-to-nation agreements. Weapons arising from biology and genetic engineering will be much harder to control. Try your skill at designing tracking mechanisms that identify individuals or groups trying to fabricate weapons out of biological substances. The new approach has significant implications for the loss of privacy.

Criminal justice. In the United States, opposition to gun registration and weapons bans have stymied efforts to reduce mass murders. Consider an alternative approach based on computer chip technology that would allow only the licensed owner to fire the gun.

Urban development. The lack of moderately priced housing close to urban centers of employment creates metropolitan sprawl and nightmarish commutes. In the central city, economic incentives encourage developers to knock down small homes and replace them with higher-priced McMansions. Governments seeking to provide affordable dwellings traditionally respond with public housing and vouchers. Might a zoning policy based on the replacement of existing homes with micro-housing create a market incentive that more closely matches housing prices to worker incomes?

Health care. The United States is running short of physicians who can serve as general practitioners. Traditional solutions include government grants that defray part of the expense incurred by medical students studying internal medicine and financial penalties that discourage the excessive use of emergency room facilities. Consider an alternative approach that employs nanobots to provide continuous readings of vital signs and related chemistries. Yes, the nanobots would be implanted under human skin.

Income distribution. Imagine an economically prosperous society in which humans routinely live to ages of 100 years or more. Entrepreneurship concentrates new wealth in the hands of an increasingly small group of people. How will that society pay for the needs of persons not in the workforce, such as students and retirees? The traditional solution has been population growth through higher birth rates and immigration so as to rebalance the ratio of workers to non-workers. Devise an income distribution policy that works more or less automatically without the dysfunctional effects of population booms and forced redistribution of incomes.

Space exploration. For a fraction of the hundreds of billions of dollars necessary to organize a three-year, Apollo-like expedition to the most Earth-like planet in the solar system, NASA could establish a colony of robots on Mars. Devise a plan that uses low-cost (possibly commercial) launch vehicles and high-thrust spacecraft that would allow humans to make short-term visits to that robotic colony. Don’t dismiss the long-term possibility of re-engineering humans to live permanently on Mars. It’s a radical concept, but the notion of the cyborg (a cybernetic modified organism) was first proposed by people planning space flights.

Education. Classroom education is expensive and labor-intensive. On-line education (students on computers) does not work as well. Imagine a personalized regime of education conducted by artificial intelligent robots – one device issued to each student when that person starts school.

National defense. Urban warfare waged against terrorist groups is particularly dangerous to the troops on the ground. Remotely piloted drones have started to tip the advantage to anti-terrorist forces. Take the next step and imagine autonomous entities of ever-decreasing size possessing image-recognition capabilities with the authority to kill. The entities might operate on the basis of swarm theory in which small units with limited capabilities work collectively to enhance intelligence.

Cybersecurity. By breaking into the wide variety of computer systems that humans use for modern life, malicious individuals and foreign agents can disrupt power grids and steal personal information. The conventional approach to such activity is prohibition, prosecution, and computer firewalls. Consider the ways in which government information systems can be made more secure through technologies like mesh networks and cryptography.

Other impending technologies may respond to public policies as the methods for governing them become more familiar. Here are a few more: household robots, hydrogen fueled cars, Dyson’s spheres, space elevators, terraforming techniques, fusion rocket engines, VASMIR powered rocketships, nanocomputers, microbivores, biological and molecular assemblers, 3-D printers, somatic-cell engineering, neural nets, genetic algorithms, fusion power, communication with extraterrestrial civilizations, teletransportation (also known as teleportation), missile shields, patent trolls and cavorite guns. Can you distinguish the fictional technologies from the real? Scientists once thought teleportation to be fictional until they discovered quantum entanglement. Still, it may remain hard to disable an aircraft with a gun that shoots the fictional anti-gravity substance called cavorite. As for the rest, be prepared for new challenges and the methods arising from them.

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