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Remaking the World

Technological innovation sustains a fundamental tension of civilization, the tension between humanity's quest for more control over nature and the future, and our equally strong desire for stability and predictability in the present. The original Luddites were not against technology per se. They were against losing their jobs, and so they smashed the power looms that had put them out of work. The change wrought by technological advance continually remakes society, and this transformational process is on the one hand central to the dynamic that is commonly labeled "progress," and yet on the other is a source of continual destabilization and dislocation as experienced by individuals, communities, institutions, nations, and cultures.

In the age of science and technology (S&T), the federal government has increasingly become the prime catalyst for scientific advance and technological innovation. At the same time, modern government is also continually responding to and managing the transformational power of science and technology. Yet there is little effort to understand the relation between these two critical activities—advancing knowledge and innovation, and responding to their impacts—or to link them in a way that can enhance the value and capability of each.

A single technological innovation can remake the world. When the metal stirrup finally migrated from Asia to western Europe in the 8th

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century, society was transformed to its very roots. For the first time, the energy of a galloping horse could be directly transmitted to the weapon held by the man in the saddle—a combat innovation of devastating impact. Because horses and tack were costly, they were possessed almost exclusively by landowners. Battlefield prowess and wealth were thus combined, and from this combination grew not just the traditions of a "warrior aristocracy" but the structure of European feudal society itself. Later, when the Anglo Saxon King Harold prepared to defend Britain against the invading Normans in 1066, he actually dispensed with his horse and ornamental wooden stirrups, choosing to lead his numerically superior forces on foot. The outnumbered Normans, however, boasted a strong, stirrup-equipped cavalry, and thus won the day—and the millennium.[1]

Such narrative has the ring of mythology, yet the experience of the industrialized world reinforces the knowledge that a new machine can help change everything. The invention of the cotton gin in the late 18th century allowed a vast expansion of cotton cultivation in the American south—and directly fueled a resurgence in the importation and use of slaves for plantation labor. One hundred and fifty years later, the mechanical cotton picker suddenly rendered obsolete the jobs of millions of African American share croppers, and catalyzed a 30-year migration of five million people out of the rural south and into the cities of the north. While the development of the mechanical cotton picker was no doubt inevitable, its proliferation was consciously accelerated by plantation owners who, fearing the rise of the civil rights movement, sought quickly to find a technological replacement for the existing system of exploitation labor upon which they were economically dependent.[2]

These examples point not only to the power of new technologies to transform society, but to the comprehensive interconnectedness of technological change and the complex social structure of society. The invention of the stirrup as a battlefield tool was in some very intricate way connected to the development and expansion of feudalism in Europe; the evolution of agricultural technology for a single cash crop is indissolubly bound to the ongoing struggle to overcome the U.S. legacy of slavery, segregation, and bigotry. More familiarly, a single class of technology—nuclear weapons—was a central determinant of geopolitical evolution after the end of World War II. Cars, television, air conditioning, and vaccinations have all stimulated foundational changes in society during the past century.

Of course new technologies rarely emerge in isolation. The industrial revolution is not just the story of harnessing steam power to factory production capability, but also the story of technological revolutions in transport, communication, construction, agriculture, resource extraction, and, of course, weapons development. These technological systems penetrated the innermost niches of society—home and family, school, workplace, community—and forced them to change. They also introduced completely new social phenomena, and stimulated the invention of completely new institutions.

The industrial revolution created the macroeconomic phenomenon of unemployment. Prior to the 19th century, even the most economically and politically advanced societies were dominantly agrarian and rural. For the majority of people, work was rooted in the home and the family. Vagaries of weather and transportation imposed irregularities and hardship, but most people and families harbored a diversity of skills that gave them independence from the marketplace and resilience to cope with a variety of challenges. In hard times, resort to subsistence farming and barter was usually possible.[3]

Industrialization and urbanization linked workers far more closely to the larger economic market, while removing the need and ability for them to maintain the diverse skills necessary for survival in the pre-industrial world. The traditional connection between manufacturing and agriculture in the home was sundered by new economic organization and by geography. Labor itself became a commodity, subject to the same fluctuations and influences as other commodities. During an economic downturn, factories fired people or closed down entirely. For the first time, workers could not easily respond to changing economic conditions by switching to a different type of work or moving to a subsistence mode. The political economist Karl Polanyi observed: "To separate labor from other activities of life and to subject it to the laws of the market was to annihilate all organic forms of existence and to replace them by a different type of organization, an atomistic and individualistic one."[4]

As technological innovation interacts with society to create new phenomena, such as unemployment, society also responds by developing new types of institutions and response mechanisms. Today we can recognize the problem of unemployment as central to a diversity of social, political, and economic structures and activities ranging from the organization of labor to insurance safety nets to educational programs to immigration policy. Unemployment rates are a key indicator of economic health, and a key determinant of political behavior. National and international economic policies focus strongly on managing unemployment, even as theoretical investigations seek to clarify the relation between unemployment rates and other key attributes of modern economies.

The general point is that transformational technology represents one variable in a complex assemblage of dynamic, interrelated societal activities. Decision making processes tend to address each of these activities in isolation from the others, e.g., conduct of research and development (R&D), dissemination of innovation products, development of regulations, reform of institutions. Concerted action occurs when a given innovation stimulates enough transformation to demand a response from other sectors of society. This response then triggers additional changes, which in turn demand further modulation. The process is reactive, discontinuous, disruptive, and sequential—like billiards. The challenge is to move toward a process of technology-supported societal progress where different sectors and activities can continually coevolve in response to knowledge about one another's needs and constraints—like an ecosystem. We are not there yet.

Transforming the Present

A brief consideration of evolution of information technologies helps to bring this look at societal transformation into the present. Gutenberg's perfection of the printing press of course had enormous transformational impact, allowing the broad dissemination of written texts and consequent expansion of information—and literacy—that undermined the Church's hegemony over knowledge and culture, and helped promote the dissolution of medieval social structure. Lewis Mumford suggested that the printed word represents "the media of reflective thought and deliberate action," a prerequisite, perhaps, for the intellectual achievements of the Enlightenment. But he also observed—as early as 1934—that new modes of electronic communication were increasing the speed of information exchange to levels that made reflection impossible, and increasing the volume of information transmission to a point that exceeded our absorptive capacity.[5]

The implications of the information and communication revolution on democracy itself are far from clear. On the one hand, proliferation of information dissemination networks means greater access by more people to more information—and a greater capacity to communicate one's ideas and preferences in democratic fora. Control of information by authoritarian governments is becoming increasingly futile, and organization of democratic opposition increasingly enhanced, by new information technologies. But when this same capacity translates into 10,000 identical e-mail messages sent to a Member of Congress in support of a particular bill, one is hard-pressed to suggest that democracy is the beneficiary. Of particular concern is the recent increase in public referenda aimed at bypassing the legislative process. The barriers to putting referenda on ballots have been enormously reduced by information and communication technologies that can be used to disseminate ideas and organize group action with relatively little effort. While on the one hand this type of direct democracy can be a refreshing antidote to sclerotic legislative process, on the other it is quite often devoid of any serious deliberative process or public discourse, reflecting perhaps the pique of one well-organized interest group or individual, and the substantiation of a Warholian politics where anyone with access to a decent list-serve can lead a movement for a day. Is democracy in transition?

The implications of the information and communications revolution on the distribution of economic benefits in society are also problematic. Does the troubling increase in wealth concentration that characterizes both the U.S. and the global economy derive from the way that advanced technologies diffuse in market economies? Does the synergistic character of information and communication networks mean that disenfranchised populations and nations will find it increasingly difficult to participate in the spectacular economic growth that we have seen in the past decade? In other words, are the benefits of technology becoming increasingly appropriable by particular sectors of society, and is this in part an attribute embodied in new types of technological systems? Society is ill-prepared to answer such questions, let alone act on them in a knowledgeable manner.

Paradoxically, concerns about appropriability cut both ways. In the information society, the increasing ease of information dissemination may also threaten our system for protecting intellectual property and innovation. From pirated CD's sold on the streets of Shanghai to the advent of Napster, the concept of intellectual property seems increasingly vulnerable. Are we looking to a future where such protection is no longer practically possible? Does a world without patents and copyrights seem unimaginable? More unimaginable than, say, the loss of monopoly over the written word would have seemed to the Church in 1450?

At issue here is not the value of change, but the path that change follows. What may look in retrospect like the march of progress may be experienced in real time as wrenching dislocation. The Dickensian squalor of 19th century London remains a symbol of the human impacts of technological change. Faced with unprecedented societal transformations, the English government (as well as other European states) failed to develop effective policies that could accommodate the rapid transition from rural agrarian to urban industrial society. Today, the plight of many overpopulated developing nations is the post-industrial, global manifestation of the same failure.

We see the fingerprints of societally-transforming technological systems in the controversy over genetically modified organisms; in the morally reprehensible situation where 24 million HIV-positive sub-Saharan Africans cannot possibly afford AIDS drugs that are widely available in the affluent world; in the 40 million Americans with no medical insurance; in the general inability of our public school systems to create a citizenry able to take advantage of the opportunities of the knowledge economy; in the challenges presented by the aging of our population; in the rising atmospheric carbon dioxide levels that reflect 150 years of industrial dynamism.

Even the unprecedented rise of civil and ethnic conflict throughout the world in the past decade can be plausibly connected to technological transformation. Approaching this phenomenon from entirely different directions, the political scientists Samuel Huntington and Benjamin Barber each conclude that advanced communication and information technologies have created new fora for expressing ethnic identity and pursuing and strengthening cultural solidarity. Virtual communities, for example, can act to maintain identity over great distance, while also more efficiently garnering resources to support the expression of cultural goals. As Barber observes: "Christian Fundamentalists [can] access Religion Forum on CompuServe Information Service while Muslims can surf the Internet until they find Mas'ood Cajee's Cybermuslim document." The result may be locally empowering and globally divisive.[6]

Nanotechnology and Societal Transformation

The marriage of science and technology beginning in the latter part of the 19th century accelerated the process of innovation, and thus the process of societal transformation as well. If the industrial revolution played itself out in less than 200 years, the electronics revolution seems likely to have a working life of perhaps 75 years, while the biotechnology revolution, although hardly yet on its feet, is already prophesied to be supplanted by (or perhaps to morph into) the nanotechnology revolution in the first half of the new century. What type of transformations might this revolution have in store?

Our point here is not to predict the future of nanotechnology and its impacts—an impossible task—but to illustrate the direction and scale of thinking that will be necessary if we are to successfully manage the interaction of new knowledge and innovation with society. Judging by the literature prepared by the government,[7] as well as the work of futurists and other techno-pundits,[8] the promise of nanotechnology to remake our world seems virtually infinite. So the first thing to say is that if—as is variously claimed—nanotechnology is going to revolutionize manufacturing, health care, travel, energy supply, food supply, and warfare, then it is going, as well, to transform labor and the workplace, the medical system, the transportation and power infrastructure, the agricultural enterprise, and the military. Each one of these technology-dependent sectors is operated by and for human beings, who act within institutions and cultures, according to particular regulations, norms, and heuristics, all of which may reflect decades or even centuries of evolution, negotiation, and tradition. Not one of them will be "revolutionized" without significant difficulty. The current chaos in our health care system is emblematic of this type of difficulty.

In the near term, the current state of knowledge may suggest that the first wave of useful nanotechnologies will lie in the area of detection and sensing. The capacity to detect, precisely identify, and perhaps isolate single molecules, viruses, or other complex, nanoscale structures has broad application in such areas as medical diagnosis, forensics, national defense, and environmental monitoring and control. The potential for direct benefits is obvious; how might this evolving capacity influence society?

When detection outpaces response capability—as it usually does—ethical and policy dilemmas inevitably arise. For example, it is already possible to identify genetic predisposition to certain diseases for which there are no known cures, or to diagnose congenital defects in fetuses for which the only cure is abortion. In the environmental realm, new technologies that detect pollutants at extremely low concentrations raise complex questions about risk thresholds and appropriate remediation standards. The presence of tiny amounts of toxic materials in groundwater may justifiably raise alarm among the public even if the health risk cannot be assessed, and the technological capacity for remediation does not exist. These types of dilemmas may be expected to accelerate and proliferate with the advance of nanodetection technologies.

Advances in sensing and detection may transform existing societal mechanisms and institutions that were designed to cope with uncertainty and incomplete or imprecise information. The insurance industry, for example, deals with incomplete knowledge about the health of specific individuals by spreading its risk among large populations. If there is no way to distinguish between someone who is going to suffer a potentially lethal middle-age heart attack, and someone who is going to live to 105, then they can both get health and life insurance. Society clearly gains from this arrangement: costs are broadly disseminated, and benefits are delivered to those who most need them.

Medical sensors that can, for example, "detect an array of medically relevant signals at high sensitivity and selectivity"[9] promise to aid diagnosis and treatment of disease, but also to develop predictive health profiles of individuals. Today, health and life insurance companies often use pre-existing conditions as a basis for denying or restricting coverage. The advent of nanodetection capabilities will considerably expand the information that insurance companies will want to use in making decisions about coverage. The generation of new information might thus destabilize the risk-spreading approach that allows equitable delivery of social benefits to broad populations. How will society respond?

Nanotechnology offers a dizzying range of potential benefits for military application. Recent history suggests that some of the earliest applications of nanotechnology will come in the military realm, where specific needs are well-articulated, and a customer—the Department of Defense—already exists. One area of desired nano-innovation lies in the "increased use of enhanced automation and robotics to offset reductions in military manpower, reduce risks to troops, and improve vehicle performance." (Budget, p. 20)[10] How might progress in this realm interact with the current trend toward rising civilian casualties (in absolute terms and relative to military personnel) in armed conflict worldwide? As increased robotic capability is realized in warfare, will we enter an era when it is safer to be a soldier in wartime than a civilian?

Such considerations are simple extrapolations of current trends in technological innovation and societal transformation. More adventurous speculation is tempting but is perhaps best confined to science fiction novels. The question of public response to nano-innovation, however, should not be avoided, even at this early stage. The ongoing experience of public opposition to old technologies such as nuclear power, new technologies such as genetically modified foods, and prospective technologies such as stem cell therapies, needs to be viewed as integral to the relationship between innovation and societal transformation.

Three observations are particularly relevant here. First, the impact of rapid technological innovation on people's lives is usually not consensual. Second, in the short term at least, the social changes induced by new technologies usually create both winners and losers (where what is lost may range from a job to an entire community). Third, rapid technological change can threaten the social structure, economic stability, and spiritual meaning that people strive in their lives to achieve. As the nanotechnology revolution begins to unfold in all its promise and diversity, such issues are bound to express themselves. They should not be viewed as threats, or as manifestations of intellectual weakness or repugnant ideology. Rather, they need to be recognized as a central part of the human context for technological change.

Preparing for the Revolution

> Now nanotechnology had made nearly anything possible, and so the cultural role in deciding what should be done with it had become far more important than imagining what could be done with it.
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> —Neal Stephenson, *The Diamond Age*[11]

When resources are allocated for R&D programs, the implications for complex societal transformation are not considered. The fundamental assumption underlying the allocation process is that all societal outcomes will be positive, and that technological cause will lead directly to a desired societal effect. The literature promoting the National Nanotechnology Initiative expresses this view. The current policy approach thus addresses two elements:

- Conduct of Science and Technology

- Products of Science and Technology

These elements reflect the internal workings of the R&D enterprise. The fact that societal outcomes are not a serious part of the framework seems to derive from two beliefs: (1) that the science and technology enterprise has to be granted autonomy to chose its own direction of advance and innovation; and (2) that because we cannot predict the future of science or technological innovation, we cannot prepare for it in advance. These are oft-articulated arguments, not straw men. Yet the first is contradicted by reality, and the second is irrelevant. The direction of science and technology is in fact dictated by an enormous number of constraints (only one of which is the nature of nature itself). And preparation for the future obviously does not require accurate prediction; rather, it requires a foundation of knowledge upon which to base action, a capacity to learn from experience, close attention to what is going on in the present, and healthy and resilient institutions that can effectively respond or adapt to change in a timely manner.

If we flip the current S&T policy approach on its head, and start by thinking about desired social outcomes, rather than desired inputs to the R&D enterprise (i.e., more money), where would we begin? We might identify several very general categories of outcomes that most people would agree are worth thinking about. For example:

- Social equity: the distribution of the benefits of science and technology.

- Social purpose: the actual goals of societal development that we want to pursue or advance.

- Economic and Social enterprises: the shape and make-up of the institutions at the interface between technology and the human experience.

How can consideration of these types of outcomes be integrated into the S&T policy framework? The years since World War II have seen a very gradual evolution in the effort to connect thinking about S&T to thinking about the outcomes of S&T in society. A science policy report issued by the Truman Administration, for example, mentioned in its first pages the need to prepare for both the positive and negative impacts of scientific and technological change.[12] The rise of the environmental movement in the late 1960s reflected a public demand that society devote more S&T resources to the achievement of desired social outcomes like clean air and water. The creation of the congressional

Office of Technology Assessment reflected growing public concern about the need to understand the societal implications of technological choices. Over the past decade, federally funded programs on the human dimensions of global climate change, and the ethical, legal, and social implications of the human genome project and information technologies, have been supported as adjuncts to much, much larger core research agendas in the "hard" sciences. Yet S&T policy itself remains input-driven.

Concepts such as sustainability, and analytical tools such as human development indicators, provide conceptual frameworks for linking R&D to societal outcomes, and in fact imply that outcomes are to some degree implicit in the choices we make about R&D inputs. These types of insights point the way toward the next step: to implement an approach to R&D policy that addresses the complex interconnections between technological advance and societal response. Such an approach would need to integrate the pursuit of innovation with an evolving understanding of how innovation and society interact, and include mechanisms to feed this understanding back into the innovation process itself. (In a very specific way, the private sector does this as a matter of course, as it uses consumer input to continually refine and improve the next generation of products.)

If we wanted to be serious about preparing for the transformational power of a coming nanotechnology revolution, we would need first to get serious—at this very early stage—about developing knowledge and tools for more effectively connecting R&D inputs with desired societal outcomes. This in turn would require the creation of a dedicated intellectual, analytical, and institutional capability focused on understanding the dynamics of the science-society interface and feeding back into the evolving nanotechnology enterprise. Such a capability might include the following elements:

- *Analysis of past and current societal responses to transforming technologies.* A case history approach could be used to investigate the diverse avenues that society has followed in responding to a range of technological advances. Understanding the roles and relations between the media, academia, policy makers, institutions, and cultural factors could be the basis for assessing—and anticipating—the likely trajectories of technology-induced social change.

- *Comprehensive, real time assessment and monitoring of the nanoscience and nanotechnology enterprise.* At this relatively early stage, it should be feasible to build a database of important activities in nanotechnology, and then track the evolution of the enterprise over time, in terms of directions of research and innovation, resources used, public and private sector roles, publications and patents, marketed products, and other useful indicators. This type of information is essential to understanding potential impacts.

- *A science communication initiative, to foster dialogue among scientists, technologists, policy makers, the media, and the public.* Understanding, tracking, and enhancing the processes by which information about nanotechnology diffuses from the laboratory to the outside world is central to understanding the social transformation process as it occurs. Of equal importance is the need to understand and monitor how public attitudes and needs evolve, and how they reach back into the innovation system. Empirically grounded, research-based investigations on communication can be the basis for strategies to improve social choice in ways likely to secure favorable outcomes.

- *A constructive technology assessment process, with participants drawn from representatives of the R&D effort, the policy world, and the public.* Technology assessment is both a process for bringing together a range of relevant actors, and an evolving product that can inform and link the innovation and decision-making processes. Understanding the changing capabilities of both the nanotechnology enterprise and various sectors and institutions likely to be affected by the enterprise can contribute to a healthy policy making environment where innovation paths and social goals are compatible and mutually reinforcing.

Should nanoscience and nanotechnology yield even a small proportion of their anticipated advances, the impacts on society will be far-reaching and profound—"as socially transforming as the development of running water, electricity, antibiotics, and microelectronics."[13] We can allow these transformations to surprise and overwhelm us, and perhaps even threaten the prospects for further progress. Or we can choose to be smart about preparing for, understanding, responding to, and even managing the coming changes, in order to enhance the benefits, and reduce the disruption and dislocation, that must accompany any revolution.

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