The Innovation State

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Federal support for science is essential for American prosperity.

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For all its accomplishments, classical economics lacked a sound theory of economic growth—a serious problem in a capitalist society where growth is the path to expanding societal well-being. Classical economists saw growth as tied to essentially two factors, capital supply and labor supply, operating in a closed equilibrium system, always seeking balance but in constant imbalance nevertheless, resulting in relentless business cycles. In sharp contrast, growth economists led by Nobel laureate Robert Solow have seen growth as dynamic, driven by technological and related innovation. They have seen that as a wave of innovation sweeps through an economy, increasing productivity enables real income growth. Subsequent waves of innovation can drive an economy to qualitatively higher plateaus.

Growth economics brought good news to the dismal science, yet a hard problem remained: What is the recipe for innovation? Experts of various kinds have batted around this question for decades with some promising results. But, astonishingly, our political system is not looking at this question at all. In a time of global competition—and now, economic crisis—our two political parties lack a workable theory of economic growth. They formulated their fundamental economic ideologies at a time when classical economics ruled, and are now locked into concepts from that long-gone era. The American economy has moved on; they have not.

Ask Republicans about economic policy, and the answer is always capital supply: We should alter marginal tax rates. Ask Democrats, and the answer is labor supply: We should improve health care, social safety nets and access to education. It's not that those answers are wrong. Capital and labor supply remain vital factors. It's just that a couple hundred years after the Industrial Revolution showed the way, economists eventually realized that there was a previously unidentified monster in the economic engine room: technological and related innovation.[1] Politics has yet to catch up to this realization—a sluggishness that could have profound consequences for our economic future.

Innovation Foundations

If we're to understand anything about our economic future, however, we must first look to the past. How did we get here? In the 19th century, when resources were a critical component to any economy, comparative advantage was based on natural-resource advantage, and nations so blessed were permanently blessed. The United States changed all this during World War II. While Franklin Roosevelt is remembered for his stop-gap efforts to prevent economic collapse in the 1930s, with alphabet agencies like WPA, CCC and TVA as his hallmarks, his Administration's massive initiatives in science and technology from 1938 on, which created an innovation-based growth model that is still spinning out, are his real if unacknowledged economic legacy.

In the course of World War II, a system of massive federal R&D; support was assembled under the leadership of Vannevar Bush, FDR's science adviser. Bush, along with allies like Alfred Loomis, James Conant, Ernest Lawrence and Karl Compton, created a “connected science” model that unified the R&D; stages (basic science, applied science, development, and prototyping and production) and the innovation players (universities, Federal labs, industry, and the supporting Army and Navy Departments). As one example of how large the shift of resources toward new innovation capacity was, MIT alone received eighty times more Federal research support in the five years of U.S. involvement in World War II than it received in its previous eighty-year history.

The results of this R&D; spending were astonishing: radar, the proximity fuse, jet engines, atomic weapons and so on. As the war drew to a close, Bush articulated for Roosevelt a rationale for salvaging a portion of this system in his famous polemic, *Science: The Endless Frontier*. As the Federal war machine was being dismantled in the expectation of world peace, the Truman Administration saved Federal support for basic research, the least expensive innovation stage, but it dissolved the connected-science system. Nevertheless, the momentum of wartime technology advances, coupled with continued postwar basic-research investment, was enough to keep expanding the comparative innovation advantage the U.S. government had built during the war.

The next critical innovation-capacity moment—the launch of the Soviet Sputnik satellite—seems an unlikely event to be celebrated in the annals of U.S. scientific innovation. Sputnik itself marked a major U.S. technological defeat. But indeed, in October 2007, numerous American scientific forums marked Sputnik’s fiftieth anniversary. Why?

Children brought outside by their parents to see a tiny blinking dot in the night sky weren’t aware that Sputnik signaled a Soviet ability to launch ballistic missiles carrying nuclear weapons into the American heartland. It was a galvanizing moment, one that launched a second 20th-century scientific and technological project that played an integral role in America’s victory in the Cold War. As a result of Sputnik, the United States returned to a World War II scale of scientific investment and advances, reinvigorating the entire innovation enterprise to serve both economic and security missions. The percentage of GDP invested in Federal R&D; moved up year after year into the late 1960s, and the scientific talent nurtured in that period has carried our strong innovation economy up to the present day. Sputnik carried the seeds, for example, of the wave of innovation in information technology led by the United States—a wave that turned out to be critical to both U.S. Cold War success and subsequent U.S. economic growth.

Sputnik also resurrected the connected-science model used during World War II. President Dwight Eisenhower, who was often frustrated by inter-service rivalry during his time as joint forces commander in Europe, understood why Sputnik made it into orbit before Vanguard, America’s first satellite. The military services, competing for the space mission, had run separate space programs in three separate stovepipes using disconnected teams of scientists and engineers. Four months after Sputnik, Eisenhower took space away from the services and handed it to a new entity, the Advanced Research Projects Agency (ARPA). Two months later, deciding that the manned space mission should also be under civilian control, Eisenhower gave space to the government’s long-standing aeronautics R&D; agency, NACA, which morphed into NASA.[2] ARPA remained, tackling the “command and control” mission, which we now call information technology. ARPA adopted the flexible, non-hierarchical, collaborative research model, which entities like the Rad Lab and Los Alamos had developed and perfected in World War II. But unlike those famous examples, ARPA remained lab-free and was run by a small pool of talented science and technology entrepreneurs who sought out the nation's greatest technical talent.

ARPA, which soon became known as DARPA—the Defense Advanced Research Projects Agency—was a critical institution in the U.S. response to Sputnik. Its *modus operandi* was known as "right-left": It would think hard about revolutionary technologies it wanted to emerge out of the right side of the innovation pipeline—where high-tech products rolled off the assembly line—and then go back to the left side of the pipeline and work on the breakthrough science that would get it there. This was the reverse of the other science agencies formed after World War II, based on Vannevar Bush's model of Federal support for basic research.[3] Bush's model was "left-right": Focus on basic science, and technological innovation would inevitably follow. DARPA did more than stand this left-right model on end; it tied science to technology advance, connecting basic research to development and, through allied agencies in the Pentagon, to prototyping and support for initial production. We were back to the World War II approach of government support for connected science and back to a two-way pipeline, with technology influencing science and vice-versa.

There is no getting around the governmental role in innovation. Even cowboy innovators usually have government technology supporters in their rearview mirror. Economists have long understood the difficulties in getting the market to support the basic research critical to innovation. The reality is that government support necessarily must pervade the market for radical technology advances. Vernon Ruttan's book, *Is War Necessary for Economic Growth?* (2001) demonstrates this truth by painstakingly tracing the central role of defense-agency support in five of the 20th century's most important innovations: aviation, space, nuclear power, computing and the Internet. Making incremental advances in technology calls for a private company's intimate knowledge of its industry and markets, to be sure, but qualitative technological leaps usually require fundamental breakthroughs in basic science, which the free market isn't equipped to support because of the high risk attached to science success.

This is not to say that basic research is unprofitable; far from it. Basic science research, informed by the technology side, originates the big, economy-shifting innovation waves that lead to significant new economic growth. But it takes companies large enough and with enough foresight to risk such investments. There never were many such American corporations in the 20th century, and there are even fewer in the 21st. What is more, it is becoming harder to find a large corporation that is essentially American as, say, Westinghouse or General Motors was thirty years ago.

Is Innovation Still National in a Global World?

What are the major ingredients behind innovation-based growth? Solow argues there must be "technological and related innovation." Paul Romer argues there must be "human capital engaged in research." We begin to see from these dictates two direct innovation factors: R&D; and the talent to staff it. These aren't the only factors; there is a complex mix of indirect factors as well. But these two are indispensable, and Richard R. Nelson has suggested that these factors operate in an innovation system that is most prevalent and apparent at a national level. That system includes a network of institutional actors, including firms, universities, government agencies and labs, as well as supporting public- and private-sector policies and practices.[4] From Nelson's view of innovation as a system we can derive a third direct innovation factor: innovation organization, or the institutional elements where talent and R&D; connect.

Is Nelson right that innovation is best understood at the national level? How viable are national systems of innovation in an increasingly globalized world? Is an analysis of national innovation systems still plausible when companies themselves are increasingly independent of a single national base? It is. Indeed, strange as it may sound, national innovation features are growing in importance as globalization increases.

Late-stage development and production are becoming ever more international, but, of the complex mix of direct and indirect innovation factors, three fundamental direct ones are still dominated by the nation-state: research investment, support for scientific talent via investment in higher education, and much of innovation organization. The critical early stages of innovation—on which the later stages depend—still rely on support from the state. Bengt-Ake Lundvall argues that, as global competition increases, the central role of innovation in growth forces nations that have built innovation features into their geography to exploit specialized innovation advantages to do well.[5] Thus, the state still owns a large part of the innovation system, namely the basic research and talent factors, which are particularly important for radical and breakthrough innovation. Innovation organization is arguably the third direct factor, so the government's broad implementation role in that territory is critical as well. In the United States, for example, the government's dominant role in defense and health care has been critical in spinning out technologies in those sectors.[6]

However, the U.S. national innovation system is in tension and has been undergoing major changes thanks to globalization. The old model, which endured from World War II and the Sputnik era through both the Cold War and what we could call the First Competitiveness Era (with Japan, from 1975–90), is breaking up. That model, which coexisted with John Kenneth Galbraith's "iron triangle" of large corporations, big unions and regulating government, featured its own triangular alliance between industry, universities and the Department of Defense. These were closely interacting allies operating within a comparatively unified national system for innovation.

The new model is developing a different shape. Industry is going global, so the development and manufacturing stages are moving offshore. Since industry is the key actor in incremental innovation, that capability may be shifting globally as well. Thus, industry is breaking up the old alliance.

Universities, the second group of allies, are uncertain about their role in a global economy. Some are forming tentative campus outposts abroad or entering alliances with foreign universities. They increasingly rely on foreign national talent to fill out their ranks of science and engineering doctorates and to staff their research labs. Divisions in the university workforce remain between scientists and engineers. While many scientists have long thought they were part of a global scientific "religion" that observed nature and knew no national borders, engineers knew that at least in the past, they had state support to thank for their projects that intervened into nature, making engineering more a national religion. Since universities rely on the state for basic research support (there is no international mechanism for basic research support and no new such source can be glimpsed on the horizon), they are still tethered to the state, however global their scientists may be in outlook and nationality. So the second ally remains, if with less certainty.

The third ally in the old model was the Defense Department, which remains dependent on a state innovation model—although precious few at the Defense Department still understand this. Since U.S. national security leadership has been dependent on its innovation leadership, the Department faces a giant challenge from the disintegration of its old innovation triangle. The tripartite model that served it so well in World War II and the Cold War, making the last century an American one, is now at risk. Over time, U.S. security leadership may come to be at risk, too.

The Distribution of Innovation

The global pressure will grow. IT is a great enabler for the industry role in innovation, and industry remains the lead actor. In her book, *How We Compete* (2006), Suzanne Berger demonstrated how the United States is adopting a distributed manufacturing model. In the old manufacturing model, the process was like making model airplanes. Each part had to be fitted, glued, sanded and worked individually, so there had to be a great deal of vertical integration between suppliers and assemblers with tacit knowledge constantly shared between each stage so parts could be fitted together. The new manufacturing model is more like Legos, Berger argues. With IT standards and controls, each part can fit exactly, no matter where it is made. This voids the old manufacturing requirements of vertical integration and shared tacit knowledge, allowing manufacturing to be dispersed. Parts can be made anywhere that IT standards can be followed.

Apple’s iPod is the leading example of truly distributed manufacturing. Parts made all over the globe fit together perfectly. Distributed manufacturing enabled Apple to stand up its new product in months by contracting the manufacturing stage out, thus avoiding the corresponding cost and risk of building its own plants and skipping the complexity of acquiring the tacit knowledge necessary for vertical integration with suppliers. It marked a high point for an evolving new competitive model.

This means that globalizing industries can now move the development stage they dominate to an international model, along with their manufacturing. If production and development can be globalized, what’s next? Because early stage innovation remains state dependent, innovation itself arguably will not be globalized so much by multinational firms as by new entrant states.

A globalized world economy means that others are grasping at the model of comparative-innovation advantage that served the United States so well for so long. There are growing numbers of prosperous nations, so there will be more competitors in the field of innovation. China and India are undertaking a leap-frog approach, discovering they can be both developed and developing countries by using their newly developed sectors to bring along their developing ones. Basic research is the cheapest stage in the innovation pipeline. Given talent and research infrastructure, many nations can conduct basic research, and they can do it more cheaply than a developed nation. The Internet again works as an enabler. In the 1980s, Steve Wolff and Erich Bloch of the National Science Foundation saw that the Internet was a profound tool for scientific collaboration, so they turned ARPAnet into NSFnet and spread it to nearly every university campus in the United States.[7] This built the initial customer base that paved the way for the takeoff of the Internet in the 1990s.

Wolff's and Bloch's realization is not limited to research bound by national borders—IT enables scientific collaboration worldwide, as well as the corresponding dispersal of research to all those nations prepared to make the investments necessary to become innovation actors. China and India, like Korea before them, are showing that innovation is not simply a tool to make rich nations richer. It can serve a developing nation model as well.

The United States was able to innovate its way out of the first postwar competitiveness era with Japan by cultivating the IT revolution and, later, the biotech revolution. These dramatically boosted U.S. productivity and therefore its growth rate, proving Solow's growth economics model. The Second Competitiveness Era is now beginning, with China, India and perhaps others as the challengers. This will be a far more complex and difficult competition. The chart above illustrates both eras, past and future, using Japan and China as examples.

The trend, as the challenge from China illustrates, is toward the distribution of innovation capacity. Historically, the United States has gone through three fundamentally different policy phases in its position on dispersing its economic power.[8] In the first phase, Alexander Hamilton grasped, as few politicians have since, that U.S. political liberty (in his era this meant freedom from European powers) depended on building a strong, independent commercial and manufacturing economy. He saw that an agrarian, resource-based U.S. economy would forever depend on and be vulnerable to Europe, so he worked to build the fiscal, debt, tax, commercial and manufacturing foundations that would allow U.S. economic independence and eventual supremacy. This came a half century later, when the United States mastered the technology of machine-made interchangeable parts (through War Department R&D;) and assumed leadership of the Industrial Revolution from Britain.[9]

Hamilton's understanding that U.S. independence was tied to its commercial and manufacturing economic power assumed that these capabilities were built on a protected nation-state base. This assumption lasted through World War II. During the Cold War, the United States shifted this nation-state model to allow economic integration with its allies, including Western Europe, Japan and Korea. The second phase allowed limited dispersal of its industrial power and integration with other economies as a geopolitical exercise of soft power, strengthening the economies of its allies and creating an interdependence that preserved and underpinned the alliance.

The third phase came after the end of the Cold War, marked by an attempt to bring China into the world economy through its entry into the World Trade Organization. In this stage, which we are now entering into at scale, nations integrate their production systems, capital and labor with control entirely decentralized, belonging to all of the participants and therefore to none of them. This new global system is increasingly out of the control of the state. The difficulty that national governments have had in developing coherent policies and programs to cope with the current international financial crisis illustrates this new phenomenon. There are potentially important implications for the United States as a state here. Our economic fate is moving to a globally based, complex capitalistic system outside of national control. The U.S. innovation system, at least in the later stages dominated by industry, will increasingly be tied to that global system.

Comparative Advantage in Innovation?

How well will that new interdependent system serve us? The decades-long debate over trade policy between free trade economists and protectionist labor unions and politicians was altered in 2004 by an influential article by Paul Samuelson, perhaps America's most noted economist. Samuelson stepped into this free-fire zone and observed that comparative advantage in innovation may not be permanent; like a comparative advantage in resources, it can shift as innovators acquire an advantage in innovation technique.[10]

Samuelson noted that economic history is replete with stories of comparative advantage capture, citing the movement of textile and shoe manufacturing from New England to the low-wage South early last century, the migration of farming from the east to the Midwest, and the shift in manufacturing leadership from Britain to the United States in the middle of the 19th century. Samuelson characterized such shifts as "long-run Schumpeterian effects" due to the creative destruction of capitalism, and noted that "comparative advantage cannot be counted on to create . . . net gains greater than net losses from trade."11

Samuelson's work suggests that while innovation remains key to comparative advantage, innovation *leadership* is increasingly up for grabs in a global economy where many understand the model. The ability of innovation leaders to accelerate the pace of innovation introduction to stay ahead of the "revolving wheel" of comparative innovation advantage becomes ever more important. And clearly, with the old innovation triangle breaking up, U.S. innovation leadership is now being challenged.

What have we been up to for the past eight years in forging a new model to retain innovation advantage and accelerate new technology waves? Not much. Back-to-back reports by the Council on Competitiveness in 2005 and the National Academies in 2006 sounded the alarm on the decline of U.S. R&D; investment and our science education system. In its last two years, the Bush Administration picked up those reports and proposed R&D; increases for three of the six major Federal science agencies (the National Science Foundation, the Department of Energy's Office of Science, and the National Institute of Standards and Technology). Congress passed the America Competes Act in 2007, authorizing a doubling of R&D; over a decade at those agencies and expanded science education efforts at all educational levels.

It sounded promising, but the funding promised for FY 2008 and 2009 in those twin efforts never materialized due to an ongoing budget confrontation between Congress and President Bush. Science and technology never emerged as a high-priority funding item in either branch. Although R&D; and the talent it trains are direct innovation factors, Federal R&D; as a percent of GDP was at 2 percent at its height in 1964, fell to 1.3 percent in 1988 and was below 1 percent in 2008. Federal R&D; in real dollars declined in each of the past two fiscal years. Physical science R&D; has stagnated since the end of the Cold War, and life science R&D;, after a major buildup between 1998 and 2003, has stagnated for five years.

Some technologists believe that the dual challenges of energy security and climate change will spur an energy technology innovation wave worldwide in the coming decades. Although the United States has led virtually every technology revolution since the middle of the 19th century, it is by no means clear it will lead this one. Federal energy R&D;, once 10 percent of the total, stood at less than 2 percent as the Bush Administration came to an end.[12] Federal energy R&D; between 1989 and 2005 fell some 58 percent in real dollars, and private sector energy R&D; similarly declined. While sectors that are implementing major technology advances (IT and biotech) typically spend between 15 and 20 percent of annual revenues on R&D;, the private energy sector spends less than 1 percent.

How does energy compare to other major technology initiatives? The Federal government (in 2002 dollars) invested $185 billion over nine years in R&D; and implementation in the Apollo Project, $445 billion over eight years in the Carter-Reagan defense buildup, $138 billion over five years to double NIH, and $145 billion in the first six years of the ballistic missile defense system—the major technology initiative of the Bush Administration. Federal R&D; in new energy technology in 2008 totaled under $4 billion. We can't launch an energy technology revolution if we are pinching the R&D; fuel line.

Enter Obama

During his presidential campaign in 2008, Barack Obama pushed for a doubling of basic R&D; investments, major new science and math education programs, and a $150 billion energy research and technology initiative. He discussed innovation-based growth and even held a forum on this idea in June 2008 at Carnegie Mellon. But now, as President, he faces a deficit approaching $2 trillion for FY 2009. In other words, he has inherited a bare Federal pantry. Will he still implement a growth economics agenda?

An early test was the stimulus bill, his first big economic statement. Congress passed his $800 billion bill in February, and he has argued it will lead to three million jobs, but what kinds of jobs will they be? Congress passed a classic Keynesian stimulus, funding short-term jobs in traditional infrastructure, rhetorically pouring a lot of concrete and filling endless potholes.

Recessions are not what they used to be. Before the 1990s, they revolved around business cycles. We were still a mostly pre-global economy of large, national-scale industries. Once the business cycle bottomed out, usually after nine months to a year, about half of laid-off employees of these firms began to get their jobs back. This began to change in the early 1990s recession, when almost 60 percent of employees didn't get their old jobs back. In the last recession in the early 2000s, almost 80 percent of employees didn't get their jobs back. They had to find new ones, and it took two years for the recession to bottom out. The recovery was also more gradual. The shape of the recession on employment and GDP growth charts was more like an "L" or perhaps a "U" than the traditional "V." The era of business cycle recessions appears to have been replaced by a time of structural recessions.

Yet the stimulus design Congress seems to be following fits the old cyclical recession pattern: tide workers over with short-term jobs until they get their "real" jobs back. This recession will be structural, like the last two. Whole sectors of the economy will disappear. The last two landed hardest on manufacturing, the most vulnerable sector to low-wage competition from abroad. This one, led by the financial sector, has reached both manufacturing and services. The lesson of the last two recessions was that we had to grow our way out of them. In the early 1990s recession, we brought on the IT-innovation growth wave and added a biotech wave for good measure. After September 11, 2001 and the weeding out of the dot-coms, we brought on a second, more mature (and more modest) phase of the IT wave.

If we are forced to grow our way out of our current economic decline, we won't succeed unless we introduce not just Keynesian cyclical elements but also growth elements into the economy. Aside from the short-term jobs focus, the President included in the stimulus bill $34 billion in energy technology programs, and $22 billion in overall R&D; and new research instrumentation, including $5.5 billion in energy R&D.; He therefore included a modest longer-term growth element, tilted toward energy, in his Keynesian package.

Energy constitutes a potential technology revolution we have been plugging away at for four decades. Elements of it are starting to emerge, despite past low levels of R&D.; Adding these new energy technology growth features to the stimulus could start to prime the pump. The President in his FY 2010 budget next called for a follow-on to stimulus implementation his campaign pledge of a $150 billion, ten-year Clean Energy Technology fund for R&D; and technology to build out that energy growth element. The House Energy Committee, in the pending energy/climate bill, was balking, providing $1 billion for R&D; because it was forced to use cap-and-trade revenues to subsidize established sectors like coal, oil refineries and autos. The energy-technology patient is lying on the table waiting for an R&D; and technology transfusion. Will the President be able to rescue it? Or will we postpone an energy revolution and possible corresponding growth for yet more years? The stakes for our international competitiveness and security are very high.

President Obama is a student of Abraham Lincoln. While Lincoln is thought of as a war President, he was also a growth President. Despite the terrible cost of the Civil War, he put into place building blocks that continue to resound economically. The Morrill Act, which created land grant universities, enabled the United States to become the first economy with mass higher education. His intercontinental railroad project accelerated a transportation-based innovation wave. And the war industries that provided the Union's decisive industrial strength led to the scaled up industrial powerhouse America became in the second half of the 19th century. He also founded the National Academies of Science in March 1863.

Lincoln inherited these notions from Hamilton. After all, the Republican Party of his era was a direct lineal descendant of Hamilton's party—Federalists to Whigs to Republicans. Hamilton's party was the party of commercial strength, strong finance and manufacturing—Lincoln, who built his career as a Whig and a railroad lawyer, simply extended these concepts in a new era. Hamilton's party has disappeared from the scene. Historically, the United States has had three parties, Hamilton's party and two Jeffersonian parties. The two Jeffersonian parties embody the two fundamental and contradictory policies of Hamilton's great rival: small government ("that government is best that governs least") and equality of opportunity. The southern Democratic Party was built on the former, and the northern Democratic Party was built on the latter, as transformed by FDR's New Deal into social entitlement programs. When Richard Nixon hit upon a "southern strategy" as a way to make the Republican Party competitive in Congress, he began an inexorable process whereby what was left of the Hamiltonian party—the Republican Party of Wall Street and Main Street—became dominated by what had been the Southern Democratic Party. So we are left today with two parties, each built on a contradictory, almost schizophrenic, feature in the Jeffersonian brain. The old Hamiltonian party is lost; its economic priorities are the root policies of neither of the remaining Jeffersonian parties. The two remaining parties are locked, as noted at the outset, into a classical economic model that misses the lessons of growth economics altogether.

The old three-way triangle linking defense, industry and the academy is broken. The United States needs a new model if it is to retain its leadership in innovation-based growth. Energy technology offers an opportunity for such a model. If President Obama reaches out and builds a growth program, he will be grafting Hamiltonian (and Lincolnite) features on to a Jeffersonian-FDR party base. If he cannot operationalize his campaign rhetoric on innovation and energy, there will be no foundation for innovation-based growth on the political landscape at a time when those policies have become more vital than ever to the nation's future. He must succeed.

[1]See Philip Auerswald and Zoltan J. Acs, "Defining Prosperity", *The American Interest* (May/June 2009).
[2]Vannevar Bush, as NACA's pre-war chairman, learned there how to run a large, flexible Federal science agency. G. Pascal Zachary, *Endless Frontier: Vannevar Bush, Engineer of the American Century* (MIT Press, 1999), pp. 98–104.
[3]I have detailed these developments in "Power Play", *The American Interest* (November/December 2006). The problems with "left-right" are summarized in Donald Stokes, *Pascal's Quadrant: Basic Science and Technological Innovation* (Brookings Institution Press, 1997).
[4]Nelson, *National Systems of Innovation* (Oxford University Press, 1993), pp. 3–21, 505–23. Christopher Freeman of the University of Sussex first used the term "national innovation system" in a 1987 study evaluating Japan's economy. Freeman, "Japan: A New National Innovation System", in Dosi, Freeman, Nelson, Silverberg, Losete, eds., *Technology and Economy Theory* (Pinter, 1988).
[5]Lundvall, *Innovation, Growth and Social Cohesion* (Edward Elgar, 2002), pp. 53, 58–9. Kenichi Ohmae argues, in contrast, that national systems are fading and a new system of techno-laissez-faire has evolved where national technical competency does not necessarily generate national advantage in *The End of the Nation State* (Simon & Schuster, 1995) and *The Next Global State—Challenges and Opportunities in Our Borderless World* (Wharton, 2005).
[6]See Thomas P. Hughes, *Rescuing Prometheus* (Pantheon, 1998).
[7]See Mitchell Waldrop, *Dream Machine* (Viking, 2001), pp. 462–5.
[8]These three periods are delineated in Barry C. Lynn, *The End of the Line* (Doubleday, 2005), pp. 1–18.
[9]This crucial industrialization step came as a result of some twenty years of War Department investment in machine tools and manufacturing processes in an effort to create interchangeable parts for muskets. See Vernon Ruttan, *Is War Necessary for Economic Growth?* (Oxford University Press, 2006).
[10]Samuelson, "Where Ricardo and Mill Rebut and Confirm Arguments of Mainstream Economists Supporting Globalization", *Journal of Economic Perspectives* (Summer 2004).
[11]Samuelson, "Where Ricardo and Mill . . .".
[12]See Gregory Nemet and Daniel Kammen, "U.S. Energy R&D: Declining Investment, Increasing Need, and the Feasibility of Expansion", *Energy Policy* (February 2007), p.

747; and MIT Washington Office, *Energy R&D, Historical Trends and the Challenge of Future Investment* (October 10, 2008).

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