Chapter 1

Innovation and the Invisible Hand of Government[1]

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The long, deep U.S. recession of 2007–2009 seems very different from earlier economic downturns; it suggests a possible turning point in the nation's economic trajectory. Unemployment has been worse and more persistent in this downturn, and many venerable economic institutions, from Merrill Lynch and Bear Stearns to General Motors and Chrysler, have disappeared or undergone dramatic reorganization; many other firms have had to make fundamental changes in their business models. The crisis has also forced a sharp retreat from the governing philosophy that had been in place since the election of Ronald Reagan in 1980. That philosophy—market fundamentalism—insists that "government is the problem, not the solution," and its preferred remedies for economic problems are tax cuts, relaxed regulation of business and finance, and greater reliance on markets to solve economic and social problems (Block 2007). [2] George W. Bush, who had long championed this approach, had to make a U-turn in the fall of 2008. In the face of a financial collapse, he unleashed an unprecedented government rescue of Wall Street through hundreds of billions of dollars of direct support for firms like Citibank, Bank of America, AIG, Morgan Stanley, and Goldman Sachs (Wessel 2009).

Bush's successor, Barack Obama, continued these extensive government efforts to rescue and reshape major financial institutions, and he has proposed an ambitious program of new regulations for the financial industry. Obama has loaned billions to two out of three of the major automobile firms, reorganized their top management, and guided them through a dramatic reorganization in bankruptcy court. In its early days, the new administration pushed through a huge government stimulus bill devoting billions of dollars to shifting the U.S. economy from oil and coal to alternative energy sources, and the administration continues to pursue plans to reorganize the health care industry and the energy sector.

Moreover, the new administration understands that even as it attempts to pull the economy back from crisis and recession, it faces a number of deeper long-term challenges. One of the most important is the chronic weakness of the U.S. international trade position. For a generation, this trade balance has been strongly negative because of the U.S. appetite for both foreign oil and cheap manufactured imports from Asia. Because of its huge trade deficit, the United States has relied for many years on foreign borrowing to finance its balance of payments deficit, a pattern that many observers think is unsustainable (Obstfeld and Rogoff 2007; Mann and Pluck 2007).

The seriousness of the trade problem is indicated by a measure of the U.S. trade balance in high-tech products, which has also turned negative in recent years (data available at www.census.gov/foreign-trade/Press-Release/current_press_release/ft900.pdf).[3] Historically, the U.S. surplus in global trade for technologically sophisticated products helped offset the deficit for raw materials and basic manufactured goods such as small appliances and apparel. But if the United States is starting to import more high-tech goods than it exports, then the prospects for a significant improvement in the trade balance are even dimmer.

Two other long-term challenges reinforce this focus on the economy's capacity for innovation. The first is the imminent threat of global climate change resulting from rising levels of carbon dioxide in the atmosphere. Without significant shifts away from burning fossil fuels in the United States and other countries, the globe faces rising oceans and increasingly disruptive weather patterns. And it is now widely recognized that progress in this direction requires significant technological advances to bring down the prices for several different sources of renewable energy (Weiss and Bonvillian 2009). The final challenge is the one of assuring new domestic employment opportunities as the economy recovers from the recession. With many jobs moving abroad in both the manufacturing and the service sectors, the administration's political success rests on its ability to bring about vigorous employment growth at home.

For all three of these reasons, the new administration has strongly emphasized strengthening the U.S. economy's capacity for innovation. This focus is particularly clear in the stimulus bill—the American Recovery and Reinvestment Act—passed in January 2009. The idea is that if the United States can capitalize on its scientific and engineering resources to produce a continuous stream of new high-tech products and services, including "green" energy technologies, this would strengthen U.S. exports and expand domestic employment. Just as the U.S. global leadership in computer hardware and software and in biotechnology helped sustain the U.S. economy over the past three decades, it is hoped that building new high-tech and green industries will improve the U.S. competitive position. Moreover, innovations in new energy technologies, in particular, would strengthen the trade balance by reducing U.S. imports of foreign oil (Executive Office of the President 2009) while also reducing the production of greenhouse gases.

But in prioritizing the U.S. innovation economy, the Obama administration faces a series of difficult questions. How does innovation actually work in the current U.S. economy? What are the respective contributions of the private sector and the public sector in facilitating innovation? What policies can and should the government use to accelerate innovation in the private sector?

This book is intended to provide answers to these questions. Each chapter is based on careful, in-depth research on how the innovation economy actually works both in the United States and in other nations. Through a series of detailed case studies—of particular industries and of specific government technology programs—the chapters are designed to illuminate the landscape of effective innovation and suggest the lessons that have been learned from recent innovation efforts.

This introductory chapter is designed to set the stage for the more detailed arguments of the following chapters by tracing out the history of innovation policies in the United States and by providing an overview of the complex institutional structure of the current innovation system in the United States. The introduction will elaborate the key finding that emerges from the chapters—that the United States, particularly over the past three decades, has developed a sophisticated and complex innovation system in which the government plays an absolutely central role. The current administration in Washington does not have to begin from scratch; it has the opportunity to refine and improve a system that has been developing for some time.

The introduction will also explore the intersection between the book's findings and the question of governance philosophy with which the current administration and the larger society are currently wrestling. The severity of the 2007–2009 financial and economic crisis and the fact that it was precipitated by significant regulatory failures in the financial sector has discredited the market fundamentalist views that have dominated U.S. politics since the 1980s. But the new administration has not yet advanced an alternative governing philosophy. On the contrary, the president has repeatedly affirmed his commitment to the free market and has argued that the measures he is taking are simply designed to make markets work more effectively. Obama has repeatedly invoked his commitment to pragmatism—a search for solutions unconstrained by any ideological commitments.

However, there are many reasons for doubting that pragmatism will be sufficient to guide the nation through a series of difficult transitions. It is a basic law of politics that you cannot beat something with nothing. When opponents endlessly recycle the familiar claims of market fundamentalism that government must get out of the way of the private economy, the administration has to explain that these are stale and outmoded ideas. But it is very difficult to do that without articulating an alternative governing philosophy and a roadmap of where the country is headed.

This is where the innovation economy looms large. The historical experience with the innovation economy provides powerful arguments against the core assumptions of market fundamentalism. For many technologies, it has not been Adam Smith's invisible hand, but the hand of government that has proven decisive in their development. Moreover, the innovation economy depends on a series of principles that are at fundamental variance with market fundamentalism. In fact, careful study of the innovation economy helps us see some of the outline of a new governance philosophy that could provide a durable foundation for prosperity in the United States in the twenty-first century.

The introduction will address these different tasks in three parts. The first shows how the dramatic changes in the innovation economy of the last thirty years have been built on top of a set of institutions that have a much longer history. The second part describes how the different elements of the current innovation system fit together. The third part extracts the principles of governance on which this innovation economy rests.

Historical Overview

From World War II to the early 1970s, theorists of market fundamentalism were largely on the margins of economic and political debates in the United States (Block 2007; Leopold 2009). The prevailing Keynesian consensus insisted that government had a fundamental role in guiding the economy and maintaining high levels of investment and employment. However, as the U.S. economy experienced growing economic difficulties in the 1970s, the market fundamentalist critique of Keynesianism and "big government" gained traction. Starting with the election of Ronald Reagan in 1980, market fundamentalists returned to power and their ideas dominated policy debates in the United States until the financial crisis in 2008.

Market fundamentalists argue that the best policy is to rely to the greatest extent possible on allegedly self-regulating markets while keeping the government's economic activity to a minimum. The thinkers who were most important in popularizing these ideas, particularly Milton Friedman, George Stigler, and other figures from the Chicago School of Economics, long insisted that the United States had taken a wrong turn during Franklin Roosevelt's New Deal in the 1930s, when the government role in the economy was significantly expanded through both increased regulation of business and expanded public provision through old age and unemployment assistance.

These thinkers wanted to go back to the pre–New Deal regime of limited government, and they argued that the dynamic economic growth that the country enjoyed for most of the century and a half from the founding of the Republic to the start of the New Deal was a direct consequence of reliance on markets and small government (Friedman and Friedman 1990). Their vision of a halcyon American past meant that they had to ignore or downplay the poverty, misery, and mass unemployment that was widespread as industrialization progressed during the course of the nineteenth century (Katz 1986; Keyssar 1986).

But even more importantly, they had to create a fictive American past in which the substantial economic role played by government—from the founding—was made to disappear. The history of the United States is no different from that of other modern countries; fighting wars and preparing for wars have been an absolutely critical spur to economic growth and development (Roland 2003; Ruttan 2006). Many of the key industrial and organizational breakthroughs of the late eighteenth and nineteenth centuries came in industries that were developing weapons or other supplies, such as ships or uniforms, that were being procured on a large scale by the military (Smith 1985; Ruttan 2006). Starting with the Revolutionary War, continuing with the War of 1812, the wars against the Native Americans, and the Civil War, some of the most important innovations in production and organizational technologies came in the manufacture of guns and other weapons. In fact, the rifle figures prominently in manufacturing history as one of the first instances of the use of interchangeable parts to facilitate expanded production (Hounshell 1984; Ruttan 2006; Smith 1977). Moreover, the machine tools developed for weapons production then migrated to industries producing sewing machines, bicycles, and ultimately automobiles (Rosenberg 1963; Ruttan 2006).

The government began to invest in technological expertise for military purposes in the first years of the Republic (Angevine 2004). The Army Corps of Engineers was created in 1802, and military academies such as West Point, the Naval Academy, and the Citadel were the earliest instances of government investment in higher education. As early as the 1820s and 1830s, army engineers were at work building canals and lighthouses, and improving river navigation—projects that had both military and commercial implications (Shallat 1994).

This same pattern, of course, continued into the present century. World War I dramatically accelerated the development of automobiles, airplanes, and radio. The government directly mobilized the research laboratories of major corporations for the war effort, and important scientists and engineers, drawing on the wartime experience, began to argue in the 1920s for the creation of a national research endowment through which the U.S. government would adopt a permanent role in financing key scientific and technological research. While that idea gained little political traction, the government did establish the Naval Research Laboratory in 1923, which was the military's first venture in creating a permanent peacetime laboratory (Wise 1985).

But the market fundamentalist version of the pre–New Deal past also has to ignore a very long history of deliberate state initiatives that did not have an immediate military justification.[4] This goes back to Alexander Hamilton's famous *Report on Manufactures* (1791) that insisted, against the laissez-faire orthodoxy of that day, that the young Republic needed to use policies such as tariffs and government procurement contracts to nurture new industries to make the nation competitive with the advanced nations of Europe (Bourgin 1989; Chang 2008). While Hamilton's report was never fully implemented, it still provided valuable arguments for those eager to use the state to pursue industrial ends, and U.S. industrialization proceeded behind high tariff walls through the nineteenth century.

Hamiltonian ideas helped inspire the aggressive role of state governments in building canals and railroads in the first half of the nineteenth century. Sometimes these efforts were directly financed out of state funds and sometimes state governments would organize and subsidize newly created private entities to do the work (Angevine 2004; Dobbin 1994). Either way, these transportation innovations played an important role in driving economic growth in the antebellum period.

With Lincoln's presidency and the coming of the Civil War, the initiative in economic policy shifted definitively toward the federal government. Lincoln launched the building of the intercontinental railroad, which probably ranked at the time among the most ambitious efforts in human history (Ambrose 2000). Lincoln also presided over the creation of the Department of Agriculture and the start of the land grant colleges, which were conceived as efforts to modernize society's dominant economic sector—farming. In fact, the first permanent government laboratory was established in the 1860s in the Department of Agriculture to do research on plant and animal diseases and soil quality (Harding 1947). Lincoln also recognized the growing role of scientific knowledge when he signed the legislation for the National Academy of Sciences—a nonprofit organization designed so that the organized scientific community could provide continuous input and advice to the government (Kleinman 1995).

The steps taken in the Civil War period laid the foundation for rapid economic growth and the creation of an integrated national economy in the last three decades of the nineteenth century. But the volatility and other dangers generated by this new industrial economy produced a new wave of federal initiatives in the first years of the twentieth century. In search of greater stability, Progressive Era reformers extended the reach of the national government. The first federal laboratory with expertise in the physical sciences was started in 1901 in the newly created National Bureau of Standards. This bureau was created to emulate what the USDA had done for agriculture —to promote expertise that would accelerate industrial development. The NBS (later renamed the National Institute of Standards and Technology, or NIST) played an important role in radio and telephony (Allen and Sriram 2000; Needell 2000).

A series of new federal regulatory institutions were also created in this period. The Pure Food and Drug Act of 1906 created the agency that would ultimately become the Food and Drug Administration (1906), and the Federal Reserve Board (1913) and the Federal Trade Commission (1914) were also products of this period. These agencies came to play a dual role. On the one side, they acted as regulatory police to prevent businesses from pursuing strategies that could be economically destructive. On the other, they often acted as partners or collaborators helping businesses to stabilize markets, maintain competition, and adopt more effective business practices (Hilts 2003; Greider 1987; Berk 2009). Berk (2009) conceptualizes this approach as “regulated competition” and gives Louis Brandeis much of the credit for bringing this idea into the policy arena.

In short, the market fundamentalist history of the U.S. economy before the New Deal is basically fanciful. Leaving warfare and armaments out of the history of U.S. industry is like the proverbial production of Hamlet without the prince. But even beyond that, economic development in the nineteenth century and in the first decades of the twentieth depended on an ongoing partnership between the government and business. Government provided necessary infrastructure such as roads, canals, railroads, and harbors, and helped train the labor force and build the society’s technological capabilities; government agencies worked to facilitate the diffusion of productive innovations in agriculture, industry, and services.

But if this government-business partnership has been a constant of U.S. history since the founding of the Republic, there is no question that the intensity and importance of the government role in driving innovation has intensified dramatically over the past seven decades. Three key turning points significantly tilted the curve toward a heightened role for the federal government. These are each points of inflection where the impact of government innovation activity became even more central to the organization of the U.S. economy. But there is a great deal of continuity across these different periods, and each one builds on the previous ones in important ways.

The First Turning Point: World War II and the Rise of a Science State

While the market fundamentalists emphasize FDR’s New Deal measures as the critical turning point, in reality World War II was far more important for innovation policies. Some of the newly created New Deal agencies played the same role that earlier regulatory agencies had played—

helping to facilitate innovation through regulated competition. For example, the Federal Housing Authority helped real estate developers by creating a set of standards for the building of new residential subdivisions (Weiss 1987). But the real sea change came with World War II, which saw a dramatic expansion in the government's technological capacities. Since there was an almost immediate transition to the Cold War, these new capacities became institutionalized on a permanent basis.

The first aspect of the shift was that during World War II and the early Cold War years, the government's scientific and technological capacity was expanded through the creation of an elaborate network of permanent federal laboratories staffed with highly trained scientists and engineers (Hooks 1991; Kleinman 1995; Westwick 2003). To be sure, the roots of this government capacity go back to the creation of the Army Corps of Engineers and the first laboratories at the Department of Agriculture and the Bureau of Standards. However, the Manhattan Project created the system of atomic laboratories, including Los Alamos, Lawrence Berkeley, Oak Ridge, and Sandia, that still exists almost seventy years later (Westwick 2003). As indicated in Schrank (Chapter 5) and Block and Keller (Chapter 8), this system of laboratories has become central to the current U.S. innovation system.

World War II also made the federal government the principal source of funding for foundational scientific research. This shift was consolidated in the early Cold War years with the creation of the National Science Foundation in 1950 (Kleinman 1995). The experience of the Manhattan Project, when physicists went to the government to instruct policymakers about the military implications of a new technology, marked an historical turning point. From that moment onward, the federal government exercised sufficient oversight over the scientific community through funding that it could anticipate which new technologies might have military applications. As Shelley Hurt shows (Chapter 2), even before scientists had made the key breakthroughs in combining DNA to produce new organisms, policymakers in the Nixon administration were keenly aware that developments in genetic engineering could produce new generations of biological weaponry as well as new commercial products.

Another aspect of the shift that began in World War II was that a significant cadre of government officials took more direct responsibility for pushing forward the technological frontier. Some did this by running government laboratories and motivating scientists and engineers to solve specific technological problems. Others did this in their capacity as providers of funding for research going on in the private sector and in universities or as people responsible for procurement who insisted that vendors provide products that accomplish certain technical objectives. But in all these cases, nurturing innovation became an important part of the job description for a substantial number of government workers. This also represented a significant historical shift.

Sometimes, to be sure, these officials spent large sums of money on technological dead ends or white elephants that had little durable value (Alic 2007). But it is still important that for the first time in U.S. history, a group of people were empowered by their society to direct the process of technological development in particular directions. This represented a significant change from reliance during peacetime on the creativity of scientists and engineers working in university and corporate laboratories.

Even so, it remains difficult to assess the costs and benefits of the shift that started during World War II. If we think of the years from Pearl Harbor in 1941 until the Soviet launch of Sputnik in 1957 as a single period, the technological achievements are quite spectacular. This newly created military-industrial complex built thousands of planes and tanks, developed the atomic bomb, the hydrogen bomb, civilian nuclear power, the computer, the transistor, the semiconductor, made major advances in airplane, radar, and missile technology, and completed much of the preparatory work for the laser. On the other hand, spending on technology of this period was at historically unprecedented levels, and there was unquestionably an enormous amount of waste in this system (Alic 2007). Whether or not the technological gains were proportionate with the increased spending is a debate that will not soon be resolved.

The Second Turning Point: 1957 and the Move to Greater Decentralization

Two separate events that happened in 1957 established another inflection point in the development of the innovation system in the United States. The first was the Soviet Sputnik launch in October 1957. This created considerable panic in U.S. policy circles over the loss of U.S. technological advantage relative to its Cold War enemy. Washington rushed to make adjustments, including the reorganization of the space program through the creation of NASA and the passage of the National Defense Education Act to strengthen U.S. education, particularly in math and science. But for our purposes, the most significant change was the creation in 1958 of the Defense Advanced Research Projects Agency (DARPA) in the Defense Department (Roland 2002, Bonvillian 2009).[5] Up until the creation of DARPA in 1958, all military R&D dollars were controlled by the military services themselves. The idea behind DARPA was to devote some portion of military spending to "blue sky thinking"—beyond the horizon ideas—that might not produce anything usable for another ten or twenty years. Freed from the constraints of weapons procurement, DARPA was able to experiment with new strategies for accelerating the development of innovative technologies. The agency made a huge contribution to the development of the computer industry in the 1960s and 1970s by funding the creation of computer science departments, providing early research support to some of the most promising start-up firms, supporting key research on semiconductors and on the human computer interface, and ultimately overseeing the earliest incarnation of the Internet (National Research Council 1999; Waldrop 2001).

The second key event was the 1957 revolt by a group of scientists and engineers who were working for a firm started by William Shockley, the Nobel Prize–winning physicist who had developed the first transistor at Bell Labs (Lecuyer 2006). The rebels, labeled for all history as the "traitorous eight," broke away to start a new firm with the support of Fairchild Camera and

Instrument Company. The new firm made significant advances in semiconductor technology and helped establish the engineer-run spin-off as a viable business model for pushing the technological envelope.[6]

Several of the eight went on to found Intel and other firms. One of them, Eugene Kleiner, started Kleiner Perkins, the pioneering venture capital firm which demonstrated that substantial money could be made by those willing to invest and support these engineer-run spin-offs. But most importantly, the Fairchild pioneers helped to establish a new paradigm where economic growth depended not so much on the consolidation of giant corporations, but rather on a process of economic fission that was constantly spinning off new economic challengers. Sometimes these new firms were started by defectors from established firms and sometimes by researchers in university and government laboratories, but the consequence was the same—to expand the number of ideas that were moving from laboratory to marketplace.

These two separate events achieved a convergence in the 1960s as DARPA's program officers began to exploit the possibilities of this new innovation environment. With standard defense contracting, the leverage of government officials to generate rapid technological advances was somewhat limited. Once they had a contract, big defense firms could use their political muscle on Capitol Hill to protect them from what they perceived to be excessive demands for innovation. Even when procurement officers tried to use competition among firms for the initial contract as a means to achieve ambitious technological breakthroughs, leverage was restricted because the number of firms with the appropriate competence was limited and those firms had a common interest in pushing back when they were pressured to take chances on risky, unproven technological pathways.[7]

However, DARPA's program officers came to see that things could work differently in industries where there were already some ambitious new start-up firms and the potential for more. This kind of environment made it much easier for program officers to generate real competition among different groups of researchers since those running the startup firms understood that their firm's future viability rested on meeting ambitious benchmarks. Moreover, this leverage could be had with much smaller dollar amounts than were needed to influence the decisions of giant defense contractors; a few million dollars, while insignificant for a multibillion-dollar firm, could look like a huge amount of money to a newly formed firm.

Moreover, as the possibility of creating spin-offs became institutionalized, established firms also had to adapt to the new environment. Large firms had to worry that their best scientists and engineers might leave to pursue their research interests in another setting. This meant that when DARPA expressed interest in providing funding to a research group at established firms such as IBM or Xerox, management had strong reasons to endorse the project even if it did not fit with the firm's priorities. Consequently DARPA had the ability to mobilize effort by technologists in the most common research settings—big firms, small firms, and university and government laboratories.

Since DARPA gave its program officers a great deal of discretion and avoided the elaborate grant writing and refereeing procedures used by NSF and NIH, its program officers were able to take maximum advantage of this enhanced leverage. With less paperwork, they could get the money flowing quickly, but they also had no hesitation in cutting off funding for research groups that were unable to make progress in meeting technological benchmarks. They also used their funding networks to accelerate the flow of knowledge across competing research groups. They brought their funded researchers together for periodic workshops to share ideas and find out which technological pathways had been identified as dead ends by other groups.

When DARPA officers were working with start-ups or with university researchers who had not yet created a firm, they used their network ties to help move the particular technology to the marketplace. This might mean connecting a professor with an entrepreneur who was willing to build a new firm, linking a start-up firm to venture capitalists who could provide both capital and technical assistance, locating a larger company that was willing and eager to commercialize the technology, or helping the firm get a government procurement contract that would support the commercialization process.

In addition, DARPA officers often intervened to expand the pool of scientists and engineers working on a particular problem. They did this in the 1960s by financing the creation of new computer science departments at a series of different universities. By multiplying the number of researchers with the specific expertise that was needed to improve computer programming or develop faster microprocessors, they could accelerate the pace of technological change for an extended period of time.

One particular example illustrates how effectively the DARPA model worked in synchrony with a more open and decentralized model of technological development. In the second half of the 1970s, it became apparent that the fabrication of new computer chips had become a major bottleneck for technological development. Many people, including some graduate students in computer science, had the capacity to design new chips, but getting a design into a prototype was expensive and only the more established actors were able to persuade firms to make this investment. DARPA stepped in and financed a laboratory, affiliated with the University of Southern California, whose mission was to fabricate chips from anybody who claimed to have a superior design. By taking on this expense, the agency opened the way for more participants in the effort to produce faster and better microchips (Roland 2002).

The Third Turning Point: The 1980s and More Agencies Enter the Picture

The third turning point is a bit more complicated because it coincided with the resurgence of free market rhetoric during the Reagan administration. The conventional wisdom is that during the administration of Ronald Reagan those who argued that the United States should embrace an active "industrial policy" to deal with the competitive threat from foreign firms were decisively defeated

(Graham 1992) as the government, instead, chose to rely on private markets. But under Reagan, the government took a number of major steps to build on DARPA's successes in pursuing a highly decentralized form of industrial policy. While this turning point has been largely overlooked, it has proven hugely consequential for the development of U.S. innovation capacity.

The choices made in the Reagan years flowed logically from three converging trends that dated back to the 1960s and intensified in the 1970s. The first was the continuing problem in the U.S. international trade balance. For the first two decades after the end of World War II, the United States exported much more than it imported. But as Japanese and Western European producers began to catch up with U.S. producers in a number of major industries, including automobiles, U.S. imports of manufactured goods rose, pushing the United States toward a deficit position (Block 1977; Hughes 2005). Starting in the Nixon administration and continuing in the Carter administration, there was much high-level debate about how the United States could use its scientific and technological leadership to reestablish its advantage in international trade (Hughes 2005). As early as the Nixon administration, policymakers were conceptualizing new forms of public-private partnership to address this problem (Hurt, Chapter 2).

Second, as the trade deficit worsened during the 1970s, there were increasingly vocal calls for the United States to embrace an industrial policy that followed the model that Japan had used to transform itself into an advanced industrial economy (Graham 1992; Hughes 2005). Proponents argued that the creation of a centralized industrial policy agency could help the United States both to revitalize declining industries such as auto and steel and to provide the capital and incentives required to seed the growth of new industries based on cutting-edge technologies. When the Carter administration loaned Chrysler Motors billions of dollars to avoid bankruptcy, some observers saw this as a bold first step in the direction of the Japanese model (Hughes 2005).

A third trend cut in a different direction. Over the course of the 1970s, policymakers became increasingly aware of DARPA's successes in pursuing decentralized industrial policy initiatives. It was during the 1970s that the personal computer emerged, with Apple introducing its first model in 1976. This brought a great deal of attention to the dramatic growth of the computer industry in Silicon Valley and to DARPA's critical role in setting the context for the explosive growth of personal computing (Fong 2001).

But the big developments in biotechnology in the 1970s were also critical for persuading policymakers that the computer industry was not a unique case. The founding of Genentech in 1976 showed that university-based scientists could be persuaded to transform their academic research into new businesses and that government agencies could help accelerate this process by targeting research funding and helping these academic entrepreneurs overcome the obstacles to successful commercialization of their ideas (Collins 2004; Vallas, Kleinman, and Biscotti, Chapter 3).

In the final years of the Carter administration, several steps were taken to accelerate this decentralized vision of technological development by mobilizing the government's research assets. The National Science Foundation began to experiment with the creation of industry-university research centers that would focus the energies of a group of scientists, often at multiple institutions, on the concrete technological problems faced by a particular industry (Turner 2006).

In 1980 Congress passed the Stevenson-Wydler Technology Innovation Act, which encouraged the network of federal laboratories to engage in direct collaboration with state and local governments, universities, and private industry on research efforts. It also mandated that the laboratories spend funds on technology transfer activities. The more famous Bayh-Dole Act in the same year encouraged universities and small businesses to pursue commercial exploitation of technological breakthroughs that resulted from federally funded research. While there is dispute as to how much difference this legislation has actually made (Lowe, Mowery, and Sampat 2004), the new legislation served an important symbolic function in legitimating close cooperation between university researchers and industry.

When the Reagan administration began in 1981, its free market ideology ruled out any consideration of planning or industrial policy on the Japanese model. However, the administration proved much more pragmatic when it came to building on the DARPA model of decentralized industrial policy. In fact, the Reagan administration significantly accelerated the implementation of policy ideas that had been generated by the Nixon and Carter administrations (Block 2008; Slaughter and Rhoades 2002). In 1982 Reagan signed the Small Business Innovation Development Act that built on a pilot program initiated by the National Science Foundation during the Carter administration. Under this Small Business Innovation Research (SBIR) program, government agencies with large research budgets were required to devote a fraction, initially 1.25 percent of their research funding, to support initiatives that came from small, independent, for-profit firms. The program provided small Phase I awards of $50,000 that could be followed by larger Phase II awards of $500,000 as firms met benchmarks for turning ideas into marketable products. As shown in Chapter 8, over the last quarter century, this program has supported many highly innovative start-up firms.

Legislation passed in 1984 created a blanket antitrust exemption for private firms to engage in cooperative research efforts to develop new products. It created the legal foundation to establish industry-wide research consortia that shared funding and information on “precompetitive” research. The Reagan administration followed up on this in 1987 by helping to fund SEMATECH—a research collaboration that helped U.S. semiconductor firms meet increasingly intense competitive pressure from Japan. A 1986 bill established the legal framework for cooperative research and development agreements (CRADAs) between federal laboratories and private firms that would give firms the right to commercially exploit research findings that originated at those laboratories.

Finally, the Omnibus Trade and Competitiveness Act of 1988 created two new programs that were designed to improve U.S. competitiveness. The Advanced Technology Program provided a federal matching grant for private sector research efforts designed to commercialize promising new technologies. Its potential recipients included both big businesses and small (Negoita, Chapter

4). The manufacturing extension program was developed on the analogy with agricultural extension. It created a decentralized program to provide expertise at the local level to help manufacturers make use of advanced technologies (Hallacher 2005).

After Reagan

The twenty years from 1989 to 2008 saw an incremental evolution of the various technology initiatives that had been put in place through the Reagan years. Spending for many of the programs expanded and an increasing number of government agencies gained experience in employing the tools that DARPA had initially developed to accelerate the commercialization of new technologies. There was also substantial growth in the network of new institutions at the state and local levels that worked in cooperation with federal programs to make a decentralized system of technology incubation effective. For example, state and local governments funded organizations that helped aspiring entrepreneurs figure out how to make effective applications to the SBIR program to fund their projects.

There were, however, some intense political fights over this newly emergent innovation system (Hughes 2005). The most intense fight centered on the Advanced Technology Program (ATP) in the Department of Commerce (Negoita, Chapter 4). The ATP program provided federal matching funds to help firms—both small and big—overcome technological barriers across all industrial sectors. When Bill Clinton became president in 1993, he had ambitious plans to expand the ATP program and he brought in a veteran of DARPA to direct this expanded effort.[8] However, Republicans opposed these plans, arguing that what ATP was doing was "industrial policy" and hence illegitimate. As Negoita (Chapter 4) shows, what made ATP vulnerable to this argument is that it did not have a mission justification, unlike the defense agencies or the National Institutes of Health that had a mission to fight disease. Nor could it be defended like the SBIR program on the grounds that it was solely a supporter of small business, since some of its funds went to large corporations.

When the Republicans gained control of Congress in 1994, they tried to eliminate the program by cutting its funding, and George W. Bush tried to do the same in successive budgets. The program was finally phased out in 2007 because it could not overcome its history as a lightning rod for criticism from the right. But what is really important about this story is how unique the political attack on ATP was. The manufacturing extension program enjoyed bipartisan support through this period (Hallacher 2005), and there are few complaints about technology initiatives at the National Science Foundation or at the Department of Energy. George W. Bush's budgets continued to increase funding for the National Institutes of Health up through 2006, and Bush also expanded funding for the National Nanotechnology Initiative designed to help develop new materials constructed at the atomic or molecular level that can be used by a wide range of different industries (Appelbaum et al., Chapter 11).

What is most striking about this recent period is that with the exception of the fights over ATP, there is a discrepancy between the growing importance of these federal initiatives and the absence of public debate or discussion about them. By the decade of the 2000s, most important innovations in the U.S. economy were receiving support from these federal initiatives and even many historically low-tech industries were taking advantage of new scientific breakthroughs nurtured by this system (Block and Keller, Chapter 8). Yet journalists rarely report on these programs, few academics write about them, and most politicians ignore them.

The contrast is particularly dramatic with the SBIR program (Wessner 2008). It serves as one of the central linchpins of this new innovation system because it is the first place that many technological entrepreneurs go for funding. Providing more than $2 billion per year in direct support to high-tech firms, the program has nurtured new enterprises and moved hundreds of new technologies from the laboratory to the marketplace. And yet the program receives little attention from journalists; the *New York Times* mentioned it only about eight times in its first twenty-five years of existence. This lack of visibility became a real problem between 2008 and 2010 when SBIR's normally routine reauthorization was jeopardized by congressional proposals that could have severely undermined the program's effectiveness. In short, the program is so obscure that even many in Congress do not recognize its value and importance.

The Obama Administration and a Possible Fourth Turning Point

The Obama administration took office in January 2009 when the U.S. economy was in free fall from the financial crisis that had begun with the meltdown of the mortgage finance system. The administration quickly pushed for a major stimulus bill that was designed to put a floor under the economy by supporting aggregate demand. Much of this bill was devoted to tax cuts and relief to state governments so that they would not have to make huge new cuts in the face of declining tax revenues. But the new administration also included a significant amount of money that was designed to finance innovation and the rebuilding of infrastructure.

More specifically, the American Recovery and Reinvestment Act allocated tens of billions of dollars to the Department of Energy to support the development of a series of alternative energy technologies as well as efforts to retrofit existing structures to reduce energy waste. Two aspects of this initiative are particularly noteworthy. First, the scale of the funding represents an unprecedented expansion of government efforts to shape innovation in the civilian economy. Newly allocated funds, as well as loan programs that had been authorized but barely used in previous legislation, mean that the Department of Energy can ramp up its efforts across the entire technological life course. At the same time, a newly funded program called ARPA-E, deliberately patterned on the Defense Department model, has allowed DOE to fund "blue sky" energy ideas that might take twenty years or longer to reach fruition. Recently the Department of Energy signaled its seriousness by funding forty-six new energy frontier research centers with $777 million over five years, thirty-one of which would be based at universities and another twelve at federal laboratories, with the remainder at nonprofits and one at a corporation.

Second, the scale of the funding means that the Department of Energy is also empowered to move mature technologies into the stage of broad production and deployment. Through matching funds and loan programs, the department is providing firms with hundreds of millions of dollars to build productive facilities for solar panels, a new generation of batteries for electric cars, and large-scale demonstration projects for biofuels made from materials that do not compete with food production. Other programs are specifically designed to overcome the obstacles to the widespread deployment of photovoltaics on the rooftops of homes and businesses.

The DOE initiatives represent an effort to overcome what has been the key weakness in the U.S. innovation system—a failure to provide government support during the critical period when a new technology has to be ramped up for mass production or mass deployment. That weakness accounts for the fact that after inventing the Internet, the United States slipped to fifteenth in the world in citizen access to high speed connections to the web. The same thing happened with the United States declining to eighth in the world in the deployment of photovoltaics to generate electricity (Knight, Chapter 9). Yet another example of this process happened with flat panel displays; while the United States pioneered the key technological breakthroughs, production quickly moved to East Asia since the U.S. government was unwilling to help domestic firms solve the problems of mass production (Block 2008).

The DOE is trying to break this pattern by providing direct assistance to firms building production facilities in the United States for the batteries needed to power a new generation of plug-in hybrid cars. And similar efforts are in motion to build U.S. productive capacity for solar energy, wind energy, and biofuels. To be sure, the success of these efforts cannot be assumed, and the resources made available through the 2009 stimulus will be exhausted within a couple of years. So it remains an open question as to whether the Obama administration will preside over a fourth turning point in the development of the U.S. government's capacity to support innovation across the civilian economy.

One factor in determining whether 2009 represents a fourth inflection point will be the success of the Obama administration in explaining to the public how its innovation policies build on government capacities that have been expanding for decades. That requires explaining how the system is organized and the principles on which it is based.

Institutional Design: How the Innovation System Is Organized

Explaining what the innovation system that has evolved since the Reagan years looks like is not easy because the system is highly decentralized and comprises a lot of overlapping elements. This complexity is, in part, intentional because the innovation process is highly uncertain; even the best scientists and engineers spend a lot of time wandering down false pathways. Moreover, overlap and redundancy increase the chances that somebody with an unorthodox but promising idea will have a chance to persuade some funding agency to support his or her efforts.

{Insert Figure 1.1 Here}

Yet a schematic diagram can be a useful aid in understanding the different parts of the system; the figure can be thought of as two intersecting mushrooms (see Figure 1.1). There are four key elements—the two stems and the two tops. While all four elements are critical for the system to work, the most important innovation activities take place in the significant area where the two tops intersect. The stem on the left represents academic scientists working in university departments to push forward the frontiers of science. Most of their research activity is funded by the government through long-established agencies such as the National Science Foundation and the National Institutes of Health. The research going on here is focused on solving scientific puzzles, but as we have learned repeatedly, this core scientific work can have unexpected practical and commercial applications.

The idea is that the stem on the left provides the necessary supports for the research work that goes on in the left top. The left top represents laboratory settings where government and university scientists and engineers are using their knowledge to solve more concrete problems, such as developing effective vaccines against HIV or upholding Moore's Law by again doubling the capacity of a microchip (Fuchs, Chapter 7). The two main types of institutions here are the network of federal laboratories and hundreds of university-based centers and laboratories with a focus on specific issues that often cut across a number of scientific fields. The federal labs range from the giant nuclear facilities such as Lawrence Berkeley, Los Alamos, and Oak Ridge to the various laboratories at the National Institutes of Health, and dozens of small, specialized laboratories in both defense and nondefense agencies. Most of these federal laboratories are multidisciplinary, so they can easily bring scientists from diverse fields to bear on particular problems.

Some of these laboratories have taken aggressive steps to encourage their scientists and engineers to start new firms to commercialize their discoveries (Schrank, Chapter 5). Consequently they have become engines of regional economic growth, spinning off a series of new firms that have created an agglomeration of new high-tech industries. But many of the federal laboratories have also become sites for nonlocal collaborations. Business firms, both small and large, increasingly come to these laboratories for help in solving their technological problems. This may mean using the facilities of the laboratories to run their experiments or developing a cooperative research and development agreement to work on a project with laboratory scientists; sometimes it involves Work for Others, where the business firm pays the lab to do research.[9]

The network of atomic laboratories evolved out of an earlier institutional structure—the university-based laboratory that relied on outside funding to hire a permanent staff—much of which was separate from academic departments. The Lawrence Berkeley National Laboratory had been founded back in 1931 as the Radiation Laboratory, and parallel institutions such as the MIT

Radiation Laboratory had a long history of support from the military (Westwick 2003). Through the Cold War years, the military services funded dozens of these specialized laboratories or research centers on university campuses to focus the attention of scientists and engineers on particular technological challenges.

The big change that started in the late 1970s was the systematic effort by the federal government to expand this model to include industry. The purest model is represented by NSF's program for industry-university collaborative research centers. These are awarded like other NSF grants on a competitive basis, but the academic entrepreneur who gets the grant has to recruit an industry advisory committee with the idea that the center could eventually become self-supporting with industry participants making annual support payments (Geiger and Sa 2008). The centers also build bridges to other academic institutions to mobilize collaborative efforts of other experts in that specific field. The center is intended to become a collaborative public space where industry and university technologists work in close cooperation to solve key technological problems (Lester and Piore 2004), ideally creating enough intellectual excitement to attract graduate students to focus their energy on this particular set of issues.

NSF-funded centers now represent a small fraction of all the specialized university-based centers and laboratories that actively include business partners. Some of these are now being initially funded by business groups, some get their funding from state and local governments, some are funded through congressional earmarks, and new ones are constantly being created by both military and civilian government agencies.

It is in this left mushroom top where much of the society's effort at technological development is now occurring. Most of the large corporations have been cutting back internally funded research operations and are now depending on these sites for key technological breakthroughs (Block and Keller, Chapter 8). But the central point is that the old dividing line between public and private has become increasingly fuzzy and indistinct in these settings. Whether in federal laboratories or university-industry centers, publicly funded scientists and engineers are often working side by side with scientists and engineers from industry. They can even be the same people, since a university-based researcher might also be the CEO of a firm that is trying to commercialize some of his or her key discoveries.

The mushroom top on the right contains the for-profit business firms, small, medium, and large, that take these new technologies through the final stages of preparation for commercial use. Almost all of these firms depend on work that has been done in the mushroom on the left, and most of the important innovation work now occurs in the area where the two mushrooms intersect—active collaboration between technologists from different organizations. Many traditional large corporations have embraced the idea of "open innovation" that involves a recognition that some of the most valuable new ideas will come to them from the outside (Chesbrough, Vanhaverbeke, and West 2006). Firms of all sizes are engaged in a process of searching out the new technologies that are being developed elsewhere.

The enthusiasm for open innovation reflects a remarkable shift that has occurred over the last three decades; much of the private sector scientific effort has migrated from large firms to smaller firms with 500 or fewer employees. NSF data shows that by 2003, fully half of all Ph.D.'s employed by the private sector worked for firms with 500 or fewer employees (Block and Keller, Chapter 8). But this figure understates the trend because those figures measure only employees; there are also tens of thousands of additional Ph.D. scientists and engineers who are self-employed as consultants or as the proprietors of their own small businesses.[9]

The small businesses that now employ the majority of private sector Ph.D.'s depend heavily on government programs for their survival. The SBIR program is the largest single example, but there are thousands of other small firms that are kept alive by research and development funding from a wide variety of government agencies as well as government procurement contracts. To be sure, many of these small firms also work with larger firms that provide research support and subcontracts, but it is often the public sector support that provides a stable economic base.

One of the most interesting business models is a growing population of firms that are essentially private research and development laboratories that deliberately keep their size below 500 employees to remain eligible for SBIR grants that provide some of their core funding. But they combine this with working under contract with other firms and government agencies on specific projects. When the firm develops a new technology with commercial potential, the usual practice is to sell the technology or spin off a new firm to exploit it. These private R&D laboratories tend to be located in close proximity to major universities or federal laboratories to facilitate cooperation, and a number of them are employee owned, which is a way to signal their strong commitment to the ethic of scientific discovery (one example is Physical Sciences in Andover, Massachusetts).

The stem on the right is the network of support institutions that have evolved to facilitate the commercialization of new technologies. This includes the technology transfer offices at federal laboratories and universities that assist scientists and engineers in the first and second circles to find uses for their discoveries. It includes an increasingly rich mixture of local, state, and nonprofit programs that serve as technology incubators providing a variety of services and supports for start-up firms, including counseling on government grants and business problems. It also includes federally funded programs such as the manufacturing extension program and the National Technology Transfer Center that was founded in 1989 to facilitate partnerships between industry and university and government laboratories.

This stem also includes state-level and private financing sources that invest in these small high-tech firms. While private sector venture capital gets much of the attention, private venture capital firms are generally reluctant to invest in firms that are still years away from having a commercial product. Angel investors, who are willing to take greater risks over a longer period of time, play a greater role in supporting early stage firms as do university endowments, and venture funds set up by nonprofits and state governments (Keller, Chapter 6). The shortage of patient, long-term capital for these start-up firms continues to be one of the major weaknesses of this whole innovation system.

The federal government can be thought of as the soil in which these mushrooms grow. Federal agencies are responsible for most of the funding of the activity in the left mushroom and they also provide significant funding to the other side. Moreover, federal agencies are increasingly active in overcoming the network failures that are endemic to this decentralized innovation system (Whitford and Schrank, Chapter 13). Because both laboratory breakthroughs and the extended process of transforming those breakthroughs into commercial products depend on cooperation across organizational lines—involving complex networks of collaboration—there is a continuing danger that participants will be unable to find trustworthy and competent collaborators.

As detailed in the following chapters, government agencies help scientists, engineers, and entrepreneurs to overcome these network failures in a wide variety of ways. In the model pioneered by DARPA, funders bring together groups of technologists working on the same problems so they can share ideas and generate new insights. Government funders also use their own contact networks to help firms connect to the types of support and expertise that they need, for example, early-stage financing, introductions to potential business partners, or a group of highly specialized researchers at a particular laboratory or university. Officials also validate the competence of particular firms and scientists by awarding them research grants or SBIR funding. Programs such as the Manufacturing Extension Program, the Advanced Technology Program, and the university-industry cooperative research centers work to upgrade the skill levels of industry participants, helping them to master technologies at the cutting edge so they can be competent network partners.

The missing element from this graphic is the citizenry that funds government with its taxes and that purchases—either directly or indirectly—the technologies produced by this innovation system. But the public has been mostly kept in the dark about the workings of this innovation system, especially when it comes to recognizing the role that government plays in this system. There are multiple explanations for this lack of knowledge, but one of the most important is that this system does not fit with the claims of market fundamentalism. The reality is very different from the fables that market fundamentalists tell about self-regulating markets and the inherent limitations of public sector employees who are not continuously disciplined by market calculations.

This lack of public knowledge or understanding is a problem for three reasons. The first is that without public understanding, both the funding and the legitimacy of this system are in constant danger. Demands on the federal budget are intense and the financing for innovation programs always competes with other worthy programs. Moreover, without public understanding and support, ambitious government efforts such as the initiatives by the Department of Energy to accelerate the deployment of carbon-free energy are vulnerable to political attack by market fundamentalists as wasteful, incompetent, and unnecessary. Second, without knowledge, the public cannot push for spending that meets its own priorities. For example, innovation programs at the Department of Agriculture have often prioritized the needs of corporate agriculture over the needs of consumers. Finally, and most importantly, the public in many cases is not just a passive recipient of new technologies; it has to be an active partner in making those technologies effective. For example, the diffusion of the personal computer and the Internet over the past twenty years or the ongoing challenge of improving public health necessarily involved public learning. With the computer, millions and millions of people had to figure out how to boot up a computer and how to manipulate various programs; sometimes they were trained at work but sometimes they had to struggle on their own. Similarly, with health, people have to learn about diet and exercise and what kinds of warning signs indicate the need for immediate medical attention; those with chronic conditions have to master protocols to keep those conditions under control.

This is the point that John Alic elaborates in his chapter: important innovation tends to be a widely diffused process that rests on significant amounts of learning by many people (Alic, Chapter 12). It is not just about something that goes on in laboratories and start-up corporations. Creating the kind of society that is able to take advantage of the innovations that improve people's quality of life requires that the citizenry be an active part of the process. As explained in the book's final chapter (Newfield, Chapter 14), the whole society needs shared narratives about technological possibilities and this requires including the public in the conversation from an early stage.

Organizing Principles and a New Governance Philosophy

The last task of this introduction is to explain the organizing principles of this new innovation system in order to elaborate its implications for a new governance philosophy for the U.S. economy. This is inevitably a task of interpretation, since the current system is far from coherent; it contains discordant and even contradictory elements. Nevertheless, there are three principles that are quite visible in the current system and one that follows logically from the others, even though current practices have not yet embraced this final principle.

Coordinated Decentralization

The most important feature of this system is that high levels of initiative are left to actors on a widely dispersed basis in recognition that overcoming technological barriers cannot be centrally directed. As with science itself, the core idea is that progress is likely to be greatest if different teams of technologists working in different locations have the freedom to experiment with different ways to solve technological puzzles. This is a strategy designed both to prevent the waste of large sums on scientific "white elephants" that lead nowhere (Alic 2006) and to encourage the greatest level of creativity among independent teams of innovators. Decentralization also helps to partially insulate the innovation system from shifts in the balance of partisan advantage and managerial orientation in the nation's capital. As Whitford and Schrank (Chapter 13) argue, it is precisely the advantages of technological decentralization that have transformed the decentralized structure of American politics from a liability to an asset.

However, it is also important to recognize that effective decentralization can coexist with certain forms of central coordination. For example, agricultural extension services were delivered at the local level so that extension agents could compile the particular types of knowledge that were relevant to the crops, climate, and soil issues of a specific place. However, this was consistent with the Department of Agriculture setting standards of best practices for extension agents and attempting to build a sense of professional identity that unified extension agents in different parts of the country. Central coordination can also involve

processes of "road mapping" in which government agencies assemble widely dispersed groups of experts to identify the key transitions that have to occur for a particular technology to become commercially viable. And most importantly of all, actors at the center can assure that competing technology groups are aware of each other's successes and failures in meeting key goals (Fuchs, Chapter 7).

O'Riain (Chapter 10) and Appelbaum and colleagues (Chapter 11) show that Ireland and China are also struggling to achieve the proper balance between decentralization of efforts and centralized coordination. In the Irish case, there is evidence that excessive centralization weakened the initiatives that had been successful in nurturing technological startups. In China, the regime appears to be using the division of labor among different levels of government as a way to counteract excessive centralization.

Public-Private Partnership

What happens on a decentralized basis is a high level of cooperation between public entities and private entities. This is reflected most obviously in the initiatives that involve cost sharing, as when ATP or the Department of Energy matches the funds put up by private firms to cover the research required to overcome a technological barrier. But it is also present when private firms provide support for the NSF's industry-university collaborative research centers or pay the federal labs through Work for Others to tackle a particular problem. And even when the government is providing most of the funding, as with the SBIR program or the public sector venture capital initiatives, both parties still have a very substantial stake in a successful outcome.

Sometimes one side does not live up to the expectations of partnership. When DARPA, for example, pulls back from funding a research project because of insufficient progress, there is bound to be bitterness on the other side. And there have been visible instances where business firms have basically "gamed" their government partners. For example, when the Clinton administration funded the Partnership for a New Generation of Vehicles, the intention was to engage the Big Three automakers in a project of developing fuel-efficient vehicles (Sperling 2001). But the auto companies took the money while continuing to place low priority on the development of hybrid and electric vehicles.

But even when the norms of partnership are violated, it is clear to everyone that partnership implies reciprocity—an obligation to recognize and be sensitive to the legitimate needs of the partner. Government actors, on the one side, recognize that business firms must ultimately figure out a way to survive in the marketplace, while the business firms need to help their funders look good to others in the agency and ultimately to Congress.

Cooperative Sharing of Expertise

The core paradox of innovation is that while firms have strong incentives to keep their knowledge of technical processes a secret from the rest of the world, such secrecy impedes the flow of information among different groups of experts that appears necessary for breakthroughs to happen (Hargadon 2003; Lester and Piore 2004). So firms are constantly trying to figure out how they can protect potentially lucrative "intellectual property" while overcoming the technical barriers to development of a viable commercial product. In short, one of the classic network failures (Whitford and Schrank, Chapter 13) is that a firm's network partner walks away with a key idea that someone else then exploits.

This is precisely why public agencies and publicly funded scientists and engineers loom so large in this new innovation system. First, when a firm brings a problem and shares information with technologists at a federal lab or a university, the risk of commercially consequential loss of proprietary information is relatively small. Even though these scientists and engineers are being strongly encouraged to commercialize their discoveries by starting their own firms, few of them have the stomach or resources to do that while waging a legal battle over intellectual property with an existing firm. Moreover, professional ethics militate against selling a key idea to an interested third party.

Second, the public agencies often serve as a kind of honest broker to encourage firms to behave cooperatively in dealing with each other's intellectual property. In some cases, this is quite explicit. For example, some of the agencies involved with the SBIR program, especially in the military, work hard to connect its awardees with the large contractors that put together the ships, planes, and other weapons systems. Since the SBIR firm has to disclose information about its new technology to persuade Boeing or Northrop Grumman to include it as a subcontractor, it puts itself at risk of the bigger firm assigning its engineers to replicate the small firm's invention. However, the Pentagon treats the SBIR application and reports as certification of the firm's intellectual property, and it makes clear to prime contractors that it will not tolerate taking ideas without compensation.

In other cases, the mechanism is less formal but no less important. As Lester and Piore (2004) have argued, government agencies create "collaborative public spaces" in which technologists from different settings are able to talk freely without worrying about the consequences for future ownership of intellectual property. As Fuchs shows in her chapter, DARPA brings its funded scientists and engineers, some of whom work for industry, to regular workshops to share their ideas to accelerate the flow of knowledge. The funder's presence ensures that everybody behaves cooperatively by disclosing information; a grantee who sought to exploit the situation by absorbing everyone else's ideas while keeping its own progress secret would likely risk losing any future funding. A similar dynamic appears to work in the industry consortia that are funded by government agencies or in the NSF-funded industry-university collaborative research centers.

Fuchs (Chapter 7) also describes certain "platform technologies" (Tassey 2007) that might not develop at all without a government role in forging cooperation across a large number of industry actors. The problem is that the initial investment in these platform technologies is too great and too risky for any one firm or even several firms to do on their own. Her example is the shift to silicon photonics as the next strategy for developing future generations of even tinier microchips which was dependent on DARPA forging a high degree of cooperation and consensus across the entire technological community, both scientists and engineers working for industry and those working in universities and federal labs.

Gain Sharing

Partnership and cooperation logically imply that future gains should be shared among the partners, and it is here that present arrangements fall significantly short. Despite the extraordinarily important role that public agencies play in funding and supporting this innovation system, they derive no direct returns from their successful investments. The algorithm or "secret sauce" that made Google so successful as a search engine was initially funded by an NSF grant (Battelle 2005), but the only benefit that NSF received was the indirect one that Google's growth and large payroll expanded the government tax revenues that help fund NSF and other innovation agencies.

However, this is an inadequate mechanism because there are intense conflicts over how each additional federal tax dollar is spent, and the federal government has been struggling with deficits for the past decade. In this environment, it has been difficult to maintain existing levels of federal spending on research and development. With limited resources, fierce and unproductive battles have broken out that pit biological scientists against physical scientists and supporters of basic research against the advocates for programs designed to accelerate commercialization of new technologies. In short, without a mechanism to ensure that taxpayers share in the gains from the innovations that they have helped to foster the future of the current innovation system is at risk.

Moreover, the danger is compounded by the society's systematic underinvestment in education from kindergarten through university level. Ultimately, the innovation system depends on a well educated population (Alic, Chapter 12), and budget cutting, especially at the state level, over the last generation has weakened public schools and reduced access to higher education. A better system of gain sharing is necessary to ensure that we can finance the kind of high-quality, inclusive education system that is indispensable for an innovation society (Newfield 2008).

A poignant example of the violation of the principle of gain sharing is discussed by Vallas, Kleinman, and Biscotti (chapter 3). A new pharmaceutical that brings in more than $1 billion per year in revenue is a drug marketed by Genzyme. It is a drug for a rare disease that was initially developed by scientists at the National Institutes of Health. The firm set the price for a year's dosage at upward of $350,000. While legislation gives the government the right to sell such government-developed drugs at "reasonable" prices, policymakers have not exercised this right. The result is an extreme instance where the costs of developing this drug were socialized, while the profits were privatized. Moreover, some of the taxpayers who financed the development of the drug cannot obtain it for their family members because they cannot afford it.

Conclusion

The combination of these principles—coordinated decentralization, private-public partnership, cooperative sharing of expertise, and gain sharing—gives us the framework for the current innovation system and also provides a broader alternative to market fundamentalism. Whereas market fundamentalism insists that only institutions that are governed by the logic of the marketplace can be trusted to use resources efficiently, this alternative governing philosophy recognizes that our society has long been effectively pluralistic. Other institutions such as universities, government laboratories, public agencies, and the military have found ways to motivate people to be creative and effective without appealing to the maximization of individual income. Moreover, the very plurality of individual motivations is a source of strength since people are different and they respond to different incentives.

The logic of this argument has been elaborated most clearly by Michael Walzer in *Spheres of Justice* (1983), in which he argues for a society based on the principle of complex equality. Walzer's framework is relevant precisely because he recognizes that the different parts of society such as the government, the economy, the scientific community, and the universities cannot be kept separate from each other but are intertwined and interdependent. Walzer would dismiss market fundamentalism as utopian because it imagines that the government can somehow be removed from its extensive involvement in the economy. But as Viviana Zelizer (2006) has argued at length, just because things are intertwined does not mean that they have to be organized on a unitary basis. Walzer's critical insight is that each of these intertwined spheres needs to be true to its own organizing principles.

Walzer's starting point is a critique of the old egalitarianism which sought to ensure that everybody got the same or roughly equal income and life chances. Walzer sees that goal as unrealistic and argues that the different realms of society need to have their own distinct distributional principles. In the sphere of the market, it is appropriate that the one who builds a better mousetrap should earn greater rewards. In science, recognition and glory goes to those who make the most important discoveries. In the realm of health care, however, justice dictates that those with greater medical needs should receive more assistance, and in the sphere of politics, those with the greater capacity to win votes of their fellow citizens should be rewarded with a greater share of political power. The core idea of complex equality is that society needs to take steps to protect the integrity of each sphere. This means creating mechanisms to block the tendency for advantage in one sphere to spill over into others. Hence, those with political power should not be able to translate that power into economic wealth, and similarly those with economic wealth should not be able to translate that directly into political power. This is necessary to ensure that distribution in each of the different spheres is consistent with the principle of justice relevant to that sphere.

In short, complex equality is the foundation for an innovation society in which the different actors are able to coordinate despite having different goals and different values. The entrepreneur can work together with the scientist who is driven by the need to solve puzzles and with the public agency official who seeks to serve his or her country by accelerating technological progress. In fact, it is precisely because they have different immediate goals that it is easier for them to cooperate. If they were all seeking to maximize income, the coordination we have been describing would be impossible.

Of course, this moral and intellectual division of labor leaves room for people to change their minds and their institutional positions. The scientist or engineer can decide to become an entrepreneur, while the entrepreneur might decide to take a turn as a government technology officer. But it is also critical that the society construct ethical boundaries between these different spheres, so as to minimize conflicts of interests and to ensure that the values of science or public service not be undermined by the quest for profits (Biscotti et al. 2009).

More broadly, complex equality points to a pluralistic politics that would strengthen democratic governance. None of us want to live in a society that is dominated by any one of these groups; rule by the captains of industry and finance is as deeply offensive as is the rule of a narrow self-perpetuating political elite or a scientific meritocracy. But with each of these groups having a separate sphere of influence and power, the ongoing contestation creates a political space in which the people get to decide the most important questions. A true innovation society requires both complex equality and “government of the people, by the people, and for the people.”

Notes

[1]. John Alic, Shelley Hurt, Matthew R. Keller, and Andrew Schrank provided valuable criticisms of earlier drafts of this chapter, but they cannot be blamed for any remaining errors or defects.

[2] . Market fundamentalism is characterized by a discrepancy between its anti-state ideology and its use of state power to accomplish its goals. As Karl Polanyi (2001 [1944], 146) wrote: "The road to the free market was opened and kept open by an enormous increase in continuous, centrally organized and controlled interventionism."

[3]. There are, however, reasons to believe that the Commerce Department series might understate U.S. high-tech exports. In particular, some of the software and other computer services that originate in the United States but are downloaded to computers overseas might not be counted, particularly because U.S. firms gain tax advantages from attributing the income they earn on these transactions to overseas subsidiaries (O'Connell 1999).

[4]. The complexity, of course, is that any economic development initiative can almost always be justified in military terms. If the United States is at a technological disadvantage in a particular area, it could weaken the U.S. ability to prevail in military conflicts. This logic is not unique to the Cold War period; it has prevailed throughout the history of the nation.

[5]. The official name of the agency has fluctuated between ARPA and DARPA (Defense Advanced Research Projects Agency). Both names are used in the literature, but they refer to the same agency.

[6]. The high-tech spin-off model probably predated the actions of the traitorous eight (Hyde 2003), but this incident is often singled out because of its direct connection to firms, such as Intel, that are still key players in Silicon Valley. The pattern of new firm creation by spin-offs from existing firms has been common to industrial districts for centuries (Piore and Sabel 1984). What is distinctive about the Fairchild and related cases are that the people forming the new firms are highly trained scientists and engineers.

[7]. The exception to this pattern in the pre-DARPA period was Pentagon support for research at the premier corporate laboratories such as Bell Labs and the IBM laboratories because researchers in these

laboratories were effectively insulated from commercial considerations.

[8]. Although largely forgotten, Clinton also pushed the Technology Reinvestment Program, which was designed to strengthen the industrial base in the post–Cold War era. Managed initially by DARPA, the program was cut short once the Republicans gained control of the Congress in 1994 (Cohen 1998).

[9]. For recent data on the number and dollar value of the CRADA and Work for Others at the Department of Energy laboratories, see Government Accountability Office 2009.

[9]. The available data make it difficult to discern trends in the organization of the scientific labor force. For example, some of the Ph.D.s who list themselves as self-employed or as proprietors on tax forms could also be employees, most likely at universities or government laboratories.