Keys to Innovation, Competitiveness, and Jobs

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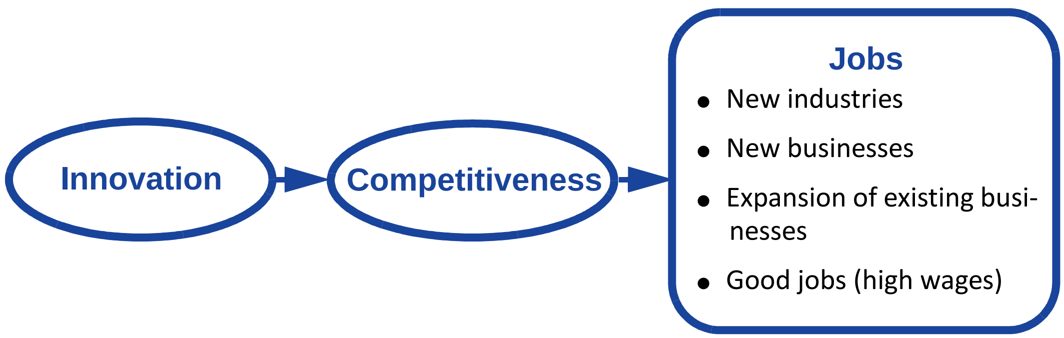
Innovation is a key driver of competitiveness, job growth, and a higher standard of living for future generations. To improve the competitiveness of the United States, it is instructive to examine the factors that previously unleashed the tremendous innovative potential of the private sector. The list of those factors is long, and it is not surprising that the recipe for successful innovation and competitiveness is complex, evolving, and differs by product and industry. To address the question of what made the United States innovative and competitive in the past, and also what will make the United States innovative and competitive in the future, this report primarily focuses on three important factors that formed the foundation of a strong innovative environment: support for research, education, and infrastructure.



A common thread between these three elements is that they are areas where government has made, and should continue to make, significant investments. In all three of these areas, investment has a social return that exceeds the return to any one company or person. Basic research often has many applications, beyond those which motivated the initial research. A more educated workforce means not just more income for those who attend school longer, but also means greater productivity in business and a more effective citizenry. Improved infrastructure provides a benefit for the greater good and facilitates productivity. Because of these broader benefits, private investment is often too low since private investors cannot capture the broader social returns. As a result, almost all governments in developed countries fund investment in these areas.

Concepts and Definitions

Before delving into these three areas, it is important to take a step back and define several terms. The COMPETES Reauthorization Act directs the Department of Commerce to "complete a comprehensive study of the economic competitiveness and innovative capacity of the United States." It is somewhat ironic, therefore, that the importance of "innovation" and "competitiveness" are matched by the lack of commonly accepted definitions and empirical measures over time and across countries. Beginning with "innovation," a 2008 Advisory Committee report to the Secretary of Commerce, *Innovation Measurement: Tracking the State of Innovation in the American Economy,* defines it as:

> "The design, invention, development and/or implementation of new or altered products, services, processes, systems, organizational structures, or business models for the purpose of creating new value for customers and financial returns for the firm."[1]

There are two main approaches to measuring innovation.[2] The first is the proxy method, where rather than measuring innovation directly, patents or spending on R&D are tracked as a proxy for the level or rate of change of innovation. Although these proxies can be useful tools for understanding innovation, they are necessarily imperfect measures. For example, many innovations are not patented, and innovative activity occurs even in industries that conduct little formal R&D. The second approach relies on economic accounting where economic growth is explained by factors that are measurable, such as the labor force and its quality. The portion of economic growth that cannot be explained by measurable factors is referred to as "technological change," "innovation," or in economic jargon, "multifactor productivity" or "total factor productivity." Using this second approach, it is estimated that between over one-third to a half of economic growth in the United States can be attributed to "innovation."[3]

Similar to innovation, "competitiveness" has also proved difficult to define and measure. A competitive business is one that is successful in the marketplace—success being measured in various ways such as market share or profitability. As the McKinsey Global Institute states, competitiveness in a sector can be defined as the "capacity to sustain growth through either increasing productivity or expanding employment."[4] Though there is not a common definition of competitiveness at the country level, a widely recognized ranking of this comes from the World Economic Forum (WEF). They define competitiveness as "the set of institutions, policies, and factors that determine the level of productivity of a country."[5] Thus, the concepts of productivity and competitiveness often go hand in hand. In this report, the term "competitiveness" is generally used, but often increasing competitiveness requires increasing productivity, and vice versa.

The competitiveness of a country and the competitiveness of businesses are also closely-linked concepts. Competitive businesses need to innovate; otherwise, they will not be able to grow and remain viable. When countries are competitive—that is, when they have a "set of institutions, policies and factors" that are conducive to productivity growth—then businesses are positioned to grow and be effective competitors against other domestic and foreign firms. According to the WEF, "(t)his requires an environment that is conducive to innovative activity, supported by both the public and the private sectors. In particular, it means sufficient investment in research and development (R&D), especially by the private sector; the presence of high quality scientific research institutions; extensive collaboration in research between universities and industry; and the protection of intellectual property."[6] Given the pace of change in today's global economy, investments to promote innovation deserve more emphasis than at any time in the past.

Ensuring a country is competitive and has sufficient capacity to innovate is also crucial because the number and quality of jobs is strongly dependent on these two concepts. As competitive businesses grow, they hire more workers and they also tend to pay well; a number of studies have shown that highly productive firms pay above-average wages.

- **Innovation leads to new industries.** Over the longer-term, new ideas, products, or discoveries can lead to new industries. Examples include the wireless communications industry (290,000 workers in 2007), software and Internet publishing firms and Internet service providers (500,000 workers), and pharmaceutical firms along with companies in biotechnology research and development services (350,000 workers).

- **Innovation leads to new firms.** Between 1980 and 2007, on average over 500,000 new businesses with employees started each year. These new firms produced an average of 3 million new jobs a year.

- **Competitive and innovative firms expand.** Between 1980 and 2007, existing businesses that grew added roughly 13.3 million jobs a year, which translates into an average employment growth rate of 13.9 percent.

- **Competitive and innovative firms create good jobs.** Wages for workers in innovative and competitive firms tend to be higher than wages elsewhere. For instance, firms that export (that is, firms that successfully compete internationally) have been found to pay significant wage premiums.[7] Similarly, a recent report shows that the science, technology, engineering, and mathematics (STEM) workforce earned about 26 percent more than their counterparts in non-STEM occupations. STEM workers also were less likely to experience joblessness, and STEM job growth over the past 10 years was three times faster than growth in non-STEM jobs.

What Made the United States So Successful in the Past?

Many different factors affect innovation and competitiveness and volumes have been written on the economic history of the United States and, more generally, on innovation. However, there is widespread agreement on at least three factors that contributed greatly to the economic strength of the United States during the last century, factors where the government played an important role: support for research, education, and infrastructure. Given the importance of each of these factors, each receives more in-depth treatment in subsequent chapters. Below is a brief description of how important they were in the past century.

Research

Federally funded R&D has resulted in innovations and discoveries, leading to new companies and entire industries that have made Americans more prosperous, healthier, and safer. For example, the first fully electronic U.S. digital computer—the ENIAC—was funded by the U.S. Federal government. For more on the Federal role in the evolution of the computer (see box 2.1).

Federal investments in life sciences have decreased mortality and morbidity rates, driving innovations that are at the cutting edge of fighting heart disease, diabetes, cancer, and HIV/AIDS. For example, "the biopharmaceutical industry draws upon (and complements) an exceptionally large publicly funded basic research effort in the life sciences."[8] The investments in health and medicine at the National Institutes of Health (NIH) continue to contribute heavily to advances in the field, and the work of NIH scientists has produced multiple Nobel Prize winners.

Cumulative gains in life expectancy after 1900 were worth over $1.2 million to the representative American in 2000, whereas post-1970 gains added about $3.2

Box 2.1

The ENIAC and the IBM 650: Federally Funded Research and the Birth of an Industry

The ENIAC or Electronic Numerical Integrator And Computer was developed to solve the very specific problem of calculating information related to the proper firing of artillery. The ENIAC was developed in the early 1940s by J. Presper Eckert and John W. Mauchly at the University of Pennsylvania, and was funded by the U.S. Army.[1]

From 1945 to 1955 collaborations between the U.S. military, universities, and the private sector led to at least 19 projects related to the development of computers. This collaborative environment helped drive the explosion in innovation, but the bulk of the funding for this research came from the Federal government, with Federal funds accounting for 59 percent of computer related R&D spending by General Electric, IBM, Sperry Rand, AT&T, Raytheon, RCA, and Computer Control Corporation from 1949 to 1959.[2]

Though the funding for these computers primarily came from the Federal government, companies were able to quickly translate the technological advances into commercial applications. For example, IBM was able to combine the benefits of this Federal R&D with its prowess as an existing office equipment producer to create the IBM 650, that sold 1,800 units in the 1950's making it the most commercially successful computer of that period.

These early Federal investments were undertaken without the commercial applications in mind, yet they provided the foundation for the evolution of the computer industry. Seventy years later, the United States. is still reaping the rewards of these early investments. Today, the lives of nearly every American are impacted in some way by the benefits of advances in computer technology. The basic research investments that led to the creation of the early computer are exactly the type of investments that the United States needs to be making today so that future generations will still be reaping the rewards of today's investments for decades into the future.

1. David C. Mowery. 2011. "Federal Policy and the Development of Semiconductors, Computer Hardware, and Computer Software: A Policy Model for Climate Change R&D?" *Accelerating Energy Innovation Insights from Multiple Sectors.* Chicago: University of Chicago Press, for the National Bureau of Economic Research; 159–188.

2. Kenneth Flamm. 1987. *Targeting the Computer: Government Support and International Competition.* Washington, DC: Brookings Institution.

trillion per year to national wealth, equal to about half of GDP. Potential gains from future health improvements are also large; for example, it is estimated that a 1 percent reduction in cancer mortality would be worth $500 billion.[9]

Federal investments in materials and military technology underpin the modern military as well as profitable innovations in the private sector. Advancements in chemicals, such as the spike in the production of synthetic rubber during World War II under the Synthetic Rubber Research Program, have spurred innovations in manufacturing that have directly supported national security. Federal investments in atomic physics in the 1930s and 1950s gave rise to the creation of GPS systems, forever changing the deployment of the military, not to mention our daily travels.[10]

The companies that can trace their roots to federally funded research span a wide variety of industries. In their report *Sparking Innovation: How federally funded university research creates innovation, new companies and jobs,* the Science Coalition identifies over 100 companies that Federally funded research helped launch. To provide a flavor of the wide array of companies included in *Sparking Innovation*, Table 2.1 lists a handful of examples that vary greatly by size, location, industry, and Federal funding source.

Education

At the beginning of the 20th century, America led the world in education, and over the following decades the average level of schooling in the United States increased significantly. Americans born in the 1870s had, on average, less than 8 years of formal education. For the cohort born in 1910, this average had risen to nearly 10 years. For the cohort born in 1940, this average had risen past 12.[11] For cohorts born between 1876 and 1951, average educational attainment grew steadily by nearly 1 year per decade[12] (see figure 2.1, page 2–8).

By the 1950s, the United States enrolled close to 80 percent of its youth in full time secondary schools.[13] The comparison with industrial Western Europe was stark. Among 18 European nations in the 1950s including France, Italy, and Great Britain, each enrolled less than 30 percent of youth in general education secondary schools; all but one (Sweden) were under 20 percent. When youth in technical schools is added, secondary enrollment in Europe did not surpass 40 percent.[14] This gap extended into higher education. In the 1950s, American enrollment in higher education was expanding rapidly and America's university attainment rates were far higher than any European country. Many factors contributed to the increased college attainment rates, including the GI Bill and an extensive public university system, especially land-grant schools that had a footprint in every state.

Additionally, the college and university system in the United States contains a disproportionate share of the world's most prestigious universities. For example,

Table 2.1

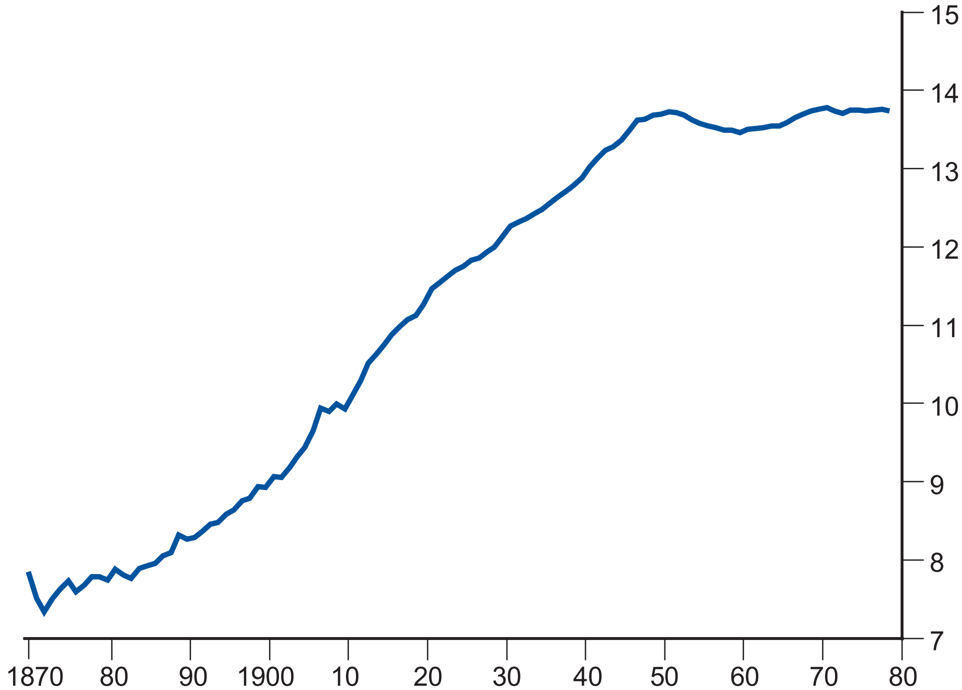
Companies Created as a Result of Discoveries in Federally Funded University Laboratories[9]

Company	Location	Year Started	Employ-ment	Innovation	Federal Funding
Arbor Networks	Chelmsford, MA	2000	125	Network security technologies	DOD, NSF
Audyssey Laboratories	Los Angeles, CA	2002	75	Technology fixes impact of room acoustics on sound reproduction	NSF
Buffalo BioBlower Technologies LLC	Buffalo, NY	2005	8	Air sterilization technology for healthcare, homeland security, battlefields	DOD
Cognex Corporation	Natick, MA	1981	729	Industrial machine vision technology	NSF
CREE, Inc.	Durham, NC	1987	3,168	Semiconductor technology increases efficiency of LED, power, and communications products	DOD
Fingerlakes Aquaculture, Inc.	Groton, NY	1996	11	Aquafilter for economical, large-scale production of farm-raised fish	USDA
Google	Mountain View, CA	1998	19,835	Internet search technology and Web-based applications	NSF
Image Sensing Systems, Inc.	St. Paul, MN	1984	80	Software for monitoring traffic conditions	DOT
ImagiSonix	Sterling, MA	2006	3	Wireless ultrasound for rural, emergency, military, and disaster settings	DOD
iRobot Corporation	Bedford, MA	1990	538	Robots for military, industrial, and consumer use	DOD, NASA
Molecular Imprints, Inc.	Austin, TX	2001	125	"Step and Flash" nano-lithography makes smaller, faster computer chips	DOD
SenSound, LLC	Detroit, MI	2003	8	Technology pinpoints exact source of noise for use in product design, develop-ment, and manufacturing	NSF
TomoTherapy, Incorporated	Madison, WI	1997	665	Machine targets radiation to cancer cells and limits damage to healthy ones	NIH
Universal Display Corporation	Ewing, NJ	1994	80	Organic LED technology for flat panel displays, lasers, and other light generating devices	DOD, DOE
Webscalers	Binghamton, NY	2002	7	Metasearch engines probe deeper into the Web than traditional search engines	NSF
Xenogen (acquired by Caliper Life Sciences)	Hopkinton, MA	1994	489	In vivo imaging allows scientists to evaluate drugs by observing their effects in living animals	DOD, NIH

Source: The Science Coalition, *Sparking Innovation: How federally funded university research creates innovation, new companies and jobs.*

Figure 2.1

Years of Schooling at Age 30, by Birth Cohorts, 1870–1979



Source: Economics and Statistics Administration (ESA) calculations based on the Integrated Public Use Microdata Series, Minnesota Population Center, University of Minnesota (see http://usa.ipums.org/usa/).

Note: Data for this figure were based on ESA calculations of mean years of education for U.S.-born individuals by birth year for those who were 30 years or older. Because the education variable was coded by category of educational attainment, such as grade levels and higher education levels, it was necessary to transform the data into a continuous variable to calculate a mean. The methodology used to recode the education variable into an estimated number of years of education was based partly on work by Goldin and Katz (2008)."

according to one set of rankings, in 2011–2012, 18 out of the top 25 universities and 30 out of the top 50 universities were in the United States; the United Kingdom was next with four in the top 25 and seven in the top 50.[15] In addition, the United States is the top destination for students studying abroad.[16]

Infrastructure

Throughout the last century, infrastructure investments, supported by the public sector, have been critical to the increased standard of living and economic growth experienced in the United States. For example, water treatment and distribution systems saved lives and facilitated commerce. Early water treatment systems were mostly targeted to protect the public from waterborne diseases, such as typhoid, dysentery, and cholera,[17] but later public water utilities also provided a consistent and dedicated water supply that was important for industrial production and the generation of power, while it also protected the public from environmental contaminants.[18] The interstate highway system, highlighted in box 1.1, was the largest public works project of its time and did more than any other program to connect our country.

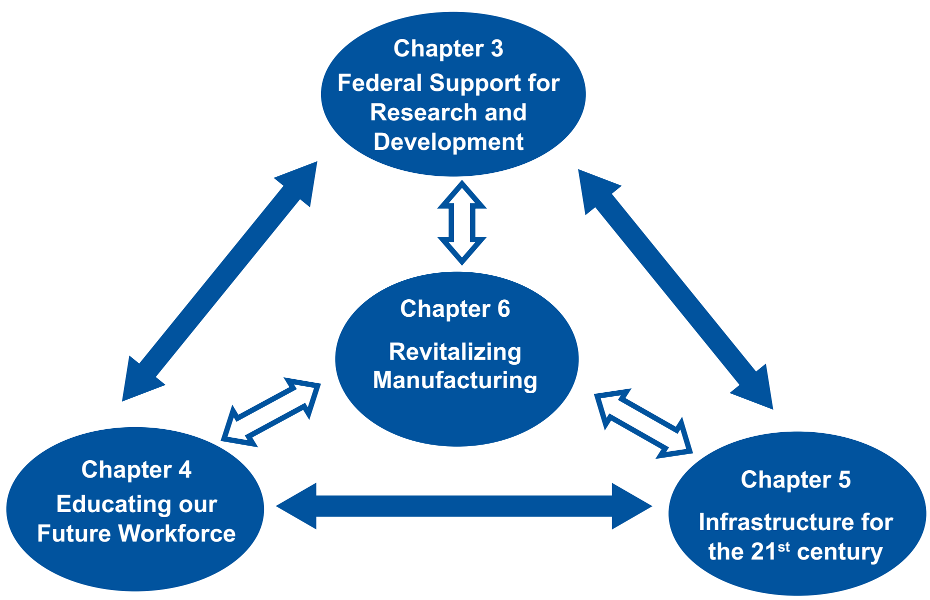
Interconnections

Research and development, education, and infrastructure are discussed separately in the chapters that follow, but they are not separate and unique entities. As some commentators have noted, the elements of competitiveness and innovation are less like silos and more like a network or ecosystem.

Changes in one part of the network—say education—ripple through the system satisfying demands for researchers, creating demands for infrastructure, and feeding back into the schools via the creation of demand for new and different skills. U.S. industries, like those discussed in the manufacturing chapter, sit in a critical juncture in this network—creating demand for labor with specific skills and participating integrally in research and in the creation and build out of new infrastructure (see figure 2.2). Thus, although this report addresses innovation and competitiveness topics sequentially in separate chapters, their interconnectedness is a sub-text that the reader should keep in mind.

Figure 2.2

The Innovation Ecosystem



Endnotes

1. The Advisory Committee on Measuring Innovation in the 21st Century Economy 2008, i.

2. Historically, these two measures have been used as proxies for innovation, but recently efforts have been made to measure innovation more directly through innovation surveys. See www.nsf.gov/statistics/infbrief/nsf09304/. It should also be mentioned that there are some objections to these proxies. For example, the OECD, in its guidelines on collecting and interpreting innovation data (often referred to as the "Oslo Manual") states that patents are not good proxies for innovation because they are inputs to innovation rather than outputs and because patents can lack any economic value. However, even the OECD recognizes that a deeper understanding of innovation necessarily requires learning more about patents.

3. For an explanation of productivity change see Jorgenson and Griliches 1967, 249–283. For discussion of intangible capital and economic growth see Corrado, Hulten and Sichel 2009. See also Bureau of Labor Statistics multifactor productivity news releases 2011a, 2011b, and 2011c.

4. Manyika et al. 2010, 10.

5. World Economic Forum 2011–2012, 4. (WEF) quantifies a wide variety of factors under its "12 Pillars of Competitiveness." Those pillars are: (1) Institutions; (2) Infrastructure; (3) Macroeconomic environment; (4) Health and primary education; (5) Higher education and training; (6) Goods market efficiency; (7) Labor market efficiency; (8) Financial market development; (9) Technological readiness; (10) Market size; (11) Business sophistication; and (12) Innovation. According to the WEF Global Competitiveness Report 2011–2012, the United States ranked fourth overall in 2010 and then fifth in 2011. However, the factors that went into the WEF ranking, how those factors are computed, and then how the factors are added together all require subjective judgments.

6. World Economic Forum 2011–2012, 8.

7. Bernard, Jensen, and Schott 2009, 514.

8. Cockburn, Stern, and Zausner 2011, 115.

9. Murphy and Topel 2006.

10. Committee on Science, Engineering, and Public Policy 1999, 31.

11. Figure 1.4, Goldin and Katz 2008, 20.

12. Goldin and Katz 2008, 19.

13. Goldin and Katz 2008, 26.

14. Figure 1.7, Goldin and Katz 2008, 24.

15. Times Higher Education 2011–2012.

16. OECD Indicators 2011, 321.

17. U.S. Environmental Protection Agency 2000.

18. Finn 2002.

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