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**NEW KNOWLEDGE: THE DRIVING FORCE OF INNOVATION,
ENTREPRENEURSHIP, AND ECONOMIC DEVELOPMENT**

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Abstract:

The claim of this paper is that new knowledge - specifically, the creation of economically useful knowledge is the main driver of innovation: that innovation is what generates economic development: and that the institutional arrangements (referred to as innovation systems) that support innovation and entrepreneurial activity vary across time and space. The paper traces the evolution of the U.S. national innovation system, the locus and nature of innovation, and the role of entrepreneurial activity over the last two centuries. The analysis shows that technologies and institutions co-evolve and that innovation systems are dynamic and path-dependent phenomena. It also shows that the function of innovation systems is not only to create or absorb ideas but also to turn ideas into innovations and commercialize them.

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NEW KNOWLEDGE: THE DRIVING FORCE OF INNOVATION, ENTREPRENEURSHIP, AND ECONOMIC DEVELOPMENT

Introduction

In the 1950s, Abramovitz (1956) and Solow (1956) observed that increased inputs of labor and capital account for only a small portion of economic growth, leaving most of the explanation to a residual factor. Solow referred to this residual as the “technology factor,” while Abramovitz called it “a measure of our ignorance.” Subsequently, endogenous growth theory (Romer 1986 and 1990, Lucas 1988 and 1993, and others) has provided a way to incorporate technology (particularly in the form of technological spillovers) into the macro production function.

But what are the spillover mechanisms that convert technological change into economic growth? In a series of papers (Acs *et al.*, 2004, 2005a and b) my co-authors and I have developed a model that distinguishes between knowledge and economically useful knowledge (following Arrow, 1962) and that introduces the notion of entrepreneurship as one of the mechanisms (in addition to incumbent firms) that translates economic knowledge into economic growth. This raises the question of where and how economically useful knowledge is created.

The claim of this paper is that new knowledge - specifically, the creation of economically useful knowledge – is the main driver of innovation; that innovation is what generates economic development (in Schumpeter’s sense, i.e., distinct from “economic growth” that is associated with the “circular flow”); and that the institutional arrangements (referred to as innovation systems) that support innovation and entrepreneurial activity vary across time and space.

Innovation creates opportunities for both incumbent firms and start-ups. It is innovation (the application and diffusion of knowledge), not invention, that stimulates economic growth.

Innovation systems at various levels – national, regional, sectoral, and technology-focused - generate technological change. They also internalize externalities such as technological spillovers. A historical review of the formation of the U.S. national innovation system shows that the intensity and locus of knowledge creation have shifted over time. World War II represents a watershed by shaping a new set of technology-based innovation systems that may be referred to collectively as the “national innovation system.” This led eventually to the transformation of the U.S. economy from a large-scale, mass production-oriented to a knowledge-based and much more flexible one. Similar innovation systems have been formed in other countries also, taking different shape depending on local circumstances. The main functions of innovation systems are to create, absorb, and diffuse new knowledge. Put differently, the functions are to generate/capture ideas (inventions), translate them into innovations, and diffuse/commercialize them. Sometimes inventions are generated within the system; sometimes they come from outside. Whether innovations are diffused via incumbent firms or new entities depends on the nature of the technology and on the institutional circumstances; there are strong spillover mechanisms in which path dependence plays an important role.

The paper is organized as follows. In the first section I show how the nature and locus of knowledge creation in the United States have shifted over time and evolved into the present “national innovation system.” Next I discuss the role of innovation systems in a few other countries. This is followed by a brief review of the empirical evidence for the contribution of innovation systems to economic development.

The Nature and Locus of Knowledge Creation: The Evolution of the U.S. National Innovation System

1750-1900

The Industrial Revolution in Britain in the late 18th and early 19th centuries was based on new technologies that caused major changes in agriculture, manufacturing, and transportation.

Inventions such as the spinning jenny (James Hargreaves, 1764), the power loom (Richard Arkwright, 1769), and the steam engine (Isaac Watt, 1775) started a shift of the previously manual labor-based economy toward machine-based manufacturing. After the invention of the puddling process for producing pig iron through the use of coke rather than charcoal, iron became cheap enough to use for industrial machinery; previous machines were usually made of wood. All these new technologies were invented through trial and error by individual tinkerers and entrepreneurs. The inventions soon spread from Britain to other European countries and to North America.

After the American War of Independence, Great Britain imposed an embargo on exports of machinery and skilled mechanics to the United States. Faced with shortages of labor (skilled mechanics in particular) and high quality iron, the Americans had to devise new ways of producing industrial machinery. This led to the so-called 'American system of manufactures' (standardization and interchangeability of parts, making possible a high degree of mechanization), applied first to the manufacture of guns and later to sewing machines, farm implements and tools, bicycles, locomotives, and automobiles. This was the result of a series of minor adaptations and improvements of existing machine tools in response to the needs of new industries and the diffusion of modern methods of production to older sectors. As a result, the

United States surpassed Britain in machine tool technology in the latter half of the 19th century (Carlsson, 1984).

In his *Scale and Scope*, Chandler (1990) describes the rise of the modern industrial enterprise and the emergence of the United States as the world's economic leader. He attributes these developments to new technologies in transportation (railroads and steam ships) and communication (telegraph) that provided unique opportunities for American entrepreneurs as they took advantage of rapid population growth and the creation of a new economy spanning an entire continent:

As a result of the regularity, increased volume, and greater speed of the flows of goods and materials made possible by the new transportation and communication systems, new and improved processes of production developed that for the first time in history enjoyed substantial economies of scale and scope. Large manufacturing works applying the new technologies could produce at lower unit costs than could the smaller works. (Chandler, 1990, p. 8)

The new technologies transformed capital-intensive industries such as the processing of tobacco, grains, sugar, vegetable oil, and other foods, and they revolutionized the refining of oil and the making of metals and other materials. The new knowledge created in these industries was practical, shop-floor oriented, built on experience, and largely experimental. Henry Ford's moving assembly line in 1913 is an example. Through such people as Nikola Tesla, Thomas Edison, George Westinghouse, and Alexander Graham Bell in the United States, Ernst Werner von Siemens in Germany, Lord Kelvin in the United Kingdom, and Ottó Bláthy in Hungary, electricity was turned from a scientific curiosity into an essential tool for modern life.

But even though the new industries that emerged based on these innovations depended more on individual ingenuity than on science and higher education, they drew their skilled labor from a growing pool of technically trained personnel, especially engineers, coming out of the

universities and engineering schools. As the needs for standards, testing, measuring, and quality control increased, firms began to establish industrial laboratories to carry out such tasks. Many of these laboratories had strong collaboration with universities. American universities and engineering schools were quick to respond as new technical breakthroughs were made. Academia and industry co-evolved.

Until the late 19th century, the main focus of universities was on preservation and codification of existing knowledge rather than on new knowledge creation. Certainly the creation of new economically useful knowledge was not seen as the mission of universities. This was true even in the engineering schools that had sprung up in France and Germany in the late 18th century and subsequently in the United States. But this began to change with the creation of land-grant universities in the United States through the Morrill Act in 1862, leading to the establishment of universities in every state. Unlike most private universities, these state universities and colleges were created not only to keep up with the educational needs of a rapidly growing population but also to create a knowledge base needed to support the expansion of the still largely agricultural economy. The land-grant universities were charged with public service obligations in agricultural experimentation and extension services, industrial training, teacher education, home economics, public health, and veterinary medicine. One of the main features of the land-grant universities was a strong practical/vocational orientation in both education and research. While the emphasis was on teaching branches of learning related to agriculture and the mechanical arts in addition to the liberal arts, there was also research. The agricultural experiment stations at the land-grant universities played a particularly important role not only in advancing knowledge in fields of practical and economic relevance but also in making the practical application of research acceptable if not required in U.S. academic institutions. (Carlsson et al., 2009)

As the U.S. population grew, partly through immigration, and as the country expanded westward, new institutions of higher education, both private and public, were established. The expansion of the U.S. system of higher education allowed it to cater not only to a rapidly growing population but also to increasing percentages of each cohort demanding higher education. This set the U.S. apart from its European competitors. As a result, by 1910 about 330,000 students were enrolled at almost one thousand colleges and universities in the United States (whose population was 92 million), while at the same time there were only about 14,000 students in sixteen universities in France (with a population of 39 million). This represented about 4 % of the college-age population in the U.S. vs. about 0.5 % in France (Graham and Diamond, 1997, p. 24). This expansion of higher education contributed importantly to the creation of a relatively highly educated industrial labor force, i.e., a relatively high capacity to absorb new technology. This made it possible for large industrial firms to recruit the skilled labor they needed.

The Morrill Act also stimulated engineering education, and the number of engineering schools grew rapidly. But in contrast to Europe, engineering subjects were taught not only at separate institutions but also in the older elite institutions. For example, Yale introduced courses in mechanical engineering in 1863, and Columbia University opened its School of Mines in 1864 (Rosenberg & Nelson, 1994, p. 327). Soon new engineering disciplines were created.

After the breakthroughs in electricity research around 1880, American universities responded almost instantly to the need for electrical engineers. In the same year (1882) in which Edison's first power station in New York City went into operation, MIT (founded in 1865) introduced its first course in electrical engineering. Cornell followed in 1883 and awarded the first doctorate in the subject in 1885. By the 1890s schools like MIT had become the chief suppliers of electrical engineers. (*ibid.*, pp. 327-328)

The story is similar in chemical engineering. Even though Britain was the “workshop of the world” and had the largest chemical industry in 1850, this industry was based on its role as supplier to the textile manufacturers, not on professional engineering competence. In fact, there were no departments of chemical engineering in Britain or anywhere else outside the United States until the 1930s. By contrast, MIT offered the first course in chemical engineering in 1888 and established the School of Chemical Engineering Practice in 1915 (Rosenberg, 2000, p. 88). Several other American universities established chemical engineering departments in the first decade of the 20th century (Rosenberg, 1998, pp. 193-200).

Even though the new industries that emerged in the late 19th century – those relying on chemical engineering, electricity, and the internal combustion engine – were based on earlier scientific breakthroughs, relatively little of their performance during this era was based directly on science, nor even on advanced technical education. American technology was practical and experimental, built on experience. The new industries needed new knowledge, but the universities did not possess the specialized knowledge, equipment, and organization that was required. Instead, a new mechanism of collaboration between universities and industry emerged in the form of industrial laboratories.

During the latter half of the 19th century a number of industrial labs were established in the United States. There were at least 139 by the turn of the century (Mowery, 1981, cited in Rosenberg, 1985, p. 51). The earliest industrial labs did not perform activities that could be regarded as research; they were set up to apply existing knowledge, not to make new discoveries. They were organized to engage in a variety of routine and elementary tasks such as testing and measuring in the production process, assuring quality control, standardizing both product and

process, and meeting the precise specifications of customers (Chandler, 1985, p. 53). This development was linked to the expansion of higher education in the United States.

Industrialization in the United States in the late 19th century was built on mass production and labor-saving technology. But around 1900, industrial growth became science-based: companies such as DuPont, General Electric, and Westinghouse, as well as the auto industry, were based on new technologies in chemical, electrical, and mechanical engineering. Most of this new knowledge was created in industry, not in academia. While the American universities were creating new engineering and applied science disciplines, they were still lagging behind their European counterparts in basic sciences such as chemistry and physics, and their research capabilities were too small to support the needs of the growing industrial giants. There was little external funding of academic research, and none from the federal government. Most R&D was carried out in corporate labs.

U.S. universities played an important role in the creation of corporate R&D laboratories, especially in chemical engineering, via collaborative research and consulting, and in developing expanded research capabilities over time, in addition to serving as the launching pad for the careers of individuals who found employment in private firm laboratories. There is also evidence of influence in the opposite direction, from firms to universities.

1900-1945

The new industries contributed to building a new industrial base in the United States during the first two decades of the 20th century. Several of them were producer-good oriented: light machinery, electrical equipment, industrial chemicals, and metals. All involved mass production. There were also mass-produced consumer goods in the form of branded packaged products

(Chandler, 1990, pp. 63-71). As electrification proceeded, first in industry and later in households, new industries for household appliances such as refrigerators, vacuum cleaners, washing machines, and dishwashers emerged. Advances in the organization of automobile production (such as standardization and the moving assembly line) led to mass production of automobiles.

With the stock market crash and the onset of the Great Depression, the demand for new consumer products suddenly diminished. However, innovation continued. After the end of World War I there was actually a boom in research – little noticed because of the overwhelmingly negative impact of the Great Depression on all sorts of economic activity. Nevertheless:

“Between 1921 and 1938 industrial research personnel rose by 300%. In 1927 approximately 25% of its employees reportedly worked on a part-time basis; by 1938 this proportion had fallen to 3%. Laboratories rose from fewer than 300 in 1920 to over 1,600 in 1931 and more than 2,200 in 1938; the personnel employed increased from about 6,000 in 1920 to over 30,000 in 1931 and over 40,000 in 1938. The annual expenditure [rose] from about \$25,000,000 in 1920 to over 120,000,000 in 1931 to about 175,000,000 in 1938. In 1937, industrial research on an organized basis in the United States ranked among the 45 manufacturing industries which provided the largest number of jobs.”
(Fano, 1987, p. 262)

In connection with the Great Depression during the 1930s, innovation became focused more on cost reduction, particularly labor saving via mechanization. In the metalworking industries there were two major new manufacturing technologies: cemented carbide (first adapted for use in machine tools by the Krupp Steel Works in Germany in 1928 and a few months later by Carboly in the United States) used for machine tools that could handle high speeds and temperature, and the automatic transfer machine consisting of a large number of work stations arranged so that work pieces can be transferred automatically from one work station to the next. The diffusion of both of these technologies was slowed down by the depression, but their availability proved crucial in the buildup of new production capacity to support the war effort

(Carlsson, 1984). For example, the scaling up of aircraft production from less than 1,000 a year to more than 10,000 that took place within two years would have been impossible without the application of production and organizational knowhow from the auto industry. The buildup of new production capacity for other kinds of military gear (warships, tanks, trucks, jeeps, ammunition, etc.) also required similar investments, resulting in an essentially new industrial base that was converted to civilian products after the war.

Other industries were also characterized by increasing utilization of large-scale equipment during the 1930s. The applications ranged from industrial locomotives and power shovels, to cement kilns, roller mills in flour milling, and milling equipment for mining industries. Along with the extended use of large equipment units came growing importance of industrial measuring, recording and controlling devices (Fano, 1987, p. 257). Also, electricity was used increasingly in industry as well as agriculture. The innovations during the 1920s and 1930s seem to have been mainly productivity-enhancing (cost-reducing, process-oriented) rather than market-expanding.

Thus, in spite of the depression, advances in large-scale equipment and mass production technology laid the foundation for wartime production and for economic growth in the postwar period. During the 1920s and 1930s, U.S. universities were still lagging behind Germany and Britain in basic science but clearly leading in engineering and applied science. External funding of academic research was quite limited. During the interwar period, U.S. academic research was funded primarily by philanthropic foundations and large corporations. The federal government was not involved in funding academic research at this time. The total value of foundation grants to academic institutions was only on the order of \$50 million in 1931 and then fell dramatically as the depression deepened. It rose again in the late 1930s but attained only \$40 million (about

\$450 million in 2006 dollars) in 1940 (Graham & Diamond, 1997, p. 28). The externally funded academic research was also concentrated in just a handful of institutions.

Thus, the foundations of the postwar expansion in high tech industries in the U.S. were laid over several decades. The build-up of a highly educated labor force began in the late 19th century as the university system expanded and the percentage of each cohort of the population receiving postsecondary education became four or five times higher than in the leading countries in Europe. The U.S. was still catching up with Europe in basic science until World War II, but it had developed strong academic programs in chemical and electrical engineering in the late 19th and early 20th centuries, long before Europe. The practical and application-oriented education nature of U.S. higher education, in combination with close collaboration between academic and corporate R&D, created a strong foundation upon which to build the postwar high-tech expansion.

The innovations that provided the foundation for the military buildup during World War II were diffused primarily through existing firms. They involved essentially a scaling up of previous activity through the application of technical and organizational knowhow that had been developed in the decades preceding the war.

1945-1980

The entry of the United States into the Second World War required mobilization of all kinds of resources. President Roosevelt summoned Vannevar Bush, former dean of engineering at MIT, to lead the mobilization of scientific manpower. For this purpose, Bush organized the Office of Scientific Research and Development (OSRD). Instead of drafting scientists to work in government labs as had been done in World War I, the OSRD developed intense collaboration

between Washington and the leading universities. Total federal R&D expenditures increased from \$83 million in 1940 to \$1,314 million in 1945 in 1930 dollars (Mowery & Rosenberg, 1998, p. 28). During the War, the Army Corps of Engineers spent \$2 billion developing the atomic bomb, and the Radiation Laboratory at MIT spent \$1.5 billion for radar systems (Geiger, 1993, p. 9). The increased research was guided by military needs and involved both basic research and its immediate application to military goods and services. In addition to the atomic bomb and radar, these efforts led to the development of the computer, jet engines, penicillin, DDT, numerically controlled machine tools, and scientific instrumentation.

Huge investments were also made in production facilities to support the war effort. Tanks, trucks, jeeps, airplanes, warships, and ammunition were needed in quantities never seen before. Civilian facilities were converted to military production, but new facilities were also needed that incorporated the new mass production techniques, especially transfer machine, that had been developed during the interwar period. As a result, the U.S. ended up at the end of the war with massive and modern production capacity unmatched anywhere in the world for the first two decades after the war.

It is noteworthy that several of the major technologies developed during the war originated in Britain and Germany and came to the U.S. via Britain; the war effort became a powerful focusing device in building domestic innovation systems and production capacity in each of these areas. For example, the Radiation Lab at MIT was initially set up in 1940 as a joint Anglo-American project to further develop British radar technology and produce radar equipment. Penicillin was mass produced in the U.S. during the war, organized by the War Production Board on the basis of discoveries made in the U.K. and Australia. The first American jet engine was

built by General Electric in 1943 after a British prototype. The civilian commercialization of these technologies that followed later was carried out primarily by existing companies.

While the conversion from military to civilian production was based in part on imported technology and largely benefitted existing companies, the development of the computer industry took place in the United States, and U.S. universities played a prominent role.

“The first digital electronic computer, the ENIAC, was brought to the full stage of a working prototype at the Moore School of Electrical Engineering at the University of Pennsylvania, in the fall of 1945... In the case of the computer, moreover, American universities not only designed and assembled the initial hardware of the computer industry; they created an entirely new discipline, of huge economic importance, along with the research infrastructure that had to be built in order to exploit the vast potential of the new hardware” (Rosenberg, 2000, p. 49)

The first computer company was Eckert-Mauchly Computer Corporation, formed in 1946. The company was sold in 1950 to Remington Rand (later Sperry Rand), which was an established maker of office equipment and electric shavers. Many other companies entered the emerging computer business during the early postwar years. Some companies were founded de novo to pursue computer development opportunities, but most start-ups sold out to become the nucleus of computer operations of established companies (Scherer, 1996, p. 240).

Although one can argue, based on the analysis in the preceding section, that there were innovation systems at work in the United States prior to World War II, the war certainly had a fundamental impact on shaping a new innovation system (or actually a whole set of partially overlapping technology-focused innovation systems). In this new system, the universities played a much more prominent role than before both in research (both basic and applied) and in education of a larger segment of the labor force. The research university as we know it today is one of the results; it became an important part of the newly emerging national innovation system.

The federal government also played a much more important role than before both in funding and in performing research. Most of the federal funding came via the Department of Defense and was conducted largely in government labs and by defense contractors. But the war-related research was organized in such a way that it also involved universities. For the first time, and quite suddenly, the federal government became the major source of funding for academic research which now included “big science” projects (systematic, programmatic research) on a scale never seen before. Basic research started to shift toward the universities. Fortunately, the American universities were ready to respond to the challenges. Several academic institutions, led by MIT, had policies (such as arrangements for consulting) and organizations (such as separate laboratories) in place to allow faculty to engage in classified military research without interfering with their role as educators and academic researchers (Carlsson et al., 2009). Also, as the war ended, the G.I. bill generated a large increase in college enrollment at all types of universities, not just the elite ones.

The war-related products (such as computers, jet engines, and radar) that resulted from the R&D were commercialized almost immediately through the military and soon after the war were converted to civilian products. The commercialization took place mainly through incumbent firms. Even though leading research universities such as MIT began spinning off new companies based on the military technologies they had developed during the war, these new start-ups were too few to affect the total number of firms materially. Overall, there were few new firms created; entrepreneurial activity declined or stagnated between 1950 and 1965.

The federal funding of defense-related R&D continued to grow until total R&D expenditures reached a peak in the mid-1960s. The total R&D spending then fell as the federal expenditures declined. At the same time, the federal funding of academic research became less focused,

dispersed to a much larger number of institutions of higher education, and used for building research infrastructure. As a result, much less of the knowledge created was economically useful. Fewer new products emerged, and the civilian spin-offs from military products began to decline. The economic growth rate fell.

Even though most R&D was still performed by industrial firms, the enhanced role of universities meant that more basic research was being done. There had been little of that before the war, even at universities. The increase in basic research was closely linked to research in the life sciences, conducted primarily at universities. But as their external funding grew, the universities also played an increasingly important role in applied research in chemical and electrical engineering. However, in microelectronics the university role seems to have been largely that of supplying highly trained personnel; many of the important discoveries were made in industry. For example, the transistor was first developed by William Shockley and colleagues at Bell Labs and then shared with academic researchers (Rosenberg, 1992, p. 34).

Thus, the economic growth in the early postwar years was largely concentrated in large existing companies, not startups. The total number of concerns in business increased initially as the return to a civilian economy began from about 2.1 million in 1946 (about the same as in 1930) and rose to 2.7 million by 1949, but then it stayed at that level until the end of the 1950s. Few new companies were formed; the number of new business incorporations was around 100,000 per year in the latter half of the 1940s, rose gradually in the 1950s and 1960s but did not really take off until the late 1970s. Nonagricultural self-employment stayed constant from the late 1940s until the mid-1960s, even though the labor force grew (i.e., the self-employment rate declined). There were few Initial Public Offerings (IPOs), and those that did occur were quite modest in size (in terms of proceeds per IPO) and often involved companies that had been started many

years earlier (Ibbotson *et al.*, 2001). The number of organizations per person declined continuously from 1948 to about 1970 and then leveled off. See Figure 1.

If there had not been sufficient absorptive capacity in U.S. industry during World War II, and if the universities had not been at or near the frontier in applied fields of science and engineering, and if they had not been organized appropriately, the transition to a knowledge-based economy would have taken much longer than it did.

The creation of an institutional infrastructure during this century that, by the 1940s, was capable of training large numbers of electrical engineers, physicists, metallurgists, mathematicians, and other experts capable of advancing these new technologies, meant that the postwar American endowment of specialized human capital was initially more abundant than that of other industrial nations. (Mowery & Rosenberg, 1998, p. 165)

The reasons the U.S. took the lead after the war even in technologies originally developed elsewhere were 1) the destruction in Europe, particularly in Germany and the U.K., 2) the high absorptive capacity in the U.S. as a result of both substantial funding of R&D, and 3) the formation of a new set of technology-focused innovation systems that together may be referred to as a “national innovation system.”

1980-2006

1980 represents something of a turning point. A number of institutional reforms (including strengthening of intellectual property rights, the enactment of the Bayh-Dole Act, changes in tax laws, and deregulation of financial institutions that created not only new financial instruments but also a whole new market for venture capital – see Mowery *et al.*, 2004, and Shane, 2004 for details) mark a transition to a new technological regime in which new business formation plays an increasing role in converting new knowledge into economic growth. These institutional

changes stimulated not only innovation but also entrepreneurial activity. The breakthrough in DNA research and the microprocessor revolution contributed to this development. Research funding for the life sciences increased dramatically both in absolute amounts and as a share of overall R&D funding. This gave rise to numerous university spin-offs in the form of dedicated biotechnology firms, whose main function is to translate scientific inventions into commercial innovations, sometimes producing and marketing their own products but more often in various collaborative arrangements (ranging from licensing to being acquired by large pharmaceutical firms) with other firms. While this development has created many new firms, the economic results are still pending in many cases. Meanwhile, the microelectronic revolution has spawned many new firms, some of which have grown to be industrial giants such as Microsoft, Intel, and Apple.

These developments have brought a significant shift in the size distribution of firms. The share of large firms in the economy began to decline for the first time, reversing the trend over the previous 100 years (Carlsson, 1992). Entrepreneurial activity (as measured by non-farm business tax returns, new business incorporations, the number of organizations per capita, the number of IPO offerings, and non-agricultural self-employment) began to pick up as the dynamism of the economy increased. See Figure 1.

The 'big picture' that emerges is one which shows the economy becoming increasingly dependent on economically useful knowledge and on the effectiveness with which that knowledge is converted into economic activity. In the late 19th century the knowledge creation was linked to a rise in the share of college-educated people in the population and codification and standardization of economically useful knowledge in industrial labs. At the turn of the 19th century, economic growth was driven primarily by science and engineering-based industries such

as chemicals, electrical equipment, and telecommunications. The leading companies in these industries built their own corporate R&D labs. These, as well as several federal laboratories, working closely with academic scientists, were the main producers of economically useful knowledge, and they were quick to reap the economic benefits.

World War II led to a massive scaling up of R&D in the United States. While most of the funding went to federal and corporate laboratories, the federal government now also began to fund academic research. At first the defense-related R&D was immediately converted into economic activity via incumbent firms producing such products as jet engines, radar, and computers. In the mid-1960s, the total R&D expenditures started falling in relation to GDP, and the economic impact of the war-related products was diminishing. The decline in R&D spending was reversed in the early 1980s, carried largely by biotechnology and the microprocessor.

The Nature and Role of Innovation Systems in Other Countries

As indicated above, not only the volume but also the organization of R&D influence the outcome as reflected in economic growth. This is one reason why there is little or no correlation between R&D spending and economic growth. See Acs et al. (2005). But there are many other reasons having to do with history (path dependence) and institutional arrangements. As shown above, institutions evolve, along with technologies. The institutions and the way they evolve involve both private and public actors.

The U.S. national innovation system is unique in that most inventions, particularly science-based ones, are generated within the system. In most other national innovation systems, most of the inventions come from outside and are converted into innovations within the system.

For example, in a study of the technological development in Swedish industry in the 1970s (Carlsson, 1979), it was found that even though Sweden was at or close to the technological frontier in many areas, the genuinely Swedish technological contributions were quite modest. Most technologies had been imported from abroad and then adapted and improved. This had been done largely through the R&D efforts of individual companies. In fact, one of the major findings of the study was that global monitoring of research, both academic and non-academic, was the most important function of corporate R&D even in the most research-intensive firms. Thus, many of the large industrial firms could be said to have designed their own innovation systems for their own needs, often with extensive networks both internally and externally – the latter in the form of both formal arrangements such as joint ventures and alliances and informal participation in conferences, seminars, research consortia, etc. Links with academic researchers were often seen as important but certainly not confined to domestic universities. MIT and Stanford were as likely to be mentioned as the Royal Institute of Technology and Chalmers University of Technology.

After the concept of national innovation system was developed in the late 1980s (Freeman 1987, 1988; Lundvall 1988, Nelson 1988, Pelikan 1988), a substantial literature has emerged on the structure and evolution of innovation systems in various countries and time periods. See for example Lundvall (1992), Nelson (1993) and Edquist (1997); see Carlsson (2006 and 2007) for surveys of the literature. What emerges from this literature is that there are many different ways in which national innovation systems have evolved; the evolutionary processes as well as their outcomes are clearly path dependent.

Although there is extensive evidence of internationalization of economic activity (including R&D) at the corporate level, involving cross-licensing, joint ventures, acquisitions, licensing

agreements, technology alliances, and the like, there is not much evidence of internationalization of the institutions that support national innovation systems. But there are numerous studies of internationalization of corporate R&D that point to the continued importance of national institutions to support innovative activity, even though that activity is becoming increasingly internationalized. Such institutions, whether they take the form of business groups such as Japanese keiretsu, Korean chaebol, Chinese government policy in combination with direct foreign investment or other configurations, can function as mechanisms to facilitate spillovers of technology from outside the national systems. Helping to overcome the spatial boundedness characteristic of knowledge spillovers by importing/absorbing ideas from abroad and then combining, selecting, and implementing them is one of the most important functions of innovation systems. In this sense, the innovative activities of firms are significantly influenced by their home country's national system of innovation (Carlsson, 2006).

Strangely missing from most of the innovation systems literature is the notion of entrepreneurial activity; the focus has been mainly on the creation of ideas rather than on innovation and commercialization. As explained in Bergek et al. (2008), there are six basic functions that have to be filled in a well-functioning innovation system: a mechanism is needed to focus the search for solutions; sufficient knowledge needs to be acquired or developed; resources need to be mobilized; given all the uncertainties surrounding new technologies, numerous entrepreneurial experiments are often required; a market (or markets) needs to be formed; and social and political legitimation is needed. Sometimes but not always, policy intervention is needed in one or more of these functions. It may well be the case that barriers to entrepreneurial activity in the form of entrenched incumbents and interest groups, as well as lack of institutions supporting entrepreneurship, are the most important impediments to economic development.

Given the complexity of both the economic development process and the innovation systems that support it, it is not surprising that there are not many studies of the contributions of innovation systems to economic development. But such studies are now beginning to emerge. For example, Fagerberg & Srholec (2008) tried to find indicators of “capabilities” representing the main features of national innovation systems as well as indicators of the quality of governance, the character of the political system, and the degree of openness of the economy for 115 countries. They found that innovation systems and the quality of governance are particularly important, much more so than the character of the political system and the degree of openness of the economy, in explaining differences among countries in economic development as reflected in GDP per capita. Thus, there is now at least some empirical evidence that innovation systems do make a difference, but clearly much more needs to be done.

Conclusion

In this paper I have tried to show that new knowledge is the main driver of innovation in advanced economies and that innovation is translated into economic development via both incumbent firms and new entities. The analysis of the experience in the United States shows that in the late 19th and early 20th centuries, firms in new industries that took advantage of economies of scale and scope were able to grow large and dominate their industries. New ideas came mainly from individual inventors or from corporate R&D labs rather than from academia. As new industries developed that were based on scientific discoveries, they became dependent on universities for recruiting highly trained, specialized personnel and for research collaboration.

The expansion of the U.S. system of higher education, the number and diversity of institutions and the students they educated, and the practical orientation of the curriculum created a relatively highly educated labor force, providing the economy with a high absorptive capacity. The early development of new academic disciplines in chemical and electrical engineering gave American firms an advantage over their foreign competitors.

The vast expansion of R&D in conjunction with World War II led to the emergence of a new national innovation system in which knowledge creation shifted much more toward the universities while also shifting toward basic sciences, particularly life sciences. Initially, large existing firms were the main vehicles to commercialize the products that resulted from the war-time research. But as new opportunities emerged in microelectronics and biotechnology and as institutional changes involving intellectual property and venture finance were made, entrepreneurial activity began to flourish.

The analysis shows that technologies and institutions co-evolve and that innovation systems are dynamic and path-dependent phenomena. It also shows that the function of innovation systems is not only to create or absorb ideas but also to turn ideas into innovations and commercialize them.

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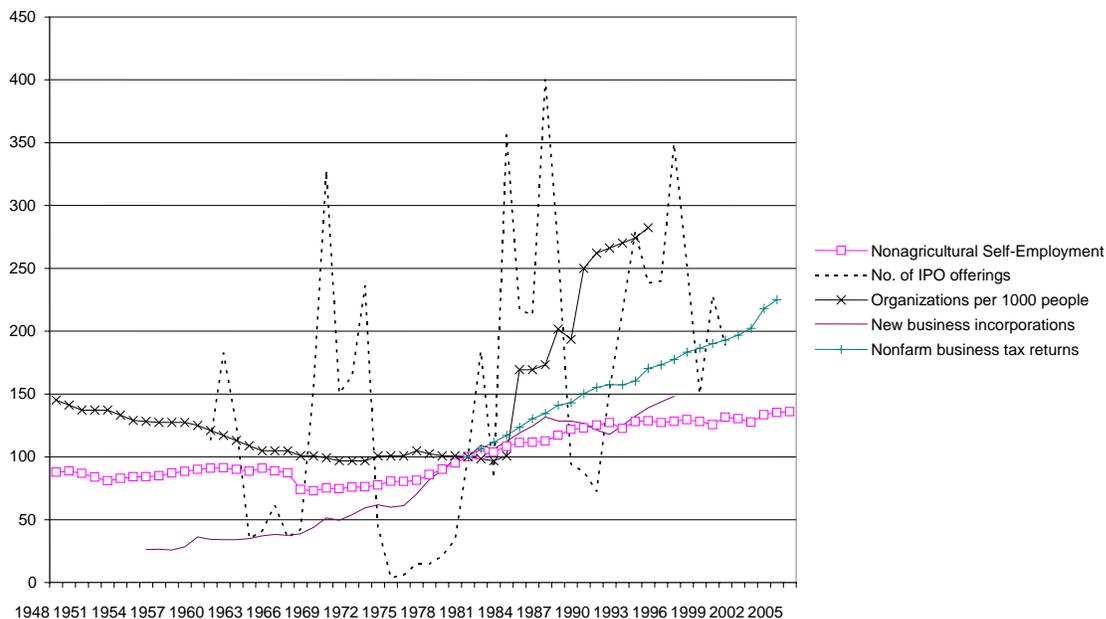
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Figure 1. Indicators of Entrepreneurial Activity, 1948-2005
Index, 1980=100



Sources: Number of IPOs: Ibbotson et al. (2001); Ritter (2006). New Business Incorporations, Nonfarm business tax returns, and Nonagricultural Self-Employment: *Statistical Abstract of the United States*, various issues. Organizations per 1000 people: Gartner and Shane (1995), p. 295.