Innovation

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Abstract

Innovation is the creation and commercial implementation of a new product or process, often (but not necessarily) based on new technology. Innovation is a major source of private business success and competitive advantage, and is the major long-term source in growth in per capita income in an economy. The innovation process is characterized by a high level of uncertainty, long lead times, and "spillovers" of economic benefits whereby innovators capture only a portion of the benefits created by an innovation. Intellectual property rights such as patents mitigate, but do not completely solve the problem of firms' inability to appropriate all of the benefits of their innovations. As a result, the private incentive to invest in innovation is lower than the social benefit, and so the private economy will invest too little in innovation in the absence of government intervention. Governments in developed economies support innovation both directly and indirectly.

INTRODUCTION

What Is it and Why Does it Matter

Joseph Schumpeter defined "innovation" as the first commercial introduction of a new product or business method. He distinguished it from "invention"—the first technical implementation of an idea, and "diffusion"—the gradual adoption of a new way of doing things by multiple actors (Schumpeter, 1942). He noted that innovation does not have to have a technological basis—it includes new business ideas that use existing technologies in new ways. In much of the literature, the technological invention step is thought of together with the commercial innovation step. I will adopt that approach here, using the term *innovation* to cover the conception, development, and commercial introduction of a new product or business method, often but not exclusively based on new technology.

Innovation thus defined is an important economic phenomenon at both a micro and macro level. At the micro level, it is the most important pathway to long-run significant profits for firms. In the short-run, it is possible to make

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money simply by being luckily in the right place at the right time. In the long run, unless one holds some kind of franchise or other legal monopoly, or owns a unique nonreproducible resource, large profits will draw competition that will typically eliminate large profits. As discussed further below, the main mechanism for long-run success in the world of competition is to come up with new products and/or new ways of operating, and to do so in a way that stays a step ahead of the competition.

At the macro level, innovation is a major source of economic growth and long-run improvement in material well-being. I will not address the deep philosophical and empirical issues around the question of whether people today are happier than people were a century ago. But if there is a case to be made that people are materially better off today, that case depends on our access to better health care, better living spaces, better transportation, better communication, and so on. All of these flow from innovation.

That said, innovation is also a source of social anxiety. It arguably undermines certain social values and contributes to unemployment of certain classes of workers, potentially contributing to income inequality and related social problems. I will return to this issue below.

KEY FEATURES AFFECTING THE STUDY OF INNOVATION

Uncertainty. All economic phenomena involve some measure of uncertainty, but uncertainty is particularly salient in the innovation process. In many cases, firms or individuals embarking on a research effort have only an indistinct notion of what the effort might yield. Even in cases where the goal is more focused, typically it is very difficult to know the likelihood or magnitude of success. In formal statistical terms, the variance of the returns to investments in innovation is typically an order of magnitude larger than the variance in returns to investments in physical assets such as infrastructure, buildings, and equipment.

Time Scale. In many cases, innovation also takes a long time to reach fruition. In the private sector, firms make investments in Research and Development (R&D) for new products and processes that may take years before any financial benefit can be realized. In the public sector, society invests in basic scientific research for which the time scale before benefits are achieved can be decades. These long time horizons interact with uncertainty to make these investments potentially unattractive to both the private and public sectors. At the same time, the combination of highly random outcomes and very long time scales makes the empirical economic study of the causes and consequences of innovation more difficult.

Intangibility. Economics use the word "capital" to describe something that has economic value because it contributes to the production of goods or services that people value. If a firm builds a new factory, or society builds a new highway, a tangible piece of capital is created. Even if the project is not a success—meaning that the output of the factory or the use of the highway is not as valued as was expected—this tangible capital typically retains some value. Further, tangible capital can be bought and sold relatively easily, so if the firm that creates a piece of capital cannot use it effectively, the firm may nonetheless earn a return on the investment that created it by selling it to another firm that can use it more effectively.

When a firm (or society) invests its research in developing a new idea, we can think of the result of that investment (if the project is successful) as knowledge capital. Knowledge capital operates like physical capital, in that, used together with other inputs (labor and physical capital), it allows a firm or society to produce more and/or more valuable goods and services than could have been produced without that knowledge capital. But unlike a factory, knowledge capital is intangible. This intangibility makes it much more difficult to redeploy the capital to different uses, or to sell it to someone else. The potential limitations on profitable deployment associated with intangibility interact with uncertainty and long time horizons to make private and social decision-making around investments in innovation difficult.

Systemic Issues and Interactions. All firms are dependent to some extent on other firms and actors. A wheat farmer can bring in a great crop, but if the railroad breaks down and s/he has trouble getting the wheat to market, its value will decline. But the development and commercialization of new products and processes is particularly subject to influences and impacts from the larger economic and social system. An all-electric car will never be widely purchased until there is a network of charging stations analogous to the existing gas stations, but firms will not want to invest in building such charging stations as long as there are very few electric cars. A new cell phone model will not sell until it is technologically capable of connecting to other cell phones sold by other companies. The profitability of some forms of firms' R&D spending will depend on the extent to which the government supports related basic scientific research. These interdependencies create *coordination problems*, by which we mean that individual firms acting on their own have difficulty making good investment decisions: because the results are interdependent, good decisions can only be made if the decisions are coordinated across firms. In the presence of such coordination problems, the fundamental notion that the "invisible hand" of competition leads markets to optimal outcomes breaks down. We need other mechanisms, such as government intervention or collective standard-setting organizations to solve the coordination problems.

FOUNDATIONAL RESEARCH

INNOVATION AND ECONOMIC GROWTH

In the 1950s, Robert Solow and Moses Abromovitz showed that approximately half of the growth in the total output of the American economy could not be explained by growth in the inputs (primarily labor and physical capital) used (Abramovitz, 1956; Solow, 1957). This gap or "residual" was assumed to be an indicator of the extent to which new technology makes capital and labor more productive. This makes sense—there is a limit to which a worker digging ditches can increase the number of ditches dug per day by using a bigger and bigger shovel. To really increase output, we need a new way of digging.

The models of the 1950s did not attempt to explain where new ways of doing things come from. Formally, productivity increases were treated as "manna from heaven" that arrived at a certain rate each year, and the project was simply to measure that rate. In the 1980s and 1990s, Paul Romer introduced the idea that productivity increases came from new ideas, and new ideas were developed by explicit investments (Romer, 1994). The resulting "endogenous growth" models bring together the microeconomic analysis of investment in new technology with the growth literature.

R&D AS AN INVESTMENT

Jacob Schmookler in the 1960s pioneered the study of new technology emerging as a response to market forces (Schmookler, 1966). He showed that growth in railroad traffic led to a growth in the rate of patenting of new railroad technologies. There is thus a "demand pull" force that is the economic manifestation of the old idea that necessity is the mother of invention. At the same time, innovation does respond also to scientific and technical developments that make it possible to do things that might have been long desired. Thus, "technological opportunity" constitutes a "technology push" that interacts with the pull of demand.

Modern thinking about the microeconomics of innovation is due primarily to Joseph Schumpeter. Schumpeter saw a modern economy as a constant process of "creative destruction," whereby firms constantly seek to gain advantage over their rivals by introducing superior products and business methods. A firm that succeeds in innovation thus earns superior economic returns, but such returns are typically temporary, as other firms will continue to strive to do better; when they do, they will displace the current leader.

The Appropriability Problem

Kenneth Arrow first pointed out an important complication to Schumpeterian competition that results from the intangible nature of knowledge (Arrow, 1962). A firm that comes up with a new way of doing things will find that new idea copied by others. (Patents are a legal institution designed to limit this, but they operate imperfectly.) The ability of a new idea to be costlessly used by multiple actors is, in the endogenous growth models described above, the mechanism that makes the creation of new ideas a source of unlimited economic growth. But for the firm that first invests in developing a new idea, the possibility of copying limits the extent to which the investing firm can appropriate the returns to its own innovation. More generally, the appropriability problem manifests itself in all of the ways that some of the benefits created by an innovation "spill over" to other firms and consumers.

The consequences of the appropriability or spillover problem are profound. It provides the conceptual basis for the creation of patents, which attempt to mitigate the problem by granting a legal monopoly over an invention. As discussed below, however, patents are a limited solution to the problem, because many aspects of knowledge creation and innovation are not patentable, and when applicable patents provide only incomplete protection. Since much of the benefit of investments in new knowledge and innovation flows to other parties, private firms will invest less in this process than is desirable from a social perspective. This inadequate private investment suggests a role for the government to intervene to increase the rate of investment (Jaffe, 1998).

General Purpose Technologies and Technology Trajectories

The appropriability problem comes together with the systemic nature of some innovations in the phenomenon dubbed by Manuel Trajtenberg and Timothy Bresnahan as "general purpose technologies" or GPTs (Bresnahan & Trajtenberg, 1995). GPTs, such as the electric motor or the computer, have the property that they facilitate and therefore spur the development of a large web of related or application innovations. The relationship between a GPT and its application technologies is characterized by a particularly important form of the "spillover" problem discussed above. Improvement in the GPT makes the application technologies more valuable, creating a spillover from the GPT firm or firms to the application firms. Conversely, improvement in the applications, and increase in the number of applications, makes the GPT more valuable, creating a spillover in the other direction. The existence of these spillovers means that GPTs are likely to be an important source of general social benefits that are not captured by any of the firms involved, and hence, GPTs are potentially important contributors to economic growth.

Another aspect of the innovation system is that technologies tend to evolve along trajectories. Without the innovation of the electric dynamo and the construction of an electricity infrastructure, many of the innovations of the twentieth century would not have occurred. Further, the evolution of electrification determined to some extent the nature and path of subsequent innovation. In extreme form, technology trajectories can lead to the phenomenon known as *lock-in*, whereby a particular technology becomes so pervasive in the infrastructure that competing technologies have difficulty competing even if they are superior in some ways (Arthur, 1989). Arguably, our current transportation system is locked into the fossil-fuel-based internal combustion engine, so that as alternative technologies develop they face an uphill battle achieving widespread diffusion.

Science and Innovation Policy

Intellectual Property Rights. The idea of a patent or government-sanctioned monopoly in a particular product goes back to fifteenth century Venice, and is enshrined in the Constitution of the US. More generally, governments recognize "intellectual property"—the intangible product of investments in new ideas and ways of doing things through mechanisms such as patents, trademarks, and copyrights. These "intellectual property rights" or "IPR" all create incentives for creating and developing new products and business methods by granting a time-limited monopoly to some degree. Of course, economics teaches that monopoly is undesirable, because a monopolist elevates prices and reduces consumer benefits. Therefore, IPR policy always involves a trade-off between the desired incentive effect and the harmful consequences of limiting competition by granting a government monopoly.

Designing patent policy to bring about the most favorable overall balance between incentives for innovation and the desirability of wide availability of new technologies is made more difficult because the incentive effects are difficult to measure. Despite the widespread belief that patents and other forms of IPR encourage innovation, and the theoretical plausibility of that concept, it is hard to demonstrate empirically that IPR does, in fact, encourage innovation (Jaffe, 2000). Many important innovations are not covered by patents, and firms do have other mechanisms besides patents to protect their investments, such as the advantage that occurs in markets to the first firm to establish a particular product. It does seem to be true that patents are important to maintaining incentives for innovation in certain specific sectors (particularly pharmaceuticals and other chemical-based industries). But in other sectors, the impact of patents on innovation incentives is unclear.

This trade-off is made particularly acute by the cumulative nature of knowledge. That is, one important consequence of new ideas is that they spur more new ideas. As Newton said, scientists and engineers "stand on the shoulders of giants," seeing farther and achieving new insights by using the insights of those who came before. If IPR are too restrictive, they not only limit consumer benefits from today's technologies, but they may also limit today's inventors' ability to build on those ideas to produce the even better technologies of tomorrow.

Public Investment and Subsidies. A major public policy to spur innovation is direct expenditure on research, and provision of incentives for private firms to engage in research. In the United States, public spending on R&D in recent years has been about 0.8% of GDP and 28% of total R&D (National Science Board, 2012). In addition, many governments provide tax credits or other incentives to private firms to reduce their cost of investing in R&D (Hall & van Reenen, 2000).

Technology Acquisition. Much direct public investment in R&D is in basic scientific research, because it is believed that the appropriability is most severe with respect to this kind of investment. The government does, however, also play a major role as a purchaser of technologically advanced products. Largely because of its defense and space missions, the US government was a major purchaser of advanced aircraft, communications, and computational technologies before products were available in a form that would likely have succeeded in private markets. These early purchases contributed greatly to the improvement of the products and reduction in the cost of their manufacture, thereby speeding the availability of commercial versions (Mowery, 2011).

Standards. As noted above, many technologies cannot thrive without a means of coordinating different aspects of their development across firms. These problems are frequently handled by the development of standards, which handle situations as disparate as making sure that your computer's Wi-Fi will work at the local Starbucks, and making sure that the gasoline at any pump station will work in your car's engine. In some cases, these standards are developed by government agencies. More frequently, they are established by private, cooperative, standard-setting organizations. The government allows and encourages this private standard-setting, by eschewing restrictions on communication among competitive firms that might otherwise be prohibited by antitrust rules, by determining how standards interact with IPR rules, and by ensuring that firms honor commitments that they make in the process of establishing standards.

CUTTING EDGE RESEARCH

Innovation is an active research topic among economists, sociologists, psychologists, historians, and business-strategy specialists. There are many ways this broad and diverse field could be characterized, but I will discuss six broad areas:

- measurement of innovation and its consequences;
- public investments and the public/private interface;
- IPR;
- the geography of innovation, and its role in regional and national economic development;
- the financing of innovation, and the role of innovation in entrepreneurship and new firm formation; and
- the role of innovation in particular sectors of public policy concern, such as health and environment.

Measurement

Because the result of research is intangible, it is intrinsically hard to measure. Further, innovations differ dramatically in their significance, so what one would really like is some overall measure of economic impact that combines the number of innovations and their importance. Such measures are typically not available, so researchers have used a variety of metrics and indicators that reflect specific aspects of the innovation process. Table 1 presents an overview of the most important measures and indicates some of their strengths and weaknesses. Counts of patents and scientific papers, frequently weighted by future citations received, are widely used as measures of the immediate output of the research process. Measures of economic impact, such as revenue from new products and measured improvements in productivity, are less widely available but have been studied in specific contexts.

Public Investment and the Public/Private Interface

Most developed nations spend some amount of public funding on either performing R&D in the public sector, or providing funds to universities and other not-for-profit entities for research. This expenditure can take the form of direct expenditure in government laboratories or institutes, grants to non-profit entities such as universities and hospitals, and research contracts with private firms. While the value of such public research is widely accepted, it has proved difficult empirically to quantify the magnitude of the impact or the overall rate of return to the investment. There are, however, many case studies and quantitative studies in particular areas documenting the interaction between public research and commercial innovation, and the role played by specific publicly funded research results and specific commercial innovations.

Table 1
Innovation Metrics

Metric or Indicator	Concept Measured	Advantages	Issues
Research expenditures	Investment in new knowledge	Reasonably widely available	Not well-measured outside of manufacturing sector
Successful patent applications	Rate of invention	Widely available	Not everything patented; patents differ greatly in importance
Patents, weighted by number of citations received from subsequent patents	Rate of invention, including quality or impact of the inventions	Widely available	Truncation effects for recent patents Measures impact within the patent system, not necessarily economic impact
Papers published; papers weighted by number of citations received from subsequent papers	Rate of new knowledge creation	Widely available	Papers differ greatly in importance; citations subject to truncation effects
Number of new products or processes introduced	Rate of innovation	Available only from specific surveys	New products differ greatly in importance
Revenue from new products	Rate of innovation, taking into account economic significance	Available only from specific surveys	—
Total factor productivity (growth rate of output or revenue minus sum of weighted growth rates of inputs)	Total economic benefit	Comprehensive in principle	Results sensitive to details of measurement and statistical specification Depending on level of aggregation (firm, industry, country), affected by spillovers to varying degree

Many governments also subsidize R&D by private firms. In the United States, there is a Research and Experimentation tax credit that allows firms to reduce their tax liability based on a formula that grants credits for increases in certain qualifying expenditures above a previous baseline level. Empirical research generally finds that this credit does increase private R&D relative to what it would otherwise have been, but there is disagreement on the efficacy of the credit in the sense of dollars of increased R&D per dollar of tax revenue lost.

Intellectual Property Rights

As noted above, IPR inherently involve a trade-off between encouraging innovation and maximizing the benefits of innovation once it occurs by allowing it to diffuse widely. How well this trade-off is being handled in different contexts is an area of much dispute and some research.

Research has looked at the operation of the patent system to try to determine if the granting and enforcement of patent rights seems appropriate to the underlying trade-off between incentives and diffusion. Many observers believe that in the last few decades, patents have become too easy to obtain, and too easy to use as a litigation threat against other firms (Jaffe & Lerner, 2006). A number of reforms in recent years, including the 2011 America Invents Act, have sought to address these concerns.

The 1980 Bayh–Dole Act in the United States made it easier for universities and other entities performing government-funded research to patent the results of that research, and license those patents to for-profit firms for exploitation. The argument for the Bayh–Dole approach is that patents coming out of government research reflect inventions that require significant additional development investment in order to make them commercially useful, and firms would not make such investments in the absence of patents to assist them in appropriating the returns. Bayh–Dole has resulted in a significant increase in patenting by universities, and some patented university technologies have been very successful, particularly in the health and information technology sectors. Many other countries have subsequently copied the Bayh–Dole approach, although the overall benefits that it creates remain controversial.

Finally, international enforcement of patents is a major issue. The United States and other developed countries have sought through the 1994 Trade Related Aspects of Intellectual Property (TRIPS) agreement to force less developed countries to protect developed-world intellectual property within their economies. Historically, countries such as China, India, and Brazil have protected intellectual property to only a limited degree. This situation is slowly changing, but there are important questions about the benefits to these countries of adopting our IPR systems. It is interesting to note that the United States achieved major development gains in the nineteenth century when it declined to enforce UK property rights, and only shifted to supporting world-wide IPR protection after it became a world technology leader.

The Geography of Innovation; Innovation in Regional and National Economic Growth

All else equal, the phenomenon of research spillovers means that the benefits of new knowledge creation are dispersed, and many parties benefit when one party increases its investment in research. From this perspective, the United States should applaud when China increases its R&D expenditure, as some of the spillovers from that research will flow to us, and we should not care whether US research investments are made in Maine or California. There is evidence, however, that research spillovers are affected by geography. They are more likely to accrue to firms and customers nearby to the innovator (Jaffe, Henderson, & Trajtenberg, 1993). This means that cities, regions, and countries need to be concerned about the extent of research investment and innovation that is occurring within their borders, because they will benefit most from research done closest to home.

Financing of Innovation

Because research and innovation are seen as sources of spillovers, and keys to regional or national economic growth, government at multiple levels is concerned as to whether firms that would like to invest in innovation are able to raise the financial capital necessary to do so. Further, the large uncertainty and long time horizon associated with these investments raise questions as to whether traditional private finance mechanisms are adequate to this task. As a result, a considerable body of research looks at the extent to which the availability of finance affects the rate of innovation (Hall & Lerner, 2010). In particular, the unique role of venture capital in the United States in financing start-up firms has been the subject of much attention.

Innovation in Particular Sectors

In the health sector, researchers have studied the contribution of new technologies to improved health outcomes, the effect of the medical payment system on the development of new technologies, and the effect of new technologies on health care costs. These include studies of the overall system, trying to quantify the overall impact of new technologies on health or the overall impact of new technology on health care costs, and studies of specific technologies that attempt to measure their efficacy and cost impact.

In the environment and energy sector, researchers have focused on innovation both out of concern that environmental regulation might inhibit innovation and recognition that solving large environmental challenges such as climate change is going to require significant innovation.

RESEARCH ISSUES GOING FORWARD

I have argued that innovation is an important source of private profit and social benefit, driven in part by private incentives but subject to coordination and appropriability problems that create an important role for the government in fostering innovation. Many of the active research questions aim to improve governments' ability to perform this function. A sampling of important and salient issues:

- What kind of IPR policies is most conducive to development and other objectives of less developed countries? Developed countries want the less developed simply to adopt first-world IPR policies, but such policies may well inhibit their own development and their ability to meet specific goals such as health and climate change mitigation. We need a better understanding on how the IPR regime in less developed countries affects indigenous innovation, foreign investment, and other forms of technology transfer from abroad.
- As research becomes ever more complex, what combinations of different kinds of research teams and researchers working in larger networks are most conducive to scientific and technical advance? We know that collaboration has been increasing, but we do not know how internal collaboration (use of larger and more diverse teams) best interacts with external collaboration (having research teams in communication with other teams at multiple institutions in a research network).
- What are the best ways to maximize commercial returns from the public investment in research? Do Bayh–Dole-like property rights for publicly funded innovation foster or inhibit commercialization of those results? Are there other mechanisms to maximize the usefulness of public research to the private sector?
- How can innovation best contribute to the global climate change challenge? Do we need new IPR rules or new modes of international collaboration in order to maximize our chance of finding the transformative technologies we need?
- How do the "big data" and digitization revolutions change the innovation landscape? Do these phenomena change the spillover/ appropriability situation, and do they require new kinds of IPR or new approaches to enforcing IPR?

- Innovation has been seen as a driver of ever-increasing health care costs. What factors mediate the interaction between innovation and costs in health care, and could innovation be a source of long-run cost efficiency?
- What modes or mechanisms of government support for research are most effective? We have methods for systematic evaluation of funding and grant programs, but they are almost never used. If we measured the results from different kinds of programs, then future money could be spent through those mechanisms that are most effective.
- What is the relationship between innovation and unemployment/inequality? Does innovation inevitably reduce the availability of low-skill jobs? Is the nature of innovation in the United States changing so that it more broadly reduces wages relative to profits? Are there government policies that would nudge innovation in directions that have the broadest social benefits?

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