COVER STORY

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What We Don't Know About Innovation...

We know innovation is important — but do we know how to make it happen?

BY JESSIE ROMERO

The printing press. The steam engine. Penicillin, personal computers, the Internet — these are turning points in history, innovations that have transformed modern life and contributed to an exponential rise in living standards throughout much of the world.

It is a foundation of economic theory that such innovations are the key to long-term economic growth. New ideas and new technologies lead to rising productivity, which leads to sustained increases in per capita income and living standards over time.

As the United States continues its slow recovery from the deepest recession since the Great Depression, restoring the country's "innovation economy" has taken on new urgency. A raft of recent policy proposals from think tanks, trade organizations, and politicians emphasize support for small business, incentives for private-sector research and development (R&D), more federal spending on science, and education and immigration reform as strategies that will lead to more innovation and thus to more growth and jobs.

These policies typically are predicated on a set of beliefs — that small companies are more innovative than large, that more government spending translates into more innovation, and that innovation in general is a phenomenon that can be measured and studied scientifically. But innovation is an elusive concept. A novel idea isn't enough in and of itself; that idea must also translate into profitable products and services, and lead to the creation of new economic value. How and why innovation actually happens — and how to make more of it — are questions that researchers are still trying to answer.

Sizing up Business Size

In 1979, Apple co-founder Steve Jobs visited Xerox PARC, the innovation lab of the Xerox Corporation. There, he saw the Xerox Alto, the first computer to operate with a mouse and the graphical user interface familiar to today's computer users. Jobs was so excited that he returned a month later with his own engineers, who paid close attention to what they saw. "If Xerox had known what it had and had taken advantage of its real opportunities, it could have been as big as IBM plus Microsoft plus Xerox combined," Jobs said in an interview years later. Instead, the story goes, the nimble, entrepreneurial startup launched the Macintosh and transformed computing while the established, slow-moving corporation failed to realize the commercial potential of what it had developed.

But the story isn't so clear-cut. Apple wasn't actually all that small at the time; the Apple II computer had been a commercial success for two years, and the company was just a year away from a $101 million initial public offering ($279 million in today's dollars), the largest since that of Ford Motor Co. in 1956. By 1983, the year before it introduced the Macintosh, Apple's revenues were $983 million (more than $2.2 billion today). And although Xerox failed in its first attempt to market a computer with a graphical interface (a successor to the Alto named the Star), Apple's first attempt to market such a computer, the Lisa, was also a flop. Moreover, while the large company is faulted in hindsight for not realizing the commercial potential of its inventions, the resources it committed to research and experimentation are what helped make innovations like the Macintosh possible.

Small businesses are the beneficiaries of many policies designed to support the next Apple. The Small Business Administration (SBA) administers several programs that help small businesses win federal technology contracts and research grants, and federal agencies are required to award a set portion of their R&D funds to small businesses. The Small Business Jobs Act of 2010 enacted new tax cuts and extended lending programs for small businesses, citing them as "the engine of our economy." And the current administration's *Strategy for American Innovation*, released in 2009 and updated in 2011, includes a number of provisions to help small businesses and entrepreneurs, such as loans, training programs, regional economic development grants, and a promise to aggressively pursue large companies for antitrust violations.

Over the past several decades, smaller businesses have performed an increasing share of R&D in the United States, according to research by Robert Hunt and Leonard Nakamura of the Philadelphia Fed. They found that nearly all of the increase in R&D between 1980 and 2000, a period when private R&D as a share of GDP about doubled, is accounted for by the increase in R&D at smaller firms. Computers and other technologies made it easier for new firms to enter the market and compete against large incumbent firms, and cheaper to develop new products. "We have a body of evidence that a very significant portion of our fairly good outcomes in terms of innovation in the last 30 years was driven by a structural change that favors smaller and younger firms," Hunt says. As Hunt notes, however, that change resulted from new technology, not from new government policies.

The special attention paid to small businesses stems from the belief that they have an inherent innovative advantage over large businesses: They are less likely to have an interest in maintaining the status quo, and they are more responsive and quicker to change. As a result, they have a disproportionate impact on "disruptive" innovation — change that creates an entirely new market — as opposed to large firms, which tend to engage in incremental innovation, some say.

Not every small business matches the popular images of the "inventor in the basement" or the company run out of a garage. The SBA's official definition of a small business is one with fewer than 500 employees — a definition that covers 99.8 percent of all employer firms in the United States.

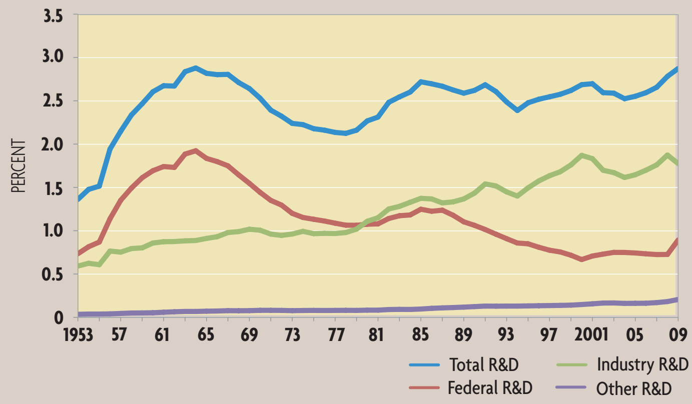
Economists have spent decades studying the complicated relationship between market structure and innovation. A large and highly influential body of research, beginning with a seminal 1962 paper by Nobel laureate Kenneth Arrow, argues that competition is more conducive to innovation than monopoly. Arrow showed that because monopolies maximize profit by raising prices and restricting quantities, they have less output over which to spread the fixed costs of innovating, and thus are less likely to invest in new technology. In addition, each firm in a competitive market may have an incentive to innovate in an effort to escape the competition, whereas monopolists don't face the same competitive pressures. But another large body of work suggests that even the mere threat of other firms entering the market might be enough to induce monopolies to act as if they are in a competitive market.

Economist Joseph Schumpeter, who pioneered the idea of "creative destruction" as the engine of capitalism, argued that large businesses — particularly monopolies — are better qualified to innovate because they have the size to take advantage of increasing returns to investments in R&D, they have greater capacity to take on risk, and they have fewer competitors to imitate their invention. Other economists also believe that large companies have greater incentives to innovate, although not necessarily because they are monopolies, as economist William Baumol of New York University discussed in his 2002 book *The Free-Market Innovation Machine*. According to Baumol, a market structure that involves competition among a few large businesses has "innovation as a prime competitive weapon," and thus "ensure[s] continued innovative activities."

This has been true in retail, where just five companies — Wal-Mart, Kroger, Target, Walgreens, and the Home Depot — account for 36 percent of the total sales of the country's 100 largest retailers. Although Wal-Mart's sales are more than the sales of the next four companies combined, it has continued to develop new supply chain technologies that have both increased its own productivity and led to higher productivity in the sector overall.

Large companies also are often the center of "innovation ecosystems," the constellation of suppliers and developers that forms around a central business. Today, Apple — the world's largest publicly traded company, as measured by market capitalization — is the center of just such a constellation. Apple and other large companies invest in key technologies and create stable platforms that make it easier for small companies to innovate,

R&D Spending as Share of GDP



NOTE: 2009 is the latest year data are available. "Other" includes college and university, nonprofit industry, and nonfederal government.
SOURCES: National Science Foundation; Bureau of Economic Analysis, Haver Analytics; *Region Focus* calculations

and the ecosystem as a whole can better handle both risk and scale, according to economist Michael Mandel of the Progressive Policy Institute. Small and large companies may have different advantages and incentives to innovate, but both are important to the process.

Should the Government Spend More?

Whether they own a Mac or a PC, most people use their computer to browse the millions of websites that have sprung up in the past two decades. The modern Internet grew out of ARPANET, a Defense Department project during the 1960s and 1970s to develop a communications network that could continue operating even if various command centers were destroyed. The Pentagon's Advanced Research Projects Agency funded research at private companies and universities nationwide into packet switching (and later the TCP/IP model), and awarded development contracts to numerous small companies, helping to create a market for the new technologies. Today, the Internet is cited as a prime example of the importance of government spending to scientific advances and innovation.

The theoretical case for such spending is strong, particularly in the case of basic research. New knowledge is a "nonrivalrous" good — once an inventor has an idea, that idea can be replicated or put to use by many other people. In addition, there is often a long lag between a new idea and its commercialization. As a result, the full economic value of a new discovery is unlikely to be realized by the discoverer, making the private sector unlikely to invest in a socially desirable amount of research. The patent system is one way to address this "market failure," by awarding a temporary monopoly to the inventor. But strict intellectual property rights can also limit the use of new ideas, making it difficult for researchers to build on earlier work. Another way to correct potential underinvestment in research by the private sector is for the government to fund the research itself, or lower the costs of private-sector investment via subsidies or tax credits.

Since the 1970s, federal spending on R&D has declined as a share of GDP, although the overall level of R&D spending has remained fairly constant due to an increase in private-sector spending (see chart). Because federal spending is more likely, in theory, to be directed toward the type of research unlikely to occur in the private sector, many are concerned that the shrinking federal share hampers the United States' ability to discover the next big thing.

In practice, government spending on R&D isn't always allocated to projects that provide the greatest public good, as political considerations might factor into the decision-making. And while the success stories — such as the Internet; the development of hybrid seed corn, which dramatically increased crop yields in the 1930s; or the mapping of the human genome, which is leading to new medical technologies — are compelling examples of the benefits of government spending on research, those cases aren't necessarily applicable to other projects or to broad policy decisions.

At most federal agencies, R&D spending is a mix of basic research, applied research, and development. (Basic research is to advance general knowledge, without a specific need or product in mind. Applied research is directed toward meeting a specific need. Development is the design and production of actual products.) The exceptions are the Department of Defense, where nearly all spending is for development, and the National Science Foundation (NSF), where nearly all is for basic research (see chart).

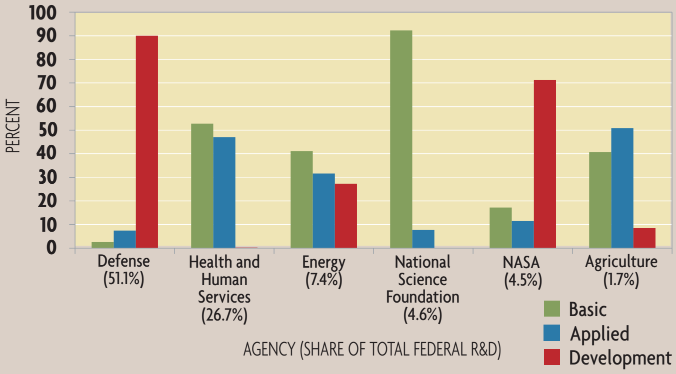
But these categories mask the fact that more than 90 percent of this spending, including that classified as basic, could be considered "mission oriented," that is, aimed at fulfilling the specific goals of the funding agency rather than at addressing a market failure, according to research by David Mowery, an economist at the University of California at Berkeley. A successful program thus might not be proof that government involvement is necessarily the way to go. Instead, "the economic effects ... are linked to complementary policies or broader structural elements of the agencies' missions. Apparently similar programs ... may produce very different outcomes in different contexts," Mowery wrote in a chapter of the 2009 anthology *The New Economics of Technology Policy*.

In the case of the Internet, the Defense Department had a unique and large-scale procurement strategy that encouraged new firms to enter the industry and contributed to the rapid commercial diffusion of the new technologies. R&D spending by the National Institutes of Health, one of the agencies that funded the Human Genome Project, tends to have large economic effects since many consumers of new health care technologies are price-insensitive. Because procurement strategies, demand conditions, and other factors vary from agency to agency and from project to project, caution is warranted when generalizing from one project to another.

An additional source of federal support for R&D is private-sector tax incentives. The largest incentive, the

Research and Experimentation Tax Credit, was enacted in 1981 as part of an economic recovery program bill. U.S. companies claimed $8.3 billion in credits in 2008, according to the National Science Foundation. (2008 is the most recent year for which the IRS has published data.) In addition, about 35 states, including the entire Fifth District with the exception of Washington, D.C., offer tax incentives for R&D. It's unclear, however, what effect such incentives actually have on R&D. For example, in a survey of 20 empirical studies, economists Bronwyn Hall of the University of California at Berkeley and John Van Reenen of the London School of Economics and Political Science concluded that a tax incentive increases R&D by about dollar for dollar. As the authors noted, however, there is a great deal of variation in the results of the studies depending on the methods used to calculate the effect. Hall and Van Reenen also pointed out that at least part of the increase could be due to "relabeling" — companies shifting activities in their budgets in order to qualify for the credit — rather than to genuine increases in investment. Private-sector firms also are likely to use the credits to first fund projects that have the highest rate of private return, rather than those likely to advance basic knowledge. This makes it difficult for policymakers and economists to determine whether the incentives are supporting R&D that firms would have undertaken anyway.

Federal Agency R&D Spending



NOTE: Data are for the top six agencies as a share of total federal R&D spending.
SOURCE: National Science Foundation, "Science and Engineering Indicators 2012"

How to Measure Innovation?

In order to study the effects of policy on innovative activity, economists and researchers must make a crucial assumption: Innovation is something that can be measured. But "the unit of analysis is quite complex," says Julia Lane, senior managing economist at the nonprofit American Institutes for Research (AIR) and the former director of the Science of Science and Innovation Policy program at the NSF. Innovation depends on "a complex system of relationships, the whole process of sharing knowledge," and is characterized by long time lags, Lane says, which makes it difficult to quantify after it has occurred — not to mention difficult to predict in advance.

At the macro level, the effects of innovation are often quantified as "total factor productivity" (TFP). In a basic model, economic growth occurs not only because labor and capital increase, but also because technological advances allow those inputs to be used more efficiently. Technological change cannot be observed directly, however, so the portion of growth in the model that cannot be attributed directly to labor or capital — the "residual" — is called TFP. Estimates of TFP are very sensitive to the assumptions underlying the model being used to measure it, and it's possible that the term might capture factors other than technological change.

Innovation can't be measured directly at the firm or industry level either. Two of the most widely used proxies for innovation are patenting rates and R&D spending; a researcher can compare the number of patents issued or the amount of spending before and after a policy change to determine the effects of that policy. But such measures are lacking, says Hunt of the Philadelphia Fed. "We have this fundamental data constraint: We know what we want to study, but what we have are a bunch of imperfect measures."

Changes over time in U.S. patent law and in patenting strategies mean that patenting rates might not be comparable across time periods or industries, Hunt says. Prior to the 1990s, for example, it was very difficult to patent software. But once federal courts began treating computer programs like other forms of technology, the number of software patents grew from 1,000 to nearly 25,000 per year, according to research by Hunt and James Bessen, director of the nonprofit organization Research on Innovation. Rather than an increase in innovation, this rise might reflect "defensive patenting," a practice common in some high-tech industries whereby companies obtain a high volume of patents for minor or trivial inventions in an effort to block their competitors or protect themselves against future litigation. (See "Patents Pending," *Region Focus*, Fourth Quarter 2011.)

Economists can try to address the limitations of patents by weighting patents according to how frequently they are cited by other patents, which gives some indication of a patent's value, but patent quality and comparability across time and industry remain challenges for researchers.

Much of innovation policy is premised on the "notion that you can just drop the magic number of R&D in one end, and automatically out the other end comes innovation," says Lane of AIR. But as with patents, an increase in R&D spending does not always reflect an increase in innovation. As a working group organized by the Organization for Economic Cooperation and Development (OECD) stated, "It is probably quite erroneous and misleading for appropriate and adequate policymaking for technology and competitiveness to equate R&D with innovative capacity." The OECD, among others, is currently working to develop new measures of innovation that better capture the complex interactions between policy, firms, and the economy as a whole.

The Congressional Budget Office reviewed more than three dozen studies that measured productivity changes at the firm, industry, and economy levels using R&D spending as a proxy for innovation. Overall, the studies concluded that additional R&D spending had a positive effect on output and productivity, but the magnitude of the effect varied tremendously. Most significantly, the effect of R&D spending was much greater in studies that compared different companies with different levels of R&D than in studies that followed changes in R&D over time at the same company. This suggests that factors other than R&D spending are responsible for productivity differences seen between companies, and perhaps that increases in R&D might not have a large effect on the economy as a whole.

As difficult as innovation is to measure after the fact, it's even harder to capture in the present. It is only with the benefit of hindsight that the revolutionary properties of a new invention seem inevitable: Johannes Gutenburg didn't know his printing press would lay the groundwork for the Renaissance and the Age of Enlightenment. Farmers were initially reluctant to try the new hybrid seed corn. And technologies with great promise — such as hydrogen-powered cars or Betamax videotapes — may fail to live up to their potential. As economic historian Joel Mokyr of Northwestern University wrote in a 1992 paper, "If every harebrained technological idea were tried and implemented, the costs would be tremendous. Like mutations, most technological innovations are duds and deserve to be eliminated. Yet ... if *no* harebrained idea were ever tried, we would still be living in the Stone Age. Unfortunately, it is impossible to know in advance whether an invention is a true improvement or a dud until the experiments are carried out."

Planting the Seeds

"We're betting our future on the idea that investing in science is going to lead us to more economic growth and competitiveness," says Lane of AIR. "But the fact is, we don't know how that works. To say, 'We're going to spend money on R&D and 20 years later a miracle is going to occur' is not a very scientific approach." Lane and other researchers are working to develop new datasets and data infrastructure that will help scientists, entrepreneurs, and policymakers better understand the links between investment, innovation, and economic growth.

In the meantime, attempting to plan or direct innovation might not be possible. "Innovation is like a forest," says Robert Litan, vice president of research and policy at the Ewing Marion Kauffman Foundation, an organization that studies entrepreneurship. "You can make sure the soil is right, and you can fertilize it. You can plant the trees, but you don't know which trees are going to grow the highest."

Still, policymakers could have an effect on the fertilizer. Many economists agree, for example, that immigration rules should make it easier for immigrants with high-tech skills to enter the United States and for foreign students to remain here after earning their degrees. More than one-half of new high-tech businesses launched in Silicon Valley between 1995 and 2005 had a foreign-born founder, yet the number of H1-B work visas for scientists and engineers has been cut by two-thirds in recent years. Opening up immigration "would bring a lot more energy and ideas to America," says Litan.

Even if the number of H1-B visas were restored to its previous peak of 195,000 per year in the early 2000s, that represents only one-tenth of 1 percent of the U.S. labor force; there is also a need to train more Americans in the STEM fields (science, technology, engineering, and mathematics). Education policies focused on achievement in these fields, such as higher salaries for top-performing STEM teachers and new community college programs, could help students and workers gain high-tech knowledge or advanced manufacturing skills.

Completing new multilateral trade agreements could also help encourage innovation, as a recent report by the Brookings Institution noted. Companies in export markets must compete internationally and can learn from technological advances in other countries. Finally, a more flexible intellectual property system that can meet the needs of companies of different sizes and in different industries, and that does not reward the filing of trivial or low-value patents, could create better incentives for companies to innovate. Such policy changes are not a guarantee that innovation and economic growth will occur, but they could help to create an environment in which ideas and firms can flourish. **RF**

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