Chapter Two

Sources of Innovation

The Rise of "Clean Meat"[a]

In late 2017, Microsoft founder Bill Gates and a group of other high-powered investors—who comprise Breakthrough Energy Ventures, such as Amazon's Jeff Bezos, Alibaba's Jack Ma, and Virgin's Richard Branson—announced their intention to fund a San Francisco–based start-up called Memphis Meats with an unusual business plan: it grew "clean" meat using stem cells, eliminating the need to breed or slaughter animals. The company had already produced beef, chicken, and duck, all grown from cells.[b]

There were many potential advantages of growing meat without animals. First, growth in the demand for meat was skyrocketing due to both population growth and development. When developing countries become wealthier, they increase their meat consumption. While humanity's population had doubled since 1960, consumption of animal products had risen fivefold and was still increasing. Many scientists and economists had begun to warn of an impending "meat crisis." Even though plant protein substitutes like soy and pea protein had gained enthusiastic followings, the rate of animal protein consumption had continued to rise. This suggested that meat shortages were inevitable unless radically more efficient methods of production were developed.

Large-scale production of animals also had a massively negative effect on the environment. The worldwide production of cattle, for example, resulted in a larger emissions of greenhouse gases than the collective effect of the world's automobiles. Animal production is also extremely water intensive: To produce each chicken sold in a supermarket, for example, requires more than 1000 gallons of water, and each egg requires 50 gallons. Each gallon of cow's milk required 900 gallons of water. A study by Oxford University indicated that meat grown from cells would produce up to 96 percent lower greenhouse gas emissions, use 45 percent less energy, 99 percent less land, and 96 percent less water.[c]

Scientists also agreed that producing animals for consumption was simply inefficient. Estimates suggested, for example, that it required roughly 23 calories worth of inputs to produce one calorie of beef. "Clean" meat promised to bring that ratio down to three calories of inputs to produce a calorie of beef—more than seven times greater efficiency. "Clean" meat also would not contain antibiotics, steroids, or bacteria such as *E. coli*—it was literally "cleaner," and that translated into both greater human health and lower perishability.

The Development of Clean Meat

In 2004, Jason Matheny, a 29-year-old recent graduate from the John Hopkins Public Health program decided to try to tackle the problems with production of animals for food. Though Matheny was a vegetarian himself, he realized that convincing enough people to adopt a plant-based diet to slow down the meat crisis was unlikely. As he noted, "You can spend your time trying to get people to turn their lights out more often, or you can invent a more efficient light bulb that uses far less energy even if you leave it on. What we need is an enormously more efficient way to get meat."[d]

Matheny founded a nonprofit organization called New Harvest that would be dedicated to promoting research into growing real meat without animals. He soon discovered that a Dutch scientist, Willem van Eelen was exploring how to culture meat from animal cells. Van Eelen had been awarded the first patent on a cultured meat production method in 1999. However, the eccentric scientist had not had much luck in attracting funding to his project, nor in scaling up his production. Matheny decided that with a little prodding, the Dutch government might be persuaded to make a serious investment in the development of meat-culturing methods. He managed to get a meeting with the Netherland's minister of agriculture where he made his case. Matheny's efforts paid off: The Dutch government agreed to invest two million euros in exploring methods of creating cultured meat at three different universities.

By 2005, clean meat was starting to gather attention. The journal *Tissue Engineering* published an article entitled "In Vitro-Cultured Meat Production," and in the same year, the *New York Times* profiled clean meat in its annual "Ideas of the Year." However, while governments and universities were willing to invest in the basic science of creating methods of producing clean meat, they did not have the capabilities and assets needed to bring it to commercial scale. Matheny knew that to make clean meat a mainstream reality, he would need to attract the interest of large agribusiness firms.

Matheny's initial talks with agribusiness firms did not go well. Though meat producers were open to the idea conceptually, they worried that consumers would balk at clean meat and perceive it as unnatural. Matheny found this criticism frustrating; after all, flying in airplanes, using air conditioning, or eating meat pumped full of steroids to accelerate its growth were also unnatural.

Progress was slow. Matheny took a job at the Intelligence Advanced Research Projects Activity (IARPA) of the U.S. Federal Government while continuing to run New Harvest on the side. Fortunately, others were also starting to realize the urgency of developing alternative meat production methods.

Enter Sergey Brin of Google

In 2009, the foundation of Sergey Brin, cofounder of Google, contacted Matheny to learn more about cultured meat technologies. Matheny referred Brin's foundation to Dr. Mark Post at Maastricht University, one of the leading scientists funded by the Dutch government's clean meat investment. Post had succeeded in growing mouse muscles in vitro and was certain his process could be replicated with the muscles of cows, poultry, and more. As he stated, "It was so clear to me that we could do this. The science was there. All we needed was funding to actually prove it, and now here was a chance to get what was needed."[e] It took more than a year to work out the details, but in 2011, Brin offered Post roughly three quarters of a million dollars to prove his process by making two cultured beef burgers, and Post's team set about meeting the challenge.

In early 2013, the moment of truth arrived: Post and his team had enough cultured beef to do a taste test. They fried up a small burger and split it into thirds to taste. It tasted like meat. Their burger was 100 percent skeletal muscle and they knew that for commercial production they would need to add fat and connective tissue to more closely replicate the texture of beef, but those would be easy problems to solve after passing this milestone. The press responded enthusiastically, and the *Washington Post* ran an article headlined, "Could a Test-Tube Burger Save the Planet?"[f]

Going Commercial

In 2015, Uma Valeti, a cardiologist at the Mayo Clinic founded his own cultured-meat research lab at the University of Minnesota. "I'd read about the inefficiency of meat-eating compared to a vegetarian diet, but what bothered me more than the wastefulness was the sheer scale of suffering of the animals."[g] As a heart doctor, Valeti also believed that getting people to eat less meat could improve human health: "I knew that poor diets and the unhealthy fats and refined carbs that my patients were eating were killing them, but so many seemed totally unwilling to eat less or no meat. Some actually told me they'd rather live a shorter life than stop eating the meats they loved." Valeti began fantasizing about a best-of-both-worlds alternative—a healthier and kinder meat. As he noted, "The main difference I thought I'd want for this meat I was envisioning was that it'd have to be leaner and more protein-packed than a cut of supermarket meat, since there's a large amount of saturated fat in that meat. . . . Why not have fats that are proven to be better for health and longevity, like omega-3s? We want to be not just like conventional meat but healthier than conventional meat."[h]

Valeti was nervous about leaving his successful position as a cardiologist—after all, he had a wife and two children to help support. However, when he sat down to discuss it with his wife (a pediatric eye surgeon), she said, "Look, Uma. We've been wanting to do this forever. I don't ever want us to look back on why we didn't have the courage to work on an idea that could make this world kinder and better for our children and their generation."[i] And thus Valeti's company, which would later be named Memphis Meats, was born.

Building on Dr. Post's achievement, Valeti's team began experimenting with ways to get just the right texture and taste. After much trial and error, and a growing number of patents, they hosted their first tasting event in December 2015. On the menu: a meatball. This time the giant agribusiness firms took notice.

At the end of 2016, Tyson Foods, the world's largest meat producer, announced that it would invest $150 million in a venture capital fund that would develop alternative proteins, including meat grown from self-reproducing cells. In August of 2017, agribusiness giant Cargill announced it was investing in Memphis Meats, and a few months later in early 2018, Tyson Foods also pledged investment.

That first meatball cost $1200; to make cultured meat a commercial reality required bringing costs down substantially. But analysts were quick to point out that the first iPhone had cost $2.6 billion in R&D—much more than the first cultured meats. Scale and learning curve efficiencies would drive that cost down. Valeti had faith that the company would soon make cultured meat not only competitive with traditional meat, but more affordable. Growing meat rather than whole animals had, after all, inherent efficiency advantages.

Some skeptics believed the bigger problem was not production economies, but consumer acceptance: would people be willing to eat meat grown without animals? Sergey Brin, Bill Gates, Jeff Bezos, Jack Ma, and Richard Branson were willing to bet that they would. As Branson stated in 2017, "I believe that in 30 years or so we will no longer need to kill any animals and that all meat will either be clean or plant-based, taste the same and also be much healthier for everyone."[j]

Discussion Questions

1. What were the potential advantages of developing clean meat? What were the challenges of developing it and bringing it to market?
2. What kinds of organizations were involved in developing clean meat? What were the different resources that each kind of organization brought to the innovation?
3. Do you think people will be willing to eat clean meat? Can you think of other products or services that faced similar adoption challenges?

[a] Adapted from a NYU teaching case by Paul Shapiro and Melissa Schilling.

[b] Friedman, Z., "Why Bill Gates and Richard Branson Invested in 'Clean' Meat," *Forbes* (August 2017).

[c] Tuomisto, H. L., and M. J. de Mattos, "Environmental Impacts of Cultured Meat Production," *Environmental Science and Technology* 14(2011): 6117–2123.

[d] Shapiro, P. *Clean Meat: How Growing Meat without Animals Will Revolutionize Dinner and the World* (New York: Gallery Books, 2018), 35.

[e] Shapiro, P. *Clean Meat: How Growing Meat without Animals Will Revolutionize Dinner and the World* (New York: Gallery Books, 2018), 60.

[f] "Could a Test-Tube Burger Save the Planet?" *Washington Post,* August 5, 2013.

[g] Shapiro, P. *Clean Meat: How Growing Meat without Animals Will Revolutionize Dinner and the World* (New York: Gallery Books, 2018), 113.

[h] Shapiro, P. *Clean Meat: How Growing Meat without Animals Will Revolutionize Dinner and the World* (New York: Gallery Books, 2018), 115.

[i] Shapiro, P. *Clean Meat: How Growing Meat without Animals Will Revolutionize Dinner and the World* (New York: Gallery Books, 2018), 118.

[j] Friedman, Z., "Why Bill Gates and Richard Branson Invested in 'Clean' Meat," *Forbes* (August 2017).

OVERVIEW

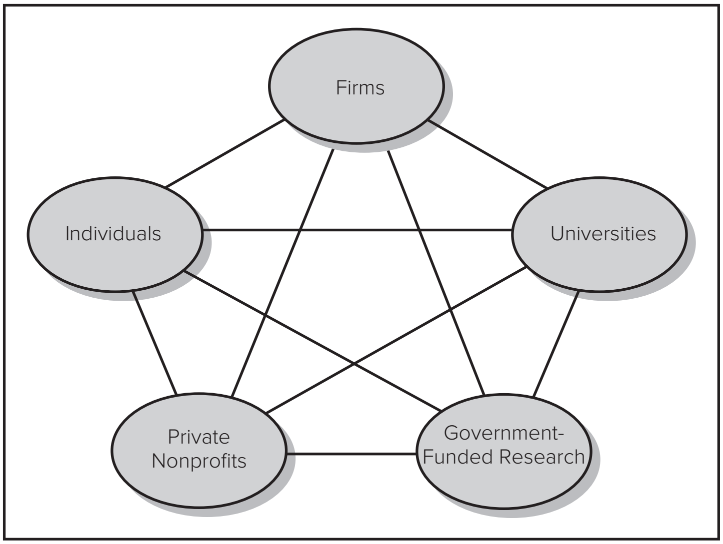
innovation
The practical implementation of an idea into a new device or process.

Innovation can arise from many different sources. It can originate with individuals, as in the familiar image of the lone inventor or users who design solutions for their own needs. Innovation can also come from the research efforts of universities, government laboratories and incubators, or private nonprofit organizations. One primary engine of innovation is firms. Firms are well suited to innovation activities because they typically have greater resources than individuals and a management system to marshal those resources toward a collective purpose. Firms also face strong incentives to develop differentiating new products and services, which may give them an advantage over nonprofit or government-funded entities.

An even more important source of innovation, however, does not arise from any one of these sources, but rather the linkages between them. Networks of innovators that leverage knowledge and other resources from multiple sources are one of the most powerful agents of technological advance.[1] We can thus think of sources of innovation as composing a complex system wherein any particular innovation may emerge primarily from one or more components of the system or the linkages between them (see Figure 2.1).

In the sections that follow, we will first consider the role of creativity as the underlying process for the generation of novel and useful ideas. We will then consider how creativity is transformed into innovative outcomes by the separate components of the innovation system (individuals, firms, etc.), and through the linkages between different components (firms' relationships with their customers, technology transfer from universities to firms, etc.).

FIGURE 2.1
Sources of Innovation as a System



CREATIVITY

idea
Something imagined or pictured in the mind.

creativity
The ability to produce novel and useful work.

Innovation begins with the generation of new **ideas**. The ability to generate new and useful ideas is termed creativity. **Creativity** is defined as the ability to produce work that is useful and novel. Novel work must be different from work that has been previously produced and surprising in that it is not simply the next logical step in a series of known solutions.[2] The degree to which a product is novel is a function both of how different it is from prior work (e.g., a minor deviation versus a major leap) and of the audience's prior experiences.[3] A product could be novel to the person who made it, but known to most everyone else. In this case, we would call it reinvention. A product could be novel to its immediate audience, yet be well known somewhere else in the world. The most creative works are novel at the individual producer level, the local audience level, and the broader societal level.[4]

Individual Creativity

An individual's creative ability is a function of his or her *intellectual abilities, knowledge, personality, motivation*, and *environment*.

The most important *intellectual abilities* for creative thinking include intelligence, memory, the ability to look at problems in unconventional ways, the ability to analyze which ideas are worth pursuing and which are not, and the ability to articulate those ideas to others and convince others that the ideas are worthwhile. One important intellectual ability for creativity is a person's ability to let their mind engage in a visual mental activity termed *primary process thinking*.[5] Because of its unstructured nature, primary process thinking can result in combining ideas that are not typically related, leading to what has been termed *remote associations* or *divergent thinking*. Sigmund Freud noted that primary process thinking was most likely to occur just before sleep or while dozing or daydreaming; others have observed that it might also be common when distracted by physical exercise, music, or other activities. Creative people may make their minds more open to remote associations and then mentally sort through these associations, selecting the best for further consideration. Having excellent working memory is useful here too—individuals with excellent working memory may be more likely or more able to search longer paths through the network of associations in their mind, enabling them to arrive at a connection between two ideas or facts that seem unexpected or strange to others.[6] A connection that appears to be random may not be random at all—it is just difficult for other people to see the association because they are not following as long of a chain of associations.

Consistent with this, studies by professors Mathias Benedek and Aljoscha Neubauer found that highly creative people usually follow the same association paths as less creative people—but they do so with such greater speed that they exhaust the common associations sooner, permitting them to get to less common associations earlier than others would.[7] Benedek and Neubauer's research argues that highly creative people's speed of association is due to exceptional working memory and executive control. In other words, the ability to hold many things in one's mind simultaneously and maneuver them with great facileness enables a person to rapidly explore many possible associations.[8]

The impact of *knowledge* on creativity is somewhat double-edged. If an individual has too little knowledge of a field, he or she is unlikely to understand it well enough to contribute meaningfully to it. On the other hand, if an individual knows a field too well, that person can become trapped in the existing logic and paradigms, preventing him or her from coming up with solutions that require an alternative perspective. Thus, an individual with only a moderate degree of knowledge of a field might be able to produce more creative solutions than an individual with extensive knowledge of the field, and breakthrough innovations are often developed by outsiders to a field.[9]

Consider, for example, Elon Musk. Elon Musk developed a city search Web portal called Zip2 in college, then founded an Internet financial payments company that merged with a rival and developed the PayPal financial payment system. Then after selling PayPal, Musk decided to found SpaceX to develop reusable rockets, and also became part of the founding team of Tesla Motors, an electric vehicle company. Tesla subsequently acquired Solar City (a solar panel company that Elon Musk had helped his cousins create) and diversified into energy storage and more. Musk crosses boundaries because he enjoys tackling new, difficult problems. He has been able to be successful in a wide range of industries in part because he challenges the traditional models in those industries.[10] For example, SpaceX was able to dramatically decrease the price of rocket components by building them in-house, and Solar City was able to dramatically increase solar panel adoption by offering a business model based on leasing that gave customers the option of putting no money down and paying for the panels with part of their energy savings.

Another great example is provided by Gavriel Iddan, a guided missile designer for the Israeli military who invented a revolutionary way to allow doctors to see inside a patient's gastrointestinal system. The traditional approach for obtaining images inside the gut is a camera on the end of a long flexible rod. This method is quite uncomfortable, and cannot reach large portions of the small intestine, but it was the industry standard for many decades. Most gastroenterologists have invested in significant training to use endoscopic tools, and many have also purchased endoscopic equipment for their clinics. Not surprisingly then, most innovation in this domain has focused on incremental improvements in the rod, cameras, and imaging software. Iddan, however, approached the problem of viewing the inside of the gut like a guided missile designer—not a gastroenterologist. He did not have the same assumptions about the need to control the camera with a rod, nor to transmit images with a wire. Instead, he invented a capsule (called the PillCam) with a power source, a light source, and two tiny cameras that the patient can swallow. The patient then goes about her day while the camera pill broadcasts images to a video pack worn by the patient. Roughly eight hours later, the patient returns to the doctor's office to have the images read by a software algorithm that can identify any locations of bleeding (the camera pill exits naturally). The PillCam has proven to be safer and less expensive than traditional endoscopy (the PillCam costs less than $500), and it is dramatically more comfortable. For patients, the camera pill was a no brainer; getting doctors to adopt it has been slower because of their existing investment and familiarity with endoscopy. The PillCam is now sold in more than 60 countries, and several companies now offer competing products. The camera pill is a remarkable solution to a difficult problem, and it is easy to see why it came from an outsider, rather than an endoscope producer.[11]

Outsiders often face resistance and skepticism. People tend to discount generalists and are suspicious of people who engage in activities that seem inconsistent with their identity. Outsiders like Musk, however, bring an advantage that insiders and industry veterans often lack. They aren't trapped by the paradigms and assumptions that have long become calcified in industry veterans, nor do they have the existing investments in tools, expertise, or supplier and customer relationships that make change difficult and unappealing.

The *personality* trait most often associated with creativity is "openness to experience."[12] Openness to experience reflects an individual's use of active imagination, aesthetic sensitivity (e.g., the appreciation for art and literature), attentiveness to emotion, a preference for variety, and intellectual curiosity. It is assessed by asking individuals to rate their degree of agreement or disagreement with statements such as "I have a vivid imagination," "I enjoy hearing new ideas," "I have a rich vocabulary," "I rarely look for deeper meaning in things" (reversed), "I enjoy going to art museums," "I avoid philosophical discussions" (reversed), "I enjoy wild flights of fantasy," and more. Individuals who score high on the openness to experience dimension tend to have great intellectual curiosity, are interested in unusual ideas, and are willing to try new things.

Intrinsic *motivation* has also been shown to be very important for creativity.[13] That is, individuals are more likely to be creative if they work on things they are genuinely interested in and enjoy. In fact, several studies have shown that creativity can be undermined by providing extrinsic motivation such as money or awards.[14] This raises serious questions about the role played by idea collection systems in organizations that offer monetary rewards for ideas. On the one hand, such extrinsic rewards could derail intrinsic motivation. On the other hand, if the monetary rewards are small, such systems may be primarily serving to invite people to offer ideas, which is a valuable signal about the culture of the firm. More research is needed in this area to know exactly what kind of solicitation for ideas, if any, is most effective.

Finally, to fully unleash an individual's creative potential usually requires a supportive *environment* with time for the individual to explore their ideas independently, tolerance for unorthodox ideas, a structure that is not overly rigid or hierarchical, and decision norms that do not require consensus.[15]

Organizational Creativity

The creativity of the organization is a function of creativity of the individuals within the organization and a variety of social processes and contextual factors that shape the way those individuals interact and behave.[16] An organization's overall creativity level is thus not a simple aggregate of the creativity of the individuals it employs. The organization's structure, routines, and incentives could thwart individual creativity or amplify it.

The most familiar method of a company tapping the creativity of its individual employees is the suggestion box. In 1895, John Patterson, founder of National Cash Register (NCR), created the first sanctioned suggestion box program to tap the ideas of the hourly worker.[17] The program was considered revolutionary in its time. The originators of adopted ideas were awarded $1. In 1904, employees submitted 7000 ideas, of which one-third were adopted. Other firms have created more elaborate systems that not only capture employee ideas, but incorporate mechanisms for selecting and implementing those ideas. Google, for example, utilizes an idea management system whereby employees e-mail their ideas for new products and processes to a company-wide database where every employee can view the idea, comment on it, and rate it (for more on how Google encourages innovation, see the Theory in Action on Inspiring Innovation at Google). Honda of America utilizes an employee-driven idea system (EDIS) whereby employees submit their ideas, and if approved, the employee who submits the idea is responsible for following through on the suggestion, overseeing its progress from concept to implementation. Honda of America reports that more than 75 percent of all ideas are implemented.[18] Bank One, one of the largest holding banks in the United States, has created an employee idea program called "One Great Idea." Employees access the company's idea repository through the company's **intranet**. There they can submit their ideas and actively interact and collaborate on the ideas of others.[19] Through active exchange, the employees can evaluate and refine the ideas, improving their fit with the diverse needs of the organization's stakeholders.

intranet
A private network, accessible only to authorized individuals. It is like the Internet but operates only within ("intra") the organization.

At Bank of New York Mellon they go a step further—the company holds enterprise-wide innovation competitions where employees form their own teams and compete in coming up with innovative ideas. These ideas are first screened by judges at both the regional and business-line level. Then, the best ideas are pitched to senior management in a "Shark Tank" style competition that is webcast around the world. If a senior executive sees an idea they like, they step forward and say they will fund it and run with it. The competition both helps the company come up with great ideas and sends a strong signal to employees about the importance of innovation.[20]

Idea collection systems (such as suggestion boxes) are relatively easy and inexpensive to implement, but are only a first step in unleashing employee creativity. Today companies such as Intel, Motorola, 3M, and Hewlett-Packard go to much greater lengths to tap the creative potential embedded in employees, including investing in creativity training programs. Such programs encourage managers to develop verbal and nonverbal cues that signal employees that their thinking and autonomy are respected. These cues shape the culture of the firm and are often more effective than monetary rewards—in fact, as noted previously, sometimes monetary rewards undermine creativity by encouraging employees to focus on extrinsic rather than intrinsic motivation.[21] The programs also often incorporate exercises that encourage employees to use creative mechanisms such as developing alternative scenarios, using analogies to compare the problem with another problem that shares similar features or structure, and restating the problem in a new way. One product design firm, IDEO, even encourages employees to develop mock prototypes of potential new products out of inexpensive materials such as cardboard or styrofoam and pretend to use the product, exploring potential design features in a tangible and playful manner.

Theory in Action Inspiring Innovation at Google

Google is always working on a surprising array of projects, ranging from the completely unexpected (such as autonomous self-driving cars and solar energy) to the more mundane (such as e-mail and cloud services).[a] In pursuit of continuous innovation at every level of the company, Google uses a range of formal and informal mechanisms to encourage its employees to innovate:[b]

20 Percent Time: All Google engineers are encouraged to spend 20 percent of their time working on their own projects. This was the source of some of Google's most famous products (e.g., Google Mail, Google News).

Recognition Awards: Managers were given discretion to award employees with "recognition awards" to celebrate their innovative ideas.

Google Founders' Awards: Teams doing outstanding work could be awarded substantial stock grants. Some employees had become millionaires from these awards alone.

Adsense Ideas Contest: Each quarter, the Adsense online sales and operations teams reviewed 100 to 200 submissions from employees around the world, and selected finalists to present their ideas at the quarterly contest.

Innovation Reviews: Formal meetings where managers present ideas originated in their divisions directly to founders Larry Page and Sergey Brin, as well as to CEO Eric Schmidt.[c]

[a] Bradbury, D. 2011. Google's rise and rise. *Backbone,* Oct:24–27.

[b] Groysberg, B., Thomas, D.A. & Wagonfeld, A.B. 2011. Keeping Google "Googley." *Harvard Business School Case* 9:409–039.

[c] Kirby, J. 2009. How Google really does it. *Canadian Business,* 82(18):54–58.

TRANSLATING CREATIVITY INTO INNOVATION

Innovation is more than the generation of creative ideas; it is the implementation of those ideas into some new device or process. Innovation requires combining a creative idea with resources and expertise that make it possible to embody the creative idea in a useful form. We will first consider the role of individuals as innovators, including innovation by inventors who specialize in creating new products and processes, and innovation by end users. We then will look at innovation activity that is organized by firms, universities, and government institutions.

The Inventor

The familiar image of the inventor as an eccentric and doggedly persistent scientist may have some basis in cognitive psychology. Analysis of personality traits of inventors suggests these individuals are likely to be interested in theoretical and abstract thinking, and have an unusual enthusiasm for problem solving. One 10-year study of inventors concludes that the most successful inventors possess the following characteristics:

1. They have mastered the basic tools and operations of the field in which they invent, but they have not specialized solely in that field; instead they have pursued two or three fields simultaneously, permitting them to bring different perspectives to each.
2. They are curious and more interested in problems than solutions.

Theory in Action Dean Kamen

In January 2001, an Internet news story leaked that iconoclastic inventor Dean Kamen had devised a fantastic new invention—a device that could affect the way cities were built, and even change the world. Shrouded in secrecy, the mysterious device, code-named "Ginger" and "IT," became the talk of the technological world and the general public, as speculation about the technology grew wilder and wilder. In December of that year, Kamen finally unveiled his invention, the Segway Human Transporter.[a] Based on an elaborate combination of motors, gyroscopes, and a motion control algorithm, the Segway HT was a self-balancing, two-wheeled scooter. Though to many it looked like a toy, the Segway represented a significant advance in technology. John Doerr, the venture capitalist behind Amazon.com and Netscape, predicted it would be bigger than the Internet. Though the Segway did not turn out to be a mass market success, its technological achievements were significant. In 2009, General Motors and Segway announced that they were developing a two-wheeled, two-seat electric vehicle based on the Segway that would be fast, safe, inexpensive, and clean. The car would run on a lithium-ion battery and achieve speeds of 35 miles per hour.

The Segway was the brainchild of Dean Kamen, an inventor with more than 150 U.S. and foreign patents, whose career began in his teenage days of devising mechanical gadgets in his parents' basement.[b] Kamen never graduated from college, though he has since received numerous honorary degrees. He is described as tireless and eclectic, an entrepreneur with a seemingly boundless enthusiasm for science and technology. Kamen has received numerous awards for his inventions, including the Kilby award, the Hoover Medal, and the National Medal of Technology. Most of his inventions have been directed at advancing health-care technology. In 1988, he invented the first self-service dialysis machine for people with kidney failure. Kamen had rejected the original proposal for the machine brought to him by Baxter, one of the world's largest medical equipment manufacturers. To Kamen, the solution was not to come up with a new answer to a known problem, but to instead reformulate the problem: "What if you can find the technology that not only fixes the valves but also makes the whole thing as simple as plugging a cassette into a VCR? Why do patients have to continue to go to these centers? Can we make a machine that can go in the home, give the patients back their dignity, reduce the cost, reduce the trauma?"[c] The result was the HomeChoice dialysis machine, which won *Design News'* 1993 Medical Product of the Year award.

In 1999, Kamen's company, DEKA Research, introduced the IBOT Mobility System, an extremely advanced wheelchair incorporating a sophisticated balancing system that enabled users to climb stairs and negotiate sand, rocks, and curbs. According to Kamen, the IBOT "allowed a disabled person, a person who cannot walk, to basically do all the ordinary things that you take for granted that they can't do even in a wheelchair, like go up a curb."[d] It was the IBOT's combination of balance and mobility that gave rise to the idea of the Segway.

[a] J. Bender, D. Condon, S. Gadkari, G. Shuster, I. Shuster, and M. A. Schilling, "Designing a New Form of Mobility: Segway Human Transporter," New York University teaching case, 2003.
[b] E. I. Schwartz, "The Inventor's Play-Ground," *Technology Review* 105, no. 8 (2002), pp. 68–73.
[c] Ibid.
[d] *The Great Inventor*. Retrieved November 19, 2002, from www.cbsnews.com.

3. They question the assumptions made in previous work in the field.
4. They often have the sense that all knowledge is unified. They seek global solutions rather than local solutions, and are generalists by nature.[22]

These traits are demonstrated by Dean Kamen, inventor of the Segway Human Transporter and the IBOT Mobility System (a technologically advanced wheelchair), profiled in the Theory in Action section on Dean Kamen. They are also illustrated in the following quotes by Nobel laureates. Sir MacFarlane Burnet, Nobel Prize–winning immunologist, noted, "I think there are dangers for a research man being too well trained in the field he is going to study,"[23] and Peter Debye, Nobel Prize–winning chemist, noted, "At the beginning of the Second World War, R. R. Williams of Bell Labs came to Cornell to try to interest me in the polymer field. I said to him, 'I don't know anything about polymers. I never thought about them.' And his answer was, 'That is why we want you.'"[24] The global search for global solutions is aptly illustrated by Thomas Edison, who did not set out to invent just a lightbulb: "The problem then that I undertook to solve was . . . the production of the multifarious apparatus, methods, and devices, each adapted for use with every other, and all forming a comprehensive system."[25]

Such individuals may spend a lifetime developing numerous creative new devices or processes, though they may patent or commercialize few. The qualities that make people inventive do not necessarily make them entrepreneurial; many inventors do not actively seek to patent or commercialize their work. Many of the most well-known inventors (e.g., Alexander Graham Bell, Thomas Alva Edison, Albert Einstein, and Benjamin Franklin), however, had both inventive and entrepreneurial traits.[26]

Innovation by Users

Innovation often originates with those who create solutions for their own needs. Users often have both a deep understanding of their unmet needs and the incentive to find ways to fulfill them.[27] While manufacturers typically create new product innovations in order to profit from the sale of the innovation to customers, user innovators often have no initial intention to profit from the sale of their innovation—they create the innovation for their own use.[28] Users may alter the features of existing products, approach existing manufacturers with product design suggestions, or develop new products themselves. For example, the extremely popular small sailboat, the Laser, was designed without any formal market research or concept testing. Instead it was the creative inspiration of three former Olympic sailors, Ian Bruce, Bruce Kirby, and Hans Vogt. They based the boat design on their own preferences: simplicity, maximum performance, transportability, durability, and low cost. The resulting sailboat became hugely successful; during the 1970s and '80s, 24 Laser sailboats were produced daily.[29]

Another dramatic example is the development of Indermil, a tissue adhesive based on Super Glue. Super Glue is a powerful instant adhesive, and while its strength and speed of action were a great asset in most product applications, these features also caused a key product concern—its tendency to bond skin. Managers at Loctite, the company that developed Super Glue, wondered if this tendency could be exploited to develop an alternative to sutures for surgical applications. In the 1970s, the company experimented with developing a version of the adhesive that could be packaged and sterilized, but the project failed and funding for it was canceled. In 1980, the project was resurrected when Loctite was approached by a pharmaceutical company that wanted to collaborate on developing a wound closure product. The two companies spent three years attempting to develop special Super Glues that would degrade quickly in the body, but ultimately shelved the project again. By this point most managers in the company no longer wanted to be involved in developing an alternative to sutures—it was considered far too risky. However, in 1988, Bernie Bolger of Loctite was contacted by Professor Alan Roberts, a worldwide figure in reconstructive surgery. Roberts proceeded to give the managers at Loctite a stunning presentation about doctors who had responded to the Bradford football stadium fire of 1983. Roberts and many other doctors had been called in to carry out surgery and skin grafting in makeshift tents around the stadium. Because stitching was too slow and skin damage was such that sutures would be ineffective, the doctors had used standard tubes of Super Glue to repair the skin and stick skin grafts in place! Roberts showed pictures of doctors in green garb standing around with Super Glue tubes stuck to their aprons, and pictures of people with large areas of skin missing and then those same people years later, with almost perfect skin repairs. Roberts begged the Loctite managers to continue their work on developing a version of Super Glue for tissue adhesion. Roberts's presentation was so compelling that the company again took up the project, this time with support from the CEO and serious funding. Approval from the U.S. Food and Drug Administration was won in 2002, and by 2003 the product was selling well in over 40 countries.[30]

basic research
Research targeted at increasing scientific knowledge for its own sake. It may or may not have any long-term commercial application.

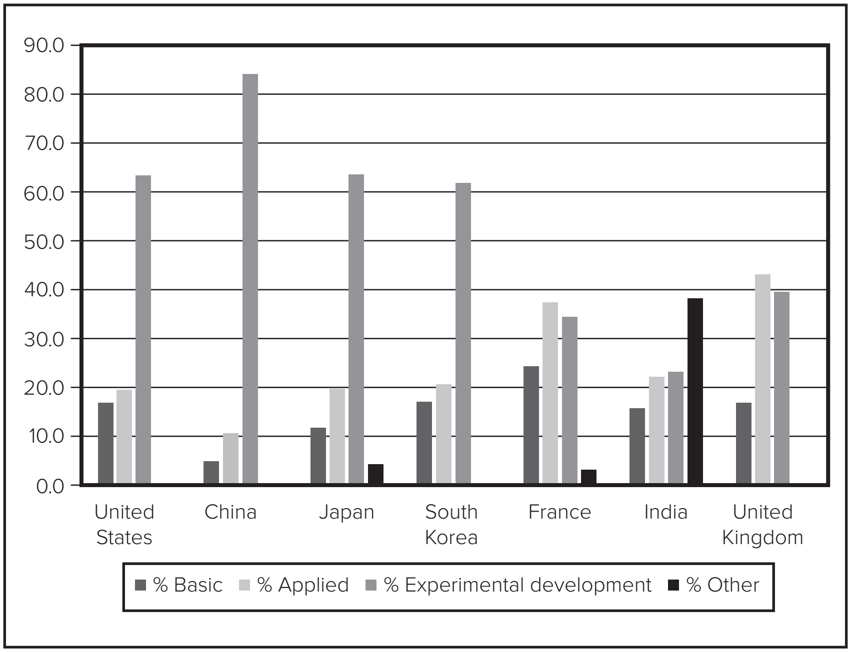
Research and Development by Firms

Across all nations, one of the most obvious sources of firm innovation is the firm's own research and development efforts. In most developed countries, firms account for the majority of R&D performed (see Figure 2.2).

applied research
Research targeted at increasing knowledge for a specific application or need.

Though the terms *research* and *development* are often lumped together, they actually represent different kinds of investment in innovation-related activities. *Research* can refer to both basic research and applied research. **Basic research** is effort directed at increasing understanding of a topic or field without a specific immediate commercial application in mind. This research advances scientific knowledge, which may (or may not) turn out to have long-run commercial implications. **Applied research** is directed

FIGURE 2.2
Percent of R&D That Is Basic, Applied, or Experimental, by Country, 2015



development Activities that apply knowledge to produce useful devices, materials, or processes.

at increasing understanding of a topic to meet a specific need. In industry, this research typically has specific commercial objectives. **Development** refers to activities that apply knowledge to produce useful devices, materials, or processes. Thus, the term *research and development* refers to a range of activities that extend from early exploration of a domain to specific commercial implementations. A firm's R&D intensity (its R&D expenditures as a percentage of its revenues) has a strong positive correlation with its sales growth rate, sales from new products, and profitability.[31]

Figure 2.2 shows the percent of R&D that was basic, applied, or experimental for a selected number of countries in 2015. As shown, China, Japan, and Korea placed much higher emphasis on development than the other countries.

During the 1950s and 1960s, scholars of innovation emphasized a *science-push* approach to research and development.[32] This approach assumed that innovation proceeded linearly from scientific discovery, to invention, to engineering, then manufacturing activities, and finally marketing. According to this approach, the primary sources of innovation were discoveries in basic science that were translated into commercial applications by the parent firm. This linear process was soon shown to have little applicability to real-world products. In the mid-1960s, another model of innovation gained prominence: the *demand-pull* model of research and development. This approach argued that innovation was driven by the perceived demand of potential users. Research staff would develop new products in efforts to respond to customer problems or suggestions. This view, however, was also criticized as being too simplistic. Rothwell, for example, points out that different phases of innovation are likely to be characterized by varying levels of science push and demand pull.[33]

Most current research suggests that firms that are successful innovators utilize multiple sources of information and ideas, including:

- In-house research and development, including basic research.
- Linkages to customers or other potential users of innovations.
- Linkages to an external network of firms that may include competitors, complementors, and suppliers.
- Linkages to other external sources of scientific and technical information, such as universities and government laboratories.[34]

Firm Linkages with Customers, Suppliers, Competitors, and Complementors

Firms often form alliances with customers, suppliers, complementors, and even competitors to jointly work on an innovation project or to exchange information and other resources in pursuit of innovation. Collaboration might occur in the form of alliances, participation in research consortia, licensing arrangements, contract research and development, joint ventures, and other arrangements. The advantages and disadvantages of different forms of collaboration are discussed in Chapter Eight. Collaborators can pool resources such as knowledge and capital, and they can share the risk of a new product development project.

The most frequent collaborations are between firms and their customers, suppliers, and local universities (see Figure 2.3).[35] Several studies indicate that firms consider

FIGURE 2.3
Percentage of Companies That Report Extensive Collaboration with Customers, Suppliers, and Universities

Source: E. Roberts, "Benchmarking Global Strategic Management of Technology," *Research Technology Management*, March–April 2001, pp. 25–36.

	North America (%)	Europe (%)	Japan (%)
Collaborates with:			
Customers	44	38	52
Suppliers	45	45	41
Universities	34	32	34

users their most valuable source of new product ideas. The use of such collaborations is consistent across North America, Europe, and Japan, though Japanese firms may be somewhat more likely to collaborate extensively with their customers (see Figure 2.3).

complementors
Producers of complementary goods or services (e.g., for video game console producers such as Sony or Nintendo, game developers) are complementors.

Firms may also collaborate with competitors and complementors. **Complementors** are organizations (or individuals) that produce complementary goods, such as lightbulbs for lamps, chargers for electric vehicles, or applications for smartphones. In some industries, firms produce a range of goods and the line between competitor and complementor can blur.

In some circumstances, firms might be bitter rivals in a particular product category and yet engage in collaborative development in that product category or complementary product categories. For instance, Microsoft competes against Rockstar Games in many video game categories, yet also licenses many Rockstar Games to play on its Xbox models. Rockstar is thus both a competitor and complementor to Microsoft. This can make the relationships between firms very complex—firms may have to manage a delicate balance between its roles of competitor versus complementor, or complementors might refuse to cooperate. For example, when Google bought Motorola Mobility in 2011, makers of mobile phone handsets that used Google's Android operating system such as Samsung and HTC were watching closely to see if Google would give Motorola handsets preferential access to Google software. Many analysts speculated that Samsung and HTC would begin developing more phones based on Microsoft's mobile operating system. To avoid the ire and defection of its complementors, Google announced that Motorola would be run as a separate entity and be given no advantages over makers of other Android-powered handsets. Android was to remain an equal-opportunity platform where any handset maker had a shot at making the next great Android phone.[36]

External versus Internal Sourcing of Innovation

absorptive capacity
The ability of an organization to recognize, assimilate, and utilize new knowledge.

Critics have often charged that firms are using external sources of technological innovation rather than investing in original research. But empirical evidence suggests that external sources of information are more likely to be complements to rather than substitutes for in-house research and development. Research by the Federation of British Industries indicated firms that had their own research and development were also the heaviest users of external collaboration networks. Presumably doing in-house R&D helps to build the firm's **absorptive capacity**, enabling it to better assimilate and utilize information obtained externally.[37] Absorptive capacity refers to the firm's ability to understand and use new information (absorptive capacity is discussed in more detail in Chapter Four).

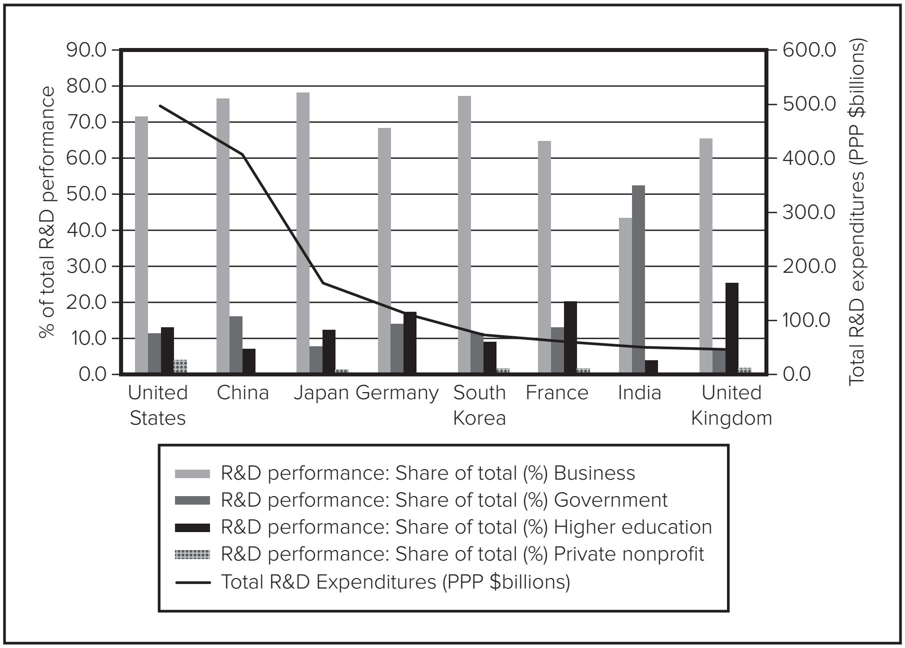
Universities and Government-Funded Research

Another important source of innovation comes from public research institutions such as universities, government laboratories, and incubators. A significant share of companies report that research from public and nonprofit institutions enabled them to develop innovations that they would not have otherwise developed.[38]

Universities

Universities in the United States performed $64.6 billion worth of R&D in 2015, making them the second largest performer of R&D in the United States after industry, and making the United States the place where universities spend the most money on R&D, on an absolute basis, in the world (see Figure 2.4). Of that, over $40 billion was for *basic research* (versus *applied research*), making universities the number one performer of basic research in the United States. The nation where universities perform the highest share of R&D, on the other hand, is the United Kingdom, where universities spend $11.9 billion, accounting for 25.6% of total R&D performance in the country. Many universities encourage their faculty to engage in research that may lead to useful innovations. Typically the intellectual property policies of a university embrace both patentable and unpatentable innovations, and the university retains sole discretion over the rights to commercialize the innovation. If an invention is successfully commercialized, the university typically shares the income with the individual inventor(s).[39]

FIGURE 2.4
Total R&D Expenditures and Percent of R&D Funds by Performing Sector, by Country 2015



To increase the degree to which university research leads to commercial innovation, many universities have established **technology transfer offices**.

technology transfer offices
Offices designed to facilitate the transfer of technology developed in a research environment to an environment where it can be commercially applied.

In the United States, the creation of university technology transfer offices accelerated rapidly after the Bayh–Dole Act was passed in 1980. This act allowed universities to collect royalties on inventions funded with taxpayer dollars. Before this, the federal government was entitled to all rights from federally funded inventions.[40] Several European and Asian countries subsequently followed the U.S. lead and established legislation similar to Bayh–Dole, including Denmark, Austria, Finland, Norway, Germany, France, United Kingdom, Japan, China, and India. Sweden and Italy, on the other hand, still have a policy of "professor's privilege" where university faculty retain sole ownership rights over their inventions. While the revenues from the university technology transfer activities are still quite small in comparison to university research budgets, their importance is growing. Initially, many anticipated that businesses would flock to license the intellectual property created by universities, leading to a substantial flow in licensing revenues. This "if you build it they will come" mindset turned out to be wrong, and licensing revenues were far less than expected. Now universities are taking a much more active role in helping to create start-ups based on their intellectual property, and in proactively forging relationships with the commercial sector.[41] Universities also contribute significantly to innovation through the publication of research results that are incorporated into the development efforts of other organizations and individuals.

Government-Funded Research

Governments of many countries actively invest in research through their own laboratories, the formation of **science parks** and **incubators**, and grants for other public or private research entities. For example, the U.S. Small Business Administration manages two programs that enable innovative small businesses to receive funding from federal agencies such as the Department of Defense, the Department of Energy, the Department of Health and Human Services, and others. The first is the Small Business Innovation Research (SBIR) program. Under the SBIR program, agencies award grants of up to $1,150,000 to small businesses to help them develop and commercialize a new innovation. The second is the Small Business Technology Transfer (STTR) program, which awards grants of up to $1,150,000 to facilitate a partnership between a small business and a nonprofit research institution—its objective is to more fully leverage the innovation that takes place in research laboratories by connecting research scientists with entrepreneurs.

science parks
Regional districts, typically set up by government, to foster R&D collaboration between government, universities, and private firms.

incubators
Institutions designed to nurture the development of new businesses that might otherwise lack access to adequate funding or advice.

Notable examples of science parks with incubators include:

- Stanford Research Park, established near Stanford University in 1951.
- Research Triangle Park, established in North Carolina in 1959.
- Sophia Antipolis Park, established in Southern France in 1969.
- Cambridge Science Park, established in Cambridge, England, in 1972.

These parks create fertile hotbeds for new start-ups and a focal point for the collaboration activities of established firms. Their proximity to university laboratories and other research centers ensures ready access to scientific expertise. Such centers also help university researchers implement their scientific discoveries in commercial applications.[42] Such parks often give rise to technology clusters that have long-lasting and self-reinforcing advantages (discussed later in the chapter).

Private Nonprofit Organizations

Private nonprofit organizations, such as private research institutes, nonprofit hospitals, private foundations, professional or technical societies, academic and industrial consortia, and trade associations, also contribute to innovation activity in a variety of complex ways. Many nonprofit organizations perform their own research and development activities, some fund the research and development activities of other organizations but do not do it themselves, and some nonprofit organizations do both in-house research and development and fund the development efforts of others.

INNOVATION IN COLLABORATIVE NETWORKS

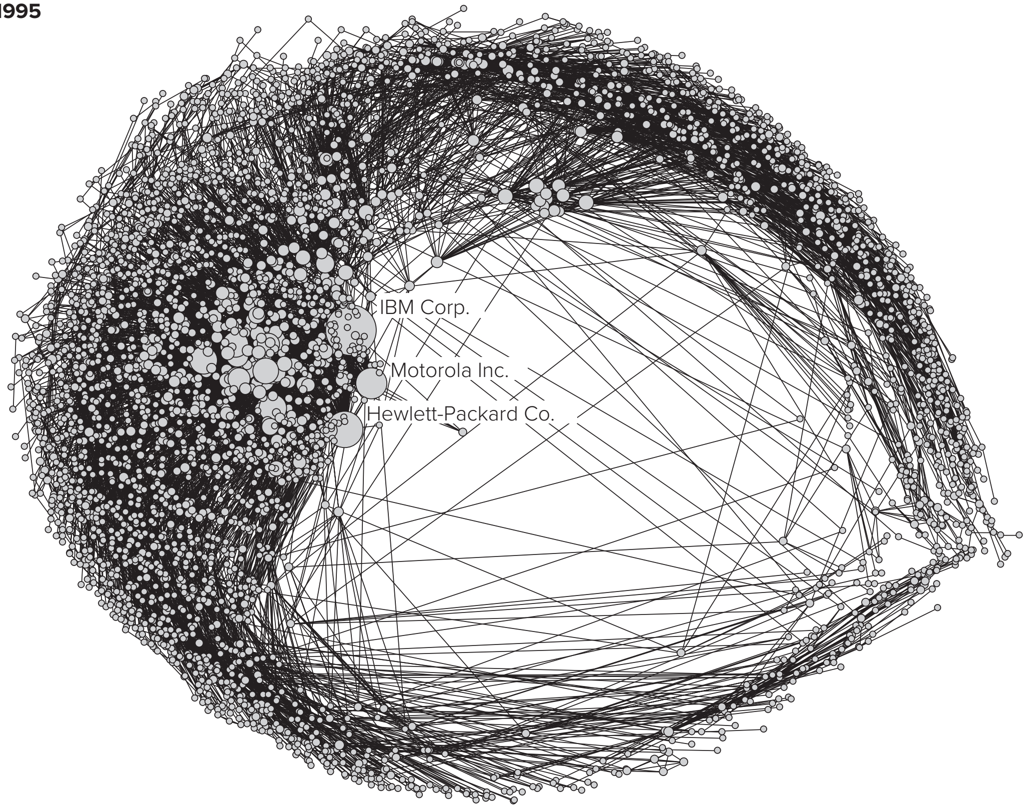
As the previous sections indicate, there is a growing recognition of the importance of collaborative research and development networks for successful innovation.[43] Such collaborations include (but are not limited to) joint ventures, licensing and second-sourcing agreements, research associations, government-sponsored joint research programs, value-added networks for technical and scientific interchange, and informal networks.[44] Collaborative research is especially important in high-technology sectors, where it is unlikely that a single individual or organization will possess all of the resources and capabilities necessary to develop and implement a significant innovation.[45]

As firms forge collaborative relationships, they weave a network of paths between them that can act as conduits for information and other resources. By providing member firms access to a wider range of information (and other resources) than individual firms possess, interfirm networks can enable firms to achieve much more than they could achieve individually.[46] Thus, interfirm networks are an important engine of innovation. Furthermore, the structure of the network is likely to influence the flow of information and other resources through the network. For example, in a dense network where there are many potential paths for information to travel between any pair of firms, information diffusion should be fairly rapid and widespread.[47]

Figure 2.5 provides pictures of the worldwide technology alliance network in 1995 and in 2000.[48] The mid-1990s saw record peaks in alliance activity as firms scrambled to respond to rapid change in information technologies. This resulted in a very large and dense web of connected firms. The network shown here connects 3856 organizations, predominantly from North America, Japan, and Europe. However, there was a subsequent decline in alliance activity toward the end of the decade that caused the web to diminish in size and splinter apart into two large components and many small components. The large component on the left is primarily made up of organizations in the chemical and medical industries. The large component on the right is primarily made up of organizations in electronics-based industries. If the size and density of the collaboration network influences the amount of information available to organizations that are connected via the network, then the difference between the network shown for 1995 and the network shown for 2000 could have resulted in a substantial change in the amount of information that was transmitted between firms. (The strategic implications for a firm's position within the network are discussed in Chapter Eight.)

FIGURE 2.5
The Global Technology Collaboration Network, 1995 and 2000[49]

1995



Technology Clusters

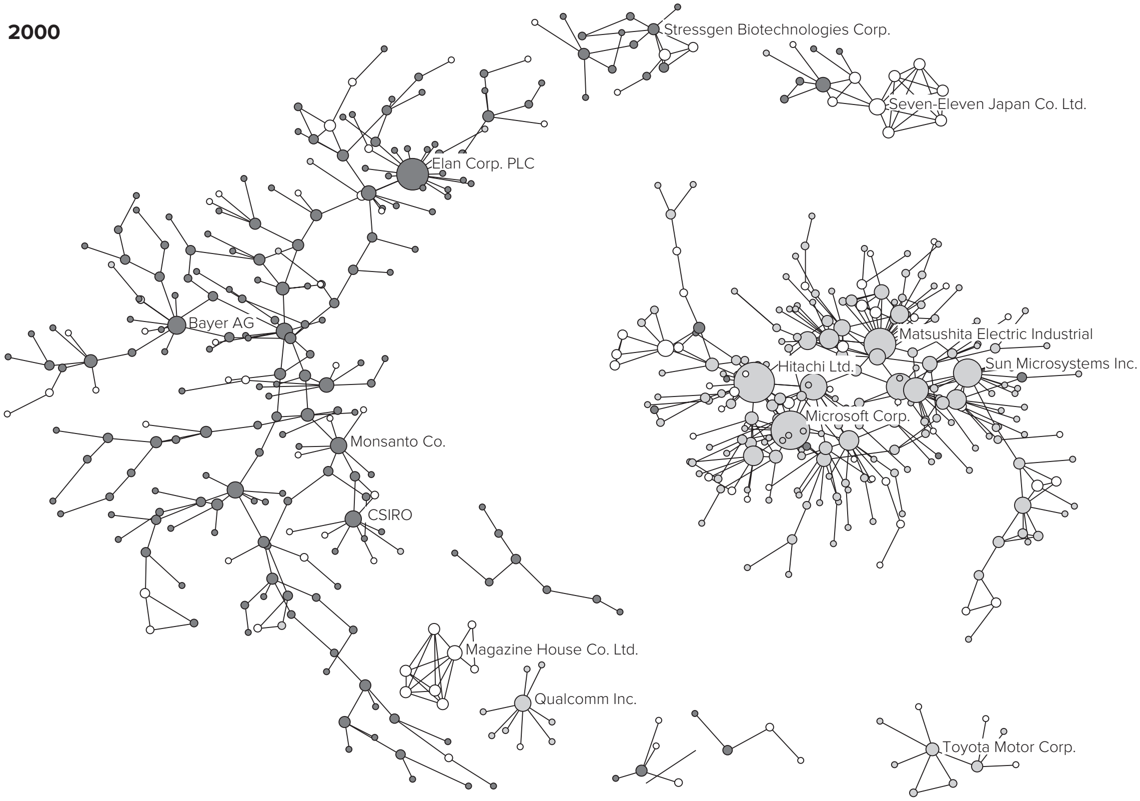
Sometimes geographical proximity appears to play a role in the formation and innovative activity of collaborative networks. Well-known regional clusters such as Silicon Valley's semiconductor firms, lower Manhattan's multimedia cluster, and the Modena, Italy, knitwear district aptly illustrate this point. This has spurred considerable interest in the factors that lead to the emergence of a cluster. City and state governments, for example, might like to know how to foster the creation of a technology cluster in their region in order to increase employment, tax revenues, and other economic benefits. For firms, understanding the drivers and benefits of clustering is useful for developing a strategy that ensures the firm is well positioned to benefit from clustering.

technology clusters
Regional clusters of firms that have a connection to a common technology, and may engage in buyer, supplier, and complementor relationships, as well as research collaboration.

Technology clusters may span a region as narrow as a city or as wide as a group of neighboring countries.[50] Clusters often encompass an array of industries that are linked through relationships between suppliers, buyers, and producers of complements. One primary reason for the emergence of regional clusters is the benefit of proximity in knowledge exchange. Though advances in information technology have

FIGURE 2.5 *Continued*

2000



made it easier, faster, and cheaper to transmit information great distances, several studies indicate that knowledge does not always transfer readily via such mechanisms.

complex knowledge
Knowledge that has many underlying components, or many interdependencies between those components, or both.

tacit knowledge
Knowledge that cannot be readily codified (documented in written form).

Proximity and interaction can directly influence firms' ability and willingness to exchange knowledge. First, knowledge that is **complex** or **tacit** may require frequent and close interaction to be meaningfully exchanged.[51] Firms may need to interact frequently to develop common ways of understanding and articulating the knowledge before they are able to transfer it.[52] Second, closeness and frequency of interaction can influence a firm's *willingness* to exchange knowledge. When firms interact frequently, they can develop trust and reciprocity norms. Firms that interact over time develop greater knowledge of each other, and their repeated interactions give them information as to the likelihood of their partner's behaving opportunistically. A shared understanding of the rules of engagement emerges, wherein each partner understands its obligations with respect to how much knowledge is exchanged, how that knowledge can be used, and how the firms are expected to reciprocate.[53]

Firms that are proximate thus have an advantage in sharing information that can lead to greater innovation productivity. This can, in turn, lead to other self-reinforcing geographical advantages. A cluster of firms with high innovation productivity can lead to more new firms starting up in the immediate vicinity and can attract other firms to the area.[54] As firms grow, divisions may be spun off into new firms,

agglomeration economies
The benefits firms reap by locating in close geographical proximity to each other.

entrepreneurial employees may start their own enterprises, and supplier and distributor markets emerge to service the cluster. Successful firms also attract new labor to the area and help to make the existing labor pool more valuable by enabling individuals to gain experience working with the innovative firms. The increase in employment and tax revenues in the region can lead to improvements in infrastructure (such as roads and utilities), schools, and other markets that service the population (shopping malls, grocery stores, health-care providers, etc.). The benefits firms reap by locating in close geographical proximity to each other are known collectively as **agglomeration economies**.[55]

There are also some downsides to geographical clustering. First, the proximity of many competitors serving a local market can lead to competition that reduces their pricing power in their relationships with both buyers and suppliers. Second, close proximity of firms may increase the likelihood of a firm's competitors gaining access to the firm's proprietary knowledge (this is one of the mechanisms of technology spillovers, discussed in the next section). Third, clustering can potentially lead to traffic congestion, inordinately high housing costs, and higher concentrations of pollution.[56]

A big part of the reason that technologies are often regionally localized is that technological knowledge is, to a large extent, held by people, and people are often only reluctantly mobile. In a well-known study, Annalee Saxenian found that engineers in Silicon Valley were more loyal to their craft than to any particular company, but they were also very likely to stay in the region even if they changed jobs.[57] This was due in part to the labor market for their skills in the region, and in part to the disruption in an individual's personal life if he or she were to move out of the region. Thus, if for some reason an innovative activity commences in a geographic locale, the knowledge and expertise that accumulates might not spread readily into other geographic locales, leading to a localized cluster of technological expertise.[58]

Studies have indicated that while many innovative activities appear to have some geographic component, the degree to which innovative activities are geographically clustered depends on things such as:

- The nature of the technology, such as its underlying knowledge base or the degree to which it can be protected by patents or copyright, and the degree to which its communication requires close and frequent interaction.
- Industry characteristics, such as the degree of market concentration or stage of the industry life cycle, transportation costs, and the availability of supplier and distributor markets.
- The cultural context of the technology, such as the population density of labor or customers, infrastructure development, or national differences in the way technology development is funded or protected.

For example, one study that examined the spatial distribution of technology sectors in different countries found that pharmaceutical development was highly clustered in the United Kingdom and France, but much more spatially diffused in Italy and Germany.[59] The same study found, however, that the manufacture of clothing demonstrated high clustering in Italy, but not in France, Germany, or the United Kingdom. While the clustering of pharmaceutical development may have been influenced by

Research Brief Knowledge Brokers

Andrew Hargadon and Robert Sutton point out that some firms play a particularly pivotal role in the innovation network—that of knowledge brokers. **Knowledge brokers** are individuals or firms that transfer information from one domain to another in which it can be usefully applied. The knowledge broker puts existing information to use in new and profitable ways. Hargadon and Sutton provide the example of Robert Fulton who, after observing the use of steam engines in mines, realized this technology could be used to propel boats and subsequently developed the first successful steamboat.[a] While Fulton did not claim to have invented the steamboat (there had been at least 30 years of prior development on steamboats), Fulton's design was the first to combine existing technologies into a successful product.

In a network of firms, a knowledge broker may be a firm that connects clusters of firms that would otherwise share no connection. By serving as the bridge between two different knowledge networks, the knowledge broker is in a position to find unique combinations from the knowledge possessed by the two groups. This can enable knowledge brokers to be exceptionally prolific in generating innovation. Consider Thomas Edison's laboratory. Edison's strategy of borrowing from different industries to create products that would ultimately serve many markets resulted in innovations in telegraphs, telephones, phonographs, generators, lightbulbs, vacuum pumps, and many others.[b]

Knowledge brokers may not create breakthroughs in any single technology, but instead may exploit the potential synergies of combining existing technologies. While this might at first seem to limit the scope of a knowledge broker's potential, research suggests that most innovation is not due to the discovery of something fundamentally new, but is instead the result of novel recombinations of known concepts and materials.[c] Thus, the knowledge broker's key expertise may lie not in a particular domain of science, but instead in the ability to recognize and capture potential solutions that may be matched to problems in an unexpected way.

[a] A. Hargadon and R. Sutton, "Building an Innovation Factory," *Harvard Business Review* May–June, 2000, pp. 157–66.

[b] A. B. Hargadon, "Firms as Knowledge Brokers: Lessons in Pursuing Continuous Innovation," *California Management Review* 40, no. 3 (1998), pp. 209–27.

[c] S. C. Gilfillan, *The Sociology of Invention* (Chicago: Follett, 1935); R. R. Nelson and S. Winter, *An Evolutionary Theory of Economic Change* (Cambridge, MA: Harvard University Press, 1982); E. G. Penrose, *The Theory of the Growth of the Firm* (New York: Wiley, 1959); J. A. Schumpeter, *The Theory of Economic Development* (Cambridge, MA: Harvard University Press, 1934); and A. Usher, *A History of Mechanical Inventions* (Cambridge, MA: Harvard University Press, 1954).

knowledge brokers
Individuals or organizations that transfer information from one domain to another in which it can be usefully applied.

the national systems of research funding and the need to share complex technological expertise, the formation of textile clusters may have been due more to cultural factors that influenced the historical rise of industrial districts.

Technological Spillovers

While the work on technology clusters has tended to emphasize the "stickiness" of knowledge, a related body of research has focused on explaining the spread of knowledge across organizational or regional boundaries. This topic is known as **technological spillovers**. Technological spillovers occur when the benefits from the research activities of one firm (or nation or other entity) spill over to other firms (or nations or other entities). Spillovers are thus a positive externality of research and development efforts. Evidence suggests that technology spillovers are a significant influence on innovative activity. For example, in a series of studies conducted in the 1980s and

technological spillovers
A positive externality from R&D resulting from the spread of knowledge across organizational or regional boundaries.

1990s, Adam Jaffe and his coauthors found that both a firm's patenting activities and profits were influenced by the R&D spending of other firms and universities in its geographical region.[60]

Whether R&D benefits will spill over is partially a function of the strength of protection mechanisms such as patents, copyrights, and trade secrets (methods of protecting innovation are discussed in greater detail in Chapter Nine). Since the strength of protection mechanisms varies significantly across industries and countries, the likelihood of spillovers varies also.[61] The likelihood of spillovers is also a function of the nature of the underlying knowledge base (e.g., as explained in the previous section, tacit knowledge may not flow readily across firm boundaries) and the mobility of the labor pool.[62]

Summary of Chapter

1. Creativity is the underlying process for innovation. Creativity enables individuals and organizations to generate new and useful ideas. Creativity is considered a function of intellectual abilities, knowledge, thinking styles, personality traits, intrinsic motivation, and environment.
2. Innovation sometimes originates with individual inventors. The most prolific inventors tend to be trained in multiple fields, be highly curious, question previously made assumptions, and view all knowledge as unified. The most well-known inventors tend to have both inventive and entrepreneurial traits.
3. Innovation can also originate with users who create solutions to their own needs.
4. Firms' research and development is considered a primary driver of innovation. In most countries, firms spend significantly more on R&D than government institutions spend on R&D, and firms consider their in-house R&D their most important source of innovation.
5. Firms often collaborate with a number of external organizations (or individuals) in their innovation activities. Firms are most likely to collaborate with customers, suppliers, and universities, though they also may collaborate with competitors, producers of complements, government laboratories, nonprofit organizations, and other research institutions.
6. Many universities have a research mission, and in recent years universities have become more active in setting up technology transfer activities to directly commercialize the inventions of faculty. Universities also contribute to innovation through the publication of research findings.
7. Government also plays an active role in conducting research and development (in its own laboratories), funding the R&D of other organizations, and creating institutions to foster collaboration networks and to nurture start-ups (e.g., science parks and incubators). In some countries, government-funded research and development exceeds that of industry-funded research.
8. Private nonprofit organizations (such as research institutes and nonprofit hospitals) are another source of innovation. These organizations both perform their own R&D and fund R&D conducted by others.

9. Probably the most significant source of innovation does not come from individual organizations or people, but from the collaborative networks that leverage resources and capabilities across multiple organizations or individuals. Collaborative networks are particularly important in high-technology sectors.
10. Collaboration is often facilitated by geographical proximity, which can lead to regional technology clusters.
11. Technology spillovers are positive externality benefits of R&D, such as when the knowledge acquired through R&D spreads to other organizations.

Discussion Questions

1. What are some of the advantages and disadvantages of (*a*) individuals as innovators, (*b*) firms as innovators, (*c*) universities as innovators, (*d*) government institutions as innovators, (*e*) nonprofit organizations as innovators?
2. What traits appear to make individuals most creative? Are these the same traits that lead to successful inventions?
3. Could firms identify people with greater capacity for creativity or inventiveness in their hiring procedures?
4. To what degree do you think the creativity of the firm is a function of the creativity of individuals, versus the structure, routines, incentives, and culture of the firm? Provide an example of a firm that does a particularly good job at nurturing and leveraging the creativity of its individuals.
5. Several studies indicate that the use of collaborative research agreements is increasing around the world. What are some reasons collaborative research is becoming more prevalent?

Suggested Further Reading

Classics

Amabile, T. M., *Social Psychology of Creativity* (New York: Springer-Verlag, 1983).

Chesbrough, H., *Open Innovation: The New Imperative for Creating and Profiting from Technology* (Boston: Harvard University Press, 2003).

Jaffe, A., "Technological Opportunity and Spillovers of R&D: Evidence from Firms' Patents, Profits, and Market Value," *American Economic Review* 76 (1986), pp. 984–1001.

Kelley, T., *The Art of Innovation: Lessons in Creativity from IDEO, America's Leading Design Firm* (New York: Random House, 2007).

Schilling, M. A., and Phelps, C., "Interfirm Collaboration Networks: The impact of Large-Scale Network Structure on Firm Innovation," *Management Science* 53 (2007), pp. 1113–1126.

Usher, A. P., *A History of Mechanical Inventions* (New York/London: McGraw-Hill, 1929).

Von Hippel, E., *Sources of Innovation* (New York: Oxford University Press, 1988).

Weber, A., *Theory of Location of Industries* (Chicago: University of Chicago, 1929).

Recent Work

Howell, Sabrina T., 2017. "Financing Innovation: Evidence from R&D Grants." *American Economic Review,* 107 (4) 2017, pp. 1136–64.

Melero, E., and Palomeras, N., "The Renaissance Man Is Not Dead! The Role of Generalists in Teams of Inventors," *Research Policy* 44 (2015), pp. 154–167.

Schilling, M. A., "Technology Shocks, Technological Collaboration, and Innovation Outcomes," *Organization Science* 26 (2015), pp. 668–686.

Schilling, M. A., *Quirky: The Remarkable Story of the Traits, Foibles, and Genius of Breakthrough Innovators Who Changed the World* (New York: Public Affairs, 2018).

Sawyer, R. K., *Explaining Creativity: The Science of Human Innovation* (Oxford: Oxford University Press, 2011).

Toole, A. A., "The Impact of Public Basic Research on Industrial Innovation: Evidence from the Pharmaceutical Industry," *Research Policy* 41 (2012), pp. 1–12.

Youtie, J., and Shapira, P., "Building an Innovation Hub: A Case Study of the Transformation of University Roles in Regional Technological Development," *Research Policy* 37 (2008), pp. 1188–1204.

Endnotes

1. R. Rothwell, "Factors for Success in Industrial Innovations, Project SAPPHO—A Comparative Study of Success and Failure in Industrial Innovation," SPRU, University of Sussex, Brighton, U.K., 1972; and L. Smith-Doerr, J. Owen-Smith, K. W. Koput, and W. W. Powell, "Networks and Knowledge Production: Collaboration and Patenting in Biotechnology," in *Corporate Social Capital,* eds. R. Leenders and S. Gabbay (Norwell, MA: Kluwer Academic Publishers, 1999), pp. 331–50.
2. F. Barron, *Creative Person and Creative Process* (New York: Holt, Rinehart, and Winston, 1969); D. W. MacKinnon, "Personality and the Realization of Creative Potential," *American Psychologist* 17 (1965), pp. 484–95; R. Oshse, *Before the Gates of Excellence: The Determinants of Creative Genius* (New York: Cambridge University Press, 1990); and T. I. Lubart, "Creativity," in *Thinking and Problem Solving,* ed. R. J. Sternberg (New York: Academic Press, 1994), pp. 289–332.
3. M. Boden, *The Creative Mind: Myths and Mechanisms* (New York: Basic Books, 1992).
4. Lubart, "Creativity."
5. Freud, S. *The unconscious*, standard edition, 14:159–214; Mednick, S. A. 1962. "The Associative Basis of the Creative Process," *Psychological Review* 69 (1962):220–32; Suler, J. "Primary Process Thinking and Creativity," *Psychological Bulletin* 80 (1980):155–65; Simonton, D. K. *Origins of Genius* (Oxford: Oxford University Press, 1999).
6. Schilling, M. A. "A Small-World Network Model of Cognitive Insight," *Creativity Research Journal* 17, nos. 2 and 3 (2005):131–154.
7. Benedek, M., and A. C. Neubauer, "Revisiting Mednick's Model on Creativity-Related Differences in Associative Hierarchies. Evidence for a Common Path to Uncommon Thought," *Journal of Creative Behavior* 47 (2013):273–289.
8. This argument is also invoked in a line of work on "defocused attention." See Martindale, C. "Biological bases of creativity," in *Handbook of Creativity*, ed. R. J. Sternberg Cambridge UK: (Cambridge University Press, 1999), 137–52.
9. Frensch, P. A., and Sternberg, R. J., "Expertise and Intelligent Thinking: When is it Worse to Know Better?" in *Advances in the Psychology of Human Intelligence*, ed. R. J. Sternberg (Hillsdale, NJ: Erlbaum, 1989), 5:157–8.
10. Schilling, M. A., *Quirky: The Remarkable Story of the Traits, Foibles, and Genius of Breakthrough Innovators Who Changed the World* (New York: Public Affairs, 2018).
11. Schilling, M. A., *Quirky: The Remarkable Story of the Traits, Foibles, and Genius of Breakthrough Innovators Who Changed the World* (New York: Public Affairs, 2018).

12. McCrae, R. R., and P. T. Costa, Jr., “Conceptions and Correlates of Openness to Experience,” in *Handbook of Personality Psychology*, ed. R. Hogan, J. A. Johnson, S. R. Briggs (San Diego: Academic Press, 1997), 825–47.
13. T. M. Amabile, *The Social Psychology of Creativity* (New York: Springer-Verlag, 1983) and T. M. Amabile, *Creativity in Context* (Boulder CO: Westview, 1996).
14. Deci, E. L., R. Koestner, and R. M. Ryan. “A Meta-Analytic Review of Experiments Examining the Effects of Extrinsic Rewards on Intrinsic Motivation,” *Psychological Bulletin* 125 (1999):627–68.
15. Schilling, M. A., *Quirky: The Remarkable Story of the Traits, Foibles, and Genius of Breakthrough Innovators Who Changed the World* (New York: Public Affairs, 2018).
16. R. W. Woodman, J. E. Sawyer, and R. W. Griffin, “Toward a Theory of Organizational Creativity,” *Academy of Management Review* 18 (1993), pp. 293–321.
17. C. Gorski and E. Heinekamp, “Capturing Employee Ideas for New Products,” in *The PDMA Toolbook for New Product Development,* eds. P. Belliveau, A. Griffin, and S. Somermeyer (New York: John Wiley & Sons, 2002).
18. Gorski and Heinekamp, “Capturing Employee Ideas for New Products”; and R. E. Mcdermott, R. J. Mikulak, and M. R. Beauregard, *Employee Driven Quality: Releasing the Creative Spirit of Your Organization through Suggestion Systems* (White Plains, NY: Quality Resource, 1993).
19. Gorski and Heinekamp, “Capturing Employee Ideas for New Products.”
20. Reiss, R. 2015. “Top CEOs share how to shepherd innovation.” *Forbes,* July 20.
21. Woodman, Sawyer, and Griffin, “Toward a Theory of Organizational Creativity”; and Amabile, *The Social Psychology of Creativity.*
22. Ibid.
23. Sir Frank Macfarlane Burnet, *Changing Patterns, an Atypical Autobiography* (Melbourne and London: Heinemann, 1968), p. 35.
24. P. Debye, interview in *The Editors of International Science and Technology, The Way of the Scientist. Interviews from the World of Science and Technology* (New York: Simon and Schuster, 1966), p. 80.
25. T. P. Hughes, “How Did the Heroic Inventors Do It?” *American Heritage of Invention and Technology,* Fall 1985, p. 21.
26. B. Z. Khan and K. I. Sokoloff, “Schemes of Practical Utility: Entrepreneurship and Innovation among ‘Great Inventors’ in the United States, 1790–1865,” *Journal of Economic History* 53, no. 2 (1993), p. 289.
27. E. Von Hippel, “Innovation by User Communities: Learning from Open-Source Software,” *Sloan Management Review* 42, no. 4 (2001), pp. 82–86.
28. E. Von Hippel, *The Sources of Innovation* (New York: Oxford University Press, 1988); S. K. Shah, “Motivation, Governance, And The Viability of Hybrid Forms In Open Source Software Development,” *Management Science* 52 (2006), pp. 1000–14.
29. R. J. Thomas, *New Product Success Stories: Lessons from Leading Innovators* (New York: John Wiley & Sons, 1995).
30. From a presentation given by Bernie Bolger of Loctite to the Masters of Science Technology Group at University College Dublin, November 21, 2003. Thanks to Brian McGrath for providing this example.
31. E. Roberts, “Benchmarking Global Strategic Management of Technology,” *Research Technology Management,* March–April 2001, pp. 25–36.
32. M. Dodgson, *The Management of Technological Innovation* (New York: Oxford University Press, 2000).
33. Ibid.
34. C. Freeman, “Networks of Innovators: A Synthesis of Research Issues,” *Research Policy* 20 (1991), pp. 499–514; Rothwell, “Factors for Success in Industrial Innovations, Project SAPPHO”;

and R. Rothwell, C. Freeman, A. Horseley, V. T. B. Jervis, A. B. Robertson, and J. Townsend, "SAPPHO Updated—Project SAPPHO Phase II," *Research Policy* 3 (1974), pp. 258–91.

35. Roberts, "Benchmarking Global Strategic Management of Technology."
36. "Supercharging Android: Google to Acquire Motorola Mobility," Google Press Release, August 15, 2011; Efrati, A & Anti, SE. "Google's $12.5 Billion Gamble: Web Giant Pays Big for Motorola's Phone Business, Patents; Risks Alienating Allies." *Wall Street Journal* (2011) August 16 (www.wsj.com)
37. W. M. Cohen and D. A. Levinthal, "Absorptive Capacity: A New Perspective on Learning and Innovation," *Administrative Science Quarterly,* March 1990, pp. 128–52.
38. M. Biese and H. Stahl, "Public Research and Industrial Innovations in Germany," *Research Policy* 28 (1999), pp. 397–422; and E. Mansfield, "Academic Research and Industrial Innovation," *Research Policy* 20 (1991), pp. 1–12.
39. A. Silverman, "Understanding University Patent Policies," *JOM* 55, no. 1 (2003), p. 64.
40. D. Rahm and V. Hansen, "Technology Policy 2000: University to Industry Transfer," *International Journal of Public Administration* 22, no. 8 (1999), pp. 1189–1211.
41. Brady Huggett, "Reinventing Tech Transfer," *Nature Biotechnology* 32 (2014) pp. 1184–119
42. Ibid.
43. G. Ahuja and C. M. Lampert, "Entrepreneurship in the Large Corporation: A Longitudinal Study of How Established Firms Create Breakthrough Inventions," *Strategic Management Journal* 22 (2001), pp. 521–43; T. J. Allen, *Managing the Flow of Technology: Technology Transfer and the Dissemination of Technological Information within the R&D Organization* (Cambridge, MA: MIT Press, 1977); R. S. Burt, *Structural Holes* (Cambridge, MA: Harvard University Press, 1992); C. Freeman, "Networks of Innovators: A Synthesis of Research Issues," *Research Policy* 20 (1991), pp. 499–514; S. C. Gilfillan, *The Sociology of Invention* (Chicago: Follett, 1935); and A. B. Hargadon and R. I. Sutton, "Technology Brokering and Innovation in a Product Development Firm," *Administrative Science Quarterly* 42 (1997) pp. 716–49, M. A. Schilling, M. A. 2015. "Technology Shocks, Technological Collaboration, and Innovation Outcomes," *Organization Science,* 26 (2015), pp. 668–686; M. A. Schilling, and C. Phelps, "Interfirm Collaboration Networks: The Impact of Large-Scale Network Structure on Firm Innovation," *Management Science,* 53 (2007), pp. 1113–1126.
44. K. Imai and Y. Baba, 1989, "Systemic Innovation and Cross-Border Networks: Transcending Markets and Hierarchies to Create a New Techno-Economic System," OECD, Conference on Science Technology and Economic Growth, Paris; and C. Freeman, "Networks of Innovators: A Synthesis of Research Issues," *Research Policy* 20 (1991), pp. 499–514.
45. J. Hagedoorn, "Inter-Firm R&D Partnerships—an Overview of Major Trends and Patterns since 1960," *Research Policy* 31 (2002), pp. 477–92; M. A. Schilling, "Technology Shocks, Technological Collaboration, and Innovation Outcomes," *Organization Science,* 26 (2015), pp. 668–686.
46. Rosenkopf and Almeida, "Overcoming Local Search through Alliances and Mobility"; and Liebeskind, Oliver, Zucker, and Brewer, "Social Networks, Learning, and Flexibility"; M. A. Schilling, "Technology Shocks, Technological Collaboration, and Innovation Outcomes," *Organization Science,* 26 (2015), pp. 668–686.
47. M. A. Schilling, "Technology Shocks, Technological Collaboration, and Innovation Outcomes," *Organization Science,* 26 (2015), pp. 668–686.
48. This analysis is from M. A. Schilling, "Technology Shocks, Technological Collaboration, and Innovation Outcomes," *Organization Science,* 26 (2015), pp. 668–686. In accordance with norms in network research, each snapshot shows the aggregate of alliances formed in the previous three years (i.e., the 1995 snapshot aggregates alliances from 1993 to 1995; the 2000

snapshot aggregates alliances from 1998 to 2000). Only large components (those greater than 15 organizations) are shown.

49. M. A. Schilling, “Technology Shocks,Technological Collaboration, and Innovation Outcomes,” *Organization Science,* 26 (2015), pp. 668–686.
50. M. E. Porter, “Location, Competition, and Economic Development: Local Clusters in a Global Economy,” *Economic Development Quarterly* 14, no. 1 (2000), pp. 15–34.
51. P. Almeida and B. Kogut, “Localization of Knowledge and the Mobility of Engineers in Regional Networks,” *Management Science* 45 (1999), pp. 905–17; P. Bourdieu, “The Forms of Capital,” in *Handbook of Theory and Research for the Sociology of Education,* ed. J. G. Richardson (Westport, CT: Greenwood Press, 1986), pp. 241–58; M. S. Granovetter, “Problems of Explanation in Economic Sociology,” in *Networks and Organizations: Structure, Form, and Action,* eds. N. Nohria and R. Eccles (Boston: Harvard Business School Press, 1992), pp. 25–56; and M. T. Hansen, “The Search-Transfer Problem: The Role of Weak Ties in Sharing Knowledge across Organization Subunits,” *Administrative Science Quarterly* 44 (1999), pp. 82–112; Arikan, A., and M. A. Schilling, “Structure and Governance in Industrial Districts: Implications for Competitive Advantage,” *Journal of Management Studies* 48 (2011): 772–803.
52. U. Zander and B. Kogut, “Knowledge and the Speed of the Transfer and Imitation of Organizational Capabilities: An Empirical Test,” *Organization Science* 6 (1995), pp. 76–92; and G. Szulanski, “Exploring Internal Stickiness: Impediments to the Transfer of Best Practice within the Firm,” *Strategic Management Journal* 17 (winter special issue) (1996), pp. 27–43.
53. J. H. Dyer and K. Nobeoka, “Creating and Managing a High-Performance Knowledge-Sharing Network: The Toyota Case,” *Strategic Management Journal* 21 (2000), pp. 345–67; and E. Von Hippel, “Cooperation between Rivals: Informal Know-How Trading,” *Research Policy* 16 (1987), pp. 291–302.
54. T. Stuart and O. Sorenson, “The Geography of Opportunity: Spatial Heterogeneity in Founding Rates and the Performance of Biotechnology Firms,” *Research Policy* 32 (2003), p. 229.
55. Arikan, A., and M. A. Schilling, “Structure and Governance in Industrial Districts: Implications for Competitive Advantage,” *Journal of Management Studies* 48 (2011): 772–803.
56. Arikan, A., and M. A. Schilling, “Structure and Governance in Industrial Districts: Implications for Competitive Advantage,” *Journal of Management Studies* 48 (2011): 772–803.
57. A. Saxenian, *Regional Advantage: Culture and Competition in Silicon Valley and Route 128* (Cambridge, MA/London: Harvard University Press, 1994).
58. P. Almeida and B. Kogut, “Localization of Knowledge and the Mobility of Engineers in Regional Networks,” *Management Science* 45 (1999), pp. 905–17.
59. S. Breschi, “The Geography of Innovation: A Cross-Sector Analysis,” *Regional Studies* 34, no. 3 (2000), pp. 213–29.
60. A. B. Jaffe, “Technological Opportunity and Spillovers of R&D: Evidence from Firms’ Patents, Profits and Market Value,” *American Economic Review* 76 (1986), pp. 984–1001; A. B. Jaffe, “Real Effects of Academic Research,” *American Economic Review* 79 (1989), pp. 957–70; and A. B. Jaffee, M. Trajtenberg, and R. Henderson, “Geographic Localization of Knowledge Spillovers as Evidenced by Citations,” *Quarterly Journal of Economics* 63 (1993), pp. 577–98.
61. W. Cohen, A. Goto, A. Nagata, R. Nelson, and J. Walsh, “R&D Spillovers, Patents and the Incentives to Innovate in Japan and the United States,” *Research Policy* 31 (2002), pp. 1349–67.
62. Almeida and Kogut, “Localization of Knowledge and the Mobility of Engineers in Regional Networks.”