Economic Experiments and Industry Know-How in Internet Access Markets

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Version 1.0 Comments Welcome

Abstract

Innovation within Internet access markets can be usefully understood through the lens of *economic experiments.* Economic experiments yield lessons to market participants through market experience. In this essay, the author distinguishes between directed and undirected economic experiments and discusses how the spreading of lessons transforms a market. As a lesson becomes common, it becomes a part of industry know-how. Further innovations build on that know how, renewing a cycle of experimentation. The essay ends with insights about why some market institutions encourage economic experiments and what policy can do to nurture a positive outcome.

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INTRODUCTION

Did economic experiments play an important role in the development of commercial Internet access? Economic experiments yield lessons to firms, which can be acquired only through market experience. Usually these lessons pertain to the value of evolving goods and markets. More important, this type of learning cannot take place in a laboratory; scientists, engineers, or marketing executives cannot distill equivalent lessons from simply building a prototype or merely interviewing potential customers and vendors.

There is good reason to think economic experiments played *some* role in the Internet access market's development, perhaps even an important one. While the commercial network today generates tens of billions of dollars in revenue a year,[1] the passage of time gives a false sense of inevitability to this accomplishment. The firms that commercialized the Internet in the United States did not follow a prescribed road map. No firm in a young market such as this could have planned for all events. Learning and sheer serendipity must have shaped actions during the earliest years while value remained uncertain.

This essay begins with a somewhat narrow goal: To show that directed and undirected economic experiments shaped the evolution of Internet access markets. *Directed experiments* are those undertaken and learned by firms for their own purposes, while *undirected experiments* are those that arise from the interplay of many firms' actions. Both types of economic experiments shaped commercial Internet access markets by affecting pricing, the quality of services, and the identity of leading firms. Yet, the underlying motivation is broader than this narrow goal. Namely, I show that the accumulation of industry knowledge depends on the spreading of lessons learned from economic experiments. Further innovations then build on that knowledge, renewing a cycle of accumulated lessons from experiments. Ultimately, this accumulation is a key driver of the market's evolution—or, in other words, knowledge accumulation sets the conditions for innovative behavior.

[1] As of 2004, Internet access markets generated $24B in revenue, not counting on-line auctions, advertising, hosting and myriad other on-line activities.

This framing represents a shift in perspective on the evolution of the Internet. By and large, most discussions of the rise of the Internet have focused on the evolution of technological experimentation, i.e., investigating the genesis of inventions from their unlikely origins, or analyzing the exploitation of a small set of core technological standards (e.g., TCP/IP, HTML, etc). Highlighting economic experiments reveals much that prior framings overlook. Rather than simply allowing a diversity of technological options, the environment also allowed for a wide range of alternative commercialization strategies – in terms of pricing structure, marketing, market segmentation, and the like. That provided great leeway for a diversity of commercial outcomes.

This change in perspective also leads to new insights about the role for public policy. While there is considerable analysis of specific regulatory rules shaping broadband, as well as analysis of the legal environment around participation in open source communities and standardization efforts[2], little research has examined the determinants of the type of exploratory behavior analyzed here.[3] This omission should be rectified. Exploratory behaviors are key ingredients in entrepreneurial-led economic development and growth, and do not happen by accident. This essay highlights the presence or absence of specific market institutions which encourage or discourage economic experiments. These institutions can (1) change as industrial policy changes, (2) alter the costs of conducting economic experiments, (3) act to coordinate experiments across firms or not, and (4) shape how the lessons from experiments spread.

A roadmap to the essay

This paper starts from premises found in prior research about learning. Specifically, firms undertake economics experiments to resolve uncertainties about market value. Firms engage in learning as a necessary consequence of – or as the unintended by-product of – participating in evolving markets for goods and services whose value is undergoing change

[2] There is considerable writing in each of these veins. See e.g., Lessig (1999), Sidak (2003), Crandall (2005), Neuchterlein and Weiser (2005), and Blumenthal and Clark (2001) among many. This list is hardly exhaustive.

[3] Emphasis on exploratory behavior are beginning to emerge. See, e.g., Greenstein (forthcoming), or Goldfarb, Kirsch and Pfarrer (2005).

(Rosenberg, 1994, Stern, 2005). Those uncertainties arise because market participants have a limited ability to imagine actual economic activity in all its complexity and detail, especially when new technologies enable new goods and services. They also arise because many choices among the details about operations to serve buyers cannot be learned except through trial and error. Planning activities or investments that anticipate learning activity can help but can never overcome these limits. Even market participants with extraordinary imaginations would still find it impossible to forecast, for example, how demand will change when prices decline for complementary goods, or how the majority of customers will react to different menus of products. As a result, experience may be the best path to teaching a decision maker about how to develop value in a new commercial opportunity enabled by technical innovation.

This essay stresses an additional factor shaping industry wide learning: any one firm has a difficult time forecasting any other firm's response to unanticipated activities from near competitors or business partners, such as those offering either substitutes or complements. Observing events in a market resolves open questions about other firm's pricing, features, and appeal to users, among other questions of this form. It is useful to stress this factor because it suits events in a network comprised of independently governed components, such as the Internet, and it supports analyzing economic experiments in its broadest form, which is what this essay does.

These conditions motivate firms to undertake two broad types of learning activities. The first, directed experiments, occurs when firms deliberately invest in their own operations in ways that allows them to learn something that benefits their business. The second, undirected experiments, occurs when firms monitor the conduct of others, seeking to learn lessons from the experience of others and through the interplay of their activities with one another. The essay illustrates how these experiments pervade a wide range of activities.

Lessons do not arise in isolation. Many experiments build on the lessons learned during prior experiments. More significant, over time lessons spread and accumulate, which motivates questions about the factors that contribute to spreading. The essay stresses the importance of dispersed technical leadership (Bresnahan and Greenstein, 1999) in Internet access markets. That is, many participating firms have the ability to hire or employ any small- or medium-sized teams of skilled personnel who can quickly access the latest publicly available technical information in their industry and use the knowledge to comprehend technical issues and contribute to valuable activities.

All participants gain from the accumulation of lessons. As shorthand, the “flow” of many lessons adds to the “stock” of knowledge. Following Nelson (2007), this stock is labeled “know-how.” What is the value of this know-how? The essay stresses distinct notions of value for know-how. In one sense the value of know-how changes over time, as in markets where firms continually conduct economic experiments. In another sense know how may not have any comparative value, as when all firms have it. Yet, it may have a large value to industry as a whole, because it supports the generation of more lessons, leading to more economic experiments that help firms grow and become more productive.

The essay explores the relationship between know-how and lessons in Internet access markets. It argues that many lessons learned from economics experiments could not be excluded from others except in rare circumstances; hence, most lessons spread quickly. By traditional economic reasoning the incentive to conduct experiments was too low. That is, there was no market for lessons, so the private benefits from conducting an experiment were much lower than the industry-wide benefits.

The essay considers many insights for policy. It stresses that more formal intellectual property is not necessarily an improvement in all settings. While increasing formal mechanisms increases incentives to experiment, it also raises the ability of one firm to exclude others from learning lessons. It also has subtler effects: More exclusion can reduce learning externalities in undirected experiments, and/or it can reduce the rate of growth in the stock of knowledge. That latter observation is especially important because all experiments build off this stock.

The essay ends with further insight for policy, stressing how institutions shape the conduct of experiments and the accumulation of knowledge. Policy also can shape the speed with which lessons spread – for example, by shaping exclusion of potential users of information. Policy also can shape contracting that shapes incentives to conduct experiments. Several examples of policy dilemmas from the first decade of the commercial Internet illustrate these observations, such as issues that arose during the diffusion of the browser, the fight between Internet Service Providers and local telephone companies, the resolution of the 56K modem war, and the on-going fight over regulations for broadband providers.

Comparing models of economic experiments to others

Economic experiments differ from models of technical evolution. Economic experiments may pertain to any change that alters knowledge about the value of a good or service or the costs for bringing a service to market. Economic experiments shape more than just technical invention; they also change business operations and organization that translate technology into economic value. By this broad definition, economic experiments encompass a range of market-based learning, as when, for example, market events reveal the previously unknown value of primitive technologies, make managers aware of broader applications for technologies invented for narrow applications, or help firms learn how to routinize a business processes through customer-suggested refinements.

The model of economic experiments overlaps with another model for analyzing learning behavior, models of "user-oriented" innovation.[4] Like this approach, a study of economic experiments closely examines how innovation becomes embodied in commercial form, and it highlights the links between the experience of market participants and the conceptualization of an idea. A model of economic experiments also resembles examination of learning found in Internet studies, such as analysis of the communities who investigate wireless technology applications before mass markets develop.[5] Like that approach, this essay also highlights the factors nurturing unanticipated developments in new technologies. In contrast to both literatures, a model of economic experiments places less importance on user communities, instead focusing on how lessons spread, typically between vendors, and how this spreading builds a knowledge base that can generate additional valuable innovation. To be clear, the framework also stresses the importance of user communities that aid the sharing of lessons, such as standards committees. However, the broader emphasis also leads to other implications for firms and policy makers.

Perhaps more significant for policy, the emphasis from examining a market with

[4] This is becoming a large literature, starting with Von Hipple (1988).
[5] See e.g., Sandvig (2007).

intense research and development (R&D) through the lens of economic experiments contrasts with the emphasis of examining it through the common "ladder model" (which Gomory labeled and critiqued in 1997).[6] To stress the differences between the ladder model and the model of economic experiments, I first characterize the ladder model in a somewhat cartoonish form: The ladder model presumes that matters follow a sequence. Initially someone invests in basic R&D at either a university or within a corporate laboratory. As a result of such investment, a researcher invents something new. It might be possible for contemporaries to forecast its usefulness in the future, but all recognize the need for more investment. Eventually this leads managers at companies to make investments in marketing and distribution, which then leads to a launch of a product using the technology. Buyers then try the new product, make use of it, and give their response to sponsoring firms. After those sales, firms begin a product cycle comprised of incremental upgrades to existing features. Through this sequential path, the performance of technology improves.

There is a significant grain of truth to the ladder model. For example, the original investment by DARPA (Defense Advanced Research Agency) in the fundamental science of packet switching led to a set of events that broadly fits this model. In other words, this model has a place in modern times and policymakers should not throw away its insights. Policymakers, however, also should not rely on the ladder model exclusively, because it overlooks a wide set of innovative conduct that helps improve the economic performance of society.

The model of economic experiments, in contrast, does not necessarily begin with events in a laboratory. It is not a sequential model at all. Instead, the model of economic experiments places emphasis on activities outside of a laboratory, stressing innovations coming from market experience. It also focuses on a cycle of innovations that reinforce one another through the spreading of lessons and the building of a stock of knowledge, insights the ladder model does not develop. As we shall see, the model of economic experiments also yields different insights about the role for policies.

[6] See Gomory (1997) for a discussion about why exposing this model to scrutiny would help eliminate the mental monopoly it held on the actions of many managers.

ILLUSTRATING ECONOMIC EXPERIMENTS

After illustrating the importance of both types of experiments in specific instances with recent events, the essay turns to discussing the factors that encourage and discourage experiments.

Directed economic experiments

The most common directed experiment is incremental in its technical scope and ambition. It aims at learning lessons with immediate consequences for a business. Though incremental, it can involve decisions of the utmost importance to the business, such as learning about the pricing for a new service using a new technology. For example, at the very outset of the browser-based commercial Internet in 1995, many ISPs (Internet Service Providers) wrestled with fundamental decisions about how to commercialize the innovation.

Recall how the first widespread directed experiments for Internet access markets arose, to which the commercialization of the browser contributed because it raised expectations about future demand. The release of Mosaic browser began in the fall of 1993. Netscape's beta browser was released in the fall of 1994, gain publicity in the winter of 1995, followed by its IPO (initial public offering) in August. Then Microsoft unveiled Internet Explorer in December 1995. Around the same time, a number of other entrants also began exploring new businesses, including Yahoo!, EBay, Amazon, Vermeer, and others. These events fueled expectations among industry insiders, futurists, and venture investors that substantial demand for the Internet at households and businesses would emerge quickly.

By 1996, ISPs offered service in every major U.S. city, and many large firms had begun building national networks. The growth was astounding to mainstream firms that had not followed closely any similar, such as the spread of the personal computer (PC) and bulletin boards. By the fall of 1996, there were over twelve thousand local phone numbers in the United States to call for commercial Internet access, and more than sixty-five thousand by fall 1998.[7] That build-out involved both scores of large national firms and thousands of small local firms.

The build-out of ISPs did not happen without considerable experimentation to resolve many open questions. A crucial question at the outset concerned the design of the opening page—or, as it was subsequently labeled, *portal*—that users would see when they first clicked on their browser. What should an ISP do? Should it design its own portal (potentially at great expense), default to another's (such as Excite or Yahoo!), or leave the decision to users altogether?

There were many contrasting strategies for addressing the question. Different ISPs made distinct choices and learned different lessons about the trade-offs between these choices. No single choice dominated, and as firms learned more, perceptions about the costs and benefits of each changed over time. Some ISPs maintained minimal home pages, which many marketed as a virtuous attempt to give users freedom to choose for themselves among Yahoo!, Excite, Lycos, and a myriad of other young portals then springing up. Of these, a portion succeeded with—or in some views, in spite of— this choice. It is always possible to rationalize after the fact why a firm made the choices it made. For example, AOL (America On-Line) chose to continue activity it already performed in the era of bulletin boards, perceiving that its prior investments in community building would continue to have value as its users transitioned into using the Internet more frequently. Its portal decisions continued to nurture those communities.

While AOL's choice may seem savvy in retrospect, many Internet enthusiasts then regarded it as risky. Indeed, AOL was the only firm among the prior large "on-line service providers" to succeed with this strategic choice in the medium term. For example, AOL was the only firm to attract the mass-market user with investment in a *walled garden* (i.e., an approach that protected content, or, in the eyes of technically sophisticated vendors, "spoon fed" content to users), which both controlled a large fraction of the user experience while sacrificing sophisticated users to other suppliers. CompuServe, Prodigy, and Genie all failed at this approach, whereas Microsoft Network (MSN) attempted a similar strategy, and with the help of its marketing advantages and budgetary tolerance for operating losses, did not

[7] See Downes and Greenstein (2002) for a description of the dial up market, or Downes and Greenstein (2007) for an analysis for why some areas had more entry than others.

exit. Nevertheless, MSN was no better than a distant second to AOL in market share throughout the 1990s.

Of course, not all of these types of experiments turned out well. For example, in the mid- to late 1990s some cable companies believed they did not understand Internet users requirements, so they ceded these decisions initially to others, such as, for example, @home . Eventually, @home merged with Excite to gain access to the perceived advantage of owning a portal, a decision that was regretted by several cable firms later. When the cooperation between cable firms and @home/Excite ended, it produced a large amount of recrimination. Although this experiment was not financially successful, the surviving firms—cable companies, in this case—learned valuable lessons about how to structure their ISP services. First, certain useful "investments" were recreated, such as geographic caching of content, and, second, certain "mistakes" were avoided, such as not depending on advertising for revenue. [8]

Exploration did focus on other fundamental determinants of value, such as the price paid for services. For example, throughout 1995 to 1998 many firms experimented with different contracting plans to offer households. Specifically, by 1995 there was already a general movement to offer unlimited monthly service for a fixed price. After AT&T WorldNet announced its intention to enter the household market with a $20-per-month contract, this contractual form became the focal standard, eventually leading to the end of marginal pricing of services. And, AOL's conversion in early 1996 was the last, most publicized, and most difficult of these conversions among the largest ISPs at the time.[9]

It would be an error to think that AOL's well-publicized troubles (and marketing recovery from them) were the end of experiments with prices. Experiments continued for years, but only the major successes received wide publicity. There were many attempts to give users choices among monthly hourly limitations in exchange for discounts. Most of these experiments did not generate a significant reaction among a large set of users. In 1999, one such experiment did: A set of entrepreneurial firms experimented with formats that offered free dial-up access services in exchange for requiring users to view advertising. Netzero eventually was the most successful entrant of this form, though, arguably, that

[8] See e.g., Rosston (2007) for an analysis of the changing views of cable firms about the source of value from controlling or not controlling a portal and ISP.
[9] See Swisher's (1998) account of this crisis.

success arose because Netzero departed from its initial strategy and eventually charged for access.[10] In other words, the most fundamental determinant of value in the retail household market—the contracting terms and pricing norms for access—continued to evolve throughout the entire first decade of the commercial Internet.

During this same period, many firms also experimented with the range of services offered. Virtually all ISPs experimented with changes to the standard bundle offered, such as default e-mail memory, instant messaging support, and hosting services in which the ISP maintained Web pages for clients. Also, in response to user requests, some local ISPs arranged for the availability of phone numbers in other locales for traveling clients. A wide range of regional ISPs experimented with performing services complementary to access, such as hosting services, networking services, and Web design. In general, very few of these product-line decisions remained fixed for very long.

Nobody was immune from this type of experimentation. Even the dominant firms extensively experimented with their product lines. For example, AOL greatly expanded its range of services in the latter half of the 1990s, through a mixture of in-house development, alliances, and the purchasing of other innovative companies. Microsoft Network also tried to provide a similar experience.

Part of AOL's expansion matched a similar (and almost parallel) expansion of services occurring at on-line portals, such as Yahoo!, Excite, and Lycos. This matching and initiating went back and forth for years and, as it gained new features, became increasingly important for some small ISPs, because they had chosen not to invest heavily in their own portals. In this sense, many small ISPs and these portals together competed with AOL and MSN.

Whether it was the redesign of a home page, the offering of new contractual forms, or changing the range of services offered, all of these experiments were directed. The firms that conducted these experiments expended resources to learn something of value to their business, usually while also performing routine business activities. And it was not just a few leading firms or a few entrepreneurial climbers that did this. No, these types of experiments occurred at virtually all the ISPs conducting business during the latter part of the 1990s.

[10] This strategy turned out to be effective for entry, but not for a sustainable business. Eventually, after growing a service for several million users, then merging with another firm, Juno, Netzero adopted a different pricing contract, one with a minimal charge.

From one perspective, this activity was mundane and almost routine. Managers would authorize the expenditure of resources, redirect personnel, alter a feature of an existing service or develop a new one, advertise it or not, and then wait to find out whether these investments paid off in terms of additional revenue, market share, or pricing authority. Failure was not regarded automatically as a waste of resources if it led to valuable learning (for example, a failed small-scale experiment could help managers avoid costly mistakes on a larger scale).

Interpreted broadly through the lens of economic experiments, directed experiments should be understood as risky and knowledge-building. Investments in and commitments to these actions had to be made before any of the managers at these firms fully knew the additional gain that could be generated from the existing customer base. Firms were learning about customer responses they could not fully imagine, using experiences to understand how to refine key business decisions, and deliberately learning through trial and error in market experience what could not be learned in a laboratory. In short, that learning led firms to change what they did.

Undirected economic experiments

Some economic experiments resulted from the interplay of one firm's action with another. While directed experiments might have partially motivated the actions of any single firm, it would be an error to regard the lessons learned as singularly resulting from only one firm's actions. Rather, the interplay of firms, their actions, and their economic experiments yielded a form of serendipity in learning—learning that resulted from the unanticipated combination of lessons learned from several actions or sources. Developments in wireless data communications technologies illustrate how such unanticipated serendipity in learning can arise. It is also a particularly good example because though some form of a market for wireless data transfer was expected, the market it took an unexpected direction toward one mode.

Futurists had predicted the rise of mobile computing even before the rise of the commercial Internet. After the boom in the Internet access investment that began in 1995, those predictions were made with additional urgency. Numerous efforts arose to anticipate it, including several efforts to design short-range data communications standards, such as HomeRF and Bluetooth.[11] In addition, because of the tremendous number of investments in technology made by cellular equipment providers and carriers to carry data over their infrastructure, a substantial number of futurists foresaw wireless data services emerging out of the cellular phone industry, as part of a number of initiatives in 3G (third generation) technologies. This large effort involved virtually every equipment firm and carrier in the cellular phone business, as well as many others.

Most of those predictions turned out to be correct in a broad sense—that is, there was substantial demand for wireless data communication technologies. Yet, in the specific sense, HomeRF did not generate the enthusiastic sales that those who designed it predicted—even though the designers considered it technically superior to the alternatives.[12] In addition, after a slow start, Bluetooth eventually found its way into a variety of products, particularly attachments to cell phones and many other consumer devices, but largely not computing devices. The 3G products and services also did not grow as hyped, initially gaining little traction with U.S. consumers. And, it is only recently that 3G products have started to make a dent in the United States.

More surprising, a wireless fidelity technology – now popularly known as Wi-Fi – became dominant. Wi-Fi arose out of undirected economic experiments. More to the point, its development did not arise from a single firm's innovative experiment. Rather, Wi-Fi began as something different that evolved through economic experiments at many firms. The evolution arose from the interplay of strategic behavior, deliberate investment strategies, learning externalities across firms, and a measure of simple and plain good fortune.

What eventually became Wi-Fi originated from discussions about a technical standard designed at the IEEE (Institute of Electrical and Electronics Engineers) Subcommittee for Committee 802. The IEEE sponsors many committees to design standards. Committee 802 was formed in the early 1980s, before the commercial Internet was ever proposed. It was well known among computing and electronics engineers because it had helped design and

[11] Both were founded in 1998. The former was organized by firms such as Motorola and Seimens, and at its peak involved over a hundred companies before it disbanded; while the latter was established by Ericsson, Sony-Ericsson, IBM (International Business Machines), Intel, Toshiba, and Nokia, and currently still exists, involving thousands of firms.

[12] For speculation about why HomeRF failed, see, e.g., http://www.cazitech.com/HomeRF_Archives.htm

diffuse the Ethernet standard.[13] By the mid-1990s it had grown larger, establishing committees for many areas, ostensibly to extend the range of uses for Ethernet.

Subcommittee 802.11 was established in 1990. Like all subcommittees of this broad family of committees, it concerned itself with a specific topic, in this case, designs for interoperability standards to enable wireless data traffic using Ethernet protocol in short ranges. As with all such committees, any standards emerging from these discussions were not legally binding on industry participants, but the committee was formed with the hope that such a standard could act as focal point, helping different firms make equipment that was interoperable, such as routers and receivers. As with most such committees, it tried to involve members who brought appropriate technical expertise and who represented views of most of the major suppliers and users for the type of equipment in which this standard would be embedded. Since participation was voluntary it might be appropriate to generalize that participants came to learn about what others were proposing and because many wanted new products to emerge from their efforts.

There were many potential business applications for this standard – one of the earliest prototypes had been in wireless terminals[14] and another had been in large scale wireless local area network for a university campus[15] – and focusing on any of them was not a bad idea. After all, it is often a smart strategy to focus development on valuable use or on users with a history of tolerance for the technical challenges affiliated with being an early adopter. At first, the group was comprised of enthusiastic designers focused on the needs of big users of local area network technologies (e.g., FedEx, UPS [United Parcel Service], Wal-Mart, Sears, and Boeing)—companies that they believed would have valuable uses for short-range wireless Ethernet (e.g., in large warehouses with complex logistical operations). More to the point, the original charter and motivation for this subcommittee was not focused on what eventually became a large market in the home and in public spaces (e.g., coffee shops).

Subsequent events fit a category of unanticipated learning that Rosenberg (1995)

[13] The story of the growth of a local area network market around the activities in committee 802 is well told in Von Burg (2001).

[14] Vic Hayes, one of the earliest developers of wireless technologies and standards, and chair of the IEEE 802.11 committee during the 1990s, first developed wireless technologies for NCR (at sub-division of AT&T then, today a division of Agere Systems). In that capacity he first developed wireless terminals for stockbrokers. See Krariff, 2003.

[15] See the description of Hills (2005), who began developing the equivalent of a Wi-Fi network for the Carnegie Mellon campus in Pittsburgh, starting in 1993.

labels (and I paraphrase here) "an invention motivated by a specific application that unexpectedly finds broader use." Specifically, the Subcommittee 802.11 first proposed a standard in 1997 that received many beta uses, but also failed to resolve many compatibility problems among many technical issues. Learning from this experience, the committee rewrote the standard. What came to be known as 802.11a was ratified in early 2000. Just prior to that in late 1999, the committee published Standard 802.11b, which altered some features (changing the frequency of spectrum it used, among other things). The latter caught on quickly and eventually widely.

Because many vendors had experimented with earlier variations of this standard, the publication of 802.11b generated a vendor response from those who were already making equipment—and others soon thereafter. As it turned out, it also generated a response from Internet enthusiasts, who at the time began using this equipment in a variety of settings, campuses, buildings, public parks, and coffee shops. Unsurprisingly, vendors tried to meet this demand as well.

Around the same time as the publication of 802.11b, firms that had helped pioneer the standard—including 3Com, Aironet (now a division of Cisco), Harris Semiconductor (now Intersil), Lucent (now Agere), Nokia, and Symbol Technologies—formed the Wireless Ethernet Compatibility Alliance (WECA). WECA branded the new technology Wi-Fi, which was a marketing ploy for the mass market, since WECA recognized that "802.11b" was a much less appealing label. The aim was clear: Nurture what enthusiasts were doing and broaden it into sales to a broader base of users.

WECA also arranged to perform testing to ensure that equipment conformed to the standard, such as certifying interoperability of antennae and receivers made by different firms. This is valuable when the set of vendors becomes large and heterogeneous, as it helps maintain maximum service for users with little effort on their part. Though this principle was well known among designers who had watched prior markets for compatible equipment, the earliest experience with 802.11 had reiterated the importance of such activity. In other words, while the IEEE committee designed the standard, a different body performed conformance testing. This activity further promoted interoperability between equipment from different vendors, which made sure an issue with the earliest designs did not reappear.

Events then took on a momentum all their own. Technical successes became widely publicized. Numerous businesses began directed experiments supporting what became known as *hot spots*, which was an innovative idea altogether. A hot-spot in a public space could be free, installed by a home-owner, or maintained by a building association for all building residences, or supported by the café or restaurant or library trying to support its local user base. Or, it could be subscription-based, with users signing contracts with providers. All became common. The latter would become common at Starbucks, for example, which subcontracted with T-mobile to provide the service throughout its cafés.

A hot spot was a use far outside the original motivation for the standard. Yet, as long as nothing precluded this unanticipated use from growing, grow it did. It grew in business buildings, in homes, in public parks, and in a wide variety of settings, eventually causing the firms behind HomeRF to give up. The growing use of Wi-Fi raised numerous unexpected technical issues about interference, privacy, and rights to signals. Most of these did not slow Wi-Fi's growing popularity. Web sites sprouted up to give users, especially travelers, directions to the nearest hot spot. As demand grew, suppliers gladly met it.[16] As in a classic network bandwagon, the growing number of users attracted more suppliers and visa-versa.

Unlike the prior examples about directed economic experiments, no single firm initiated an economic experiment that altered the state of knowledge about how to best operate equipment using IEEE Standard 802.11b. However, like the prior example, many firms responded to user demand, demonstrations of new applications, tangible market experience, vendor reactions to new market situations, and other events that they could not forecast but which yielded useful insights about the most efficient business actions to generate value.

Experiments built on the lessons of another

Not only can firms perform directed and undirected experiments, but they can also

[16] For example, in high-density settings it was possible for there to be interference among the channels, or interference with other users of the unlicensed spectrum reserved by the FCC (Federal Communications Commission), such as cordless telephone. The diffusion of so many devices also raised questions about norms for paying for access in apartment buildings, from neighbors, and others. See Sandvig (2004) on the latter.

build experiments on top of each other. Virtually all firms perform directed experiments; and sometimes these experiments lead to a product or service that naturally generates an undirected response from other firms as they watch, monitor, and compete with each other. Because this information externality is unanticipated, it is not under contract. In other words, some firms learn from another firm's directed experiment and consequently reap the benefits of the lessons learned without having to undertake the cost of performing the experiment. Although some firms might try (and ultimately fail) to keep their directed experiments private, most firms recognize that they are part of a broader interplay of firms. Thus, the original directed experiment leads to one or many undirected experiments.

In contrast, the process of building directed experiments on top of undirected ones requires a different type of reaction to the evolution of the market. For example, later events in the development of Wi-Fi illustrate how directed learning can build on top of an undirected economic experiment. Reacting to the undirected experiment that generated Wi-Fi, Intel performed a directed experiment that led to the creation of *Centrino*, a large program that would install wireless capability in its notebook computers. It was officially launched in March 2003, though industry insiders knew about the plans much earlier.

This Centrino program is easy to misunderstand. Embedding a Wi-Fi connection in all notebooks that used Intel microprocessors *did not* involve redesigning *only* the Intel microprocessor, which is the component for which Intel is best known. It involved redesigning the motherboard for desktop PCs and notebooks by adding new parts.[17] This came with one obvious benefit, namely, it eliminated the need for an external card for the notebook, which was usually supplied by a firm other than Intel and installed by users (or original equipment manufacturers [OEMs]) in an expansion slot. Intel hoped for additional benefits for users, such as more reliability, less set-up difficulties, longer-lived batteries (due to less need for heat reduction), thinner notebook designs (due to smaller cooling units) and less frequent incompatibility in new settings.

Intel had crept into the motherboard business slowly over the prior decade as it initiated a variety of improvements to the designs of computers using its microprocessors. Years earlier Intel designed prototypes of these motherboards and by the time it announced

[17] Specially, it involves designing an appropriate chipset and wireless network adaptor, as well as the Intel Microprocessor.

the Centrino program, it was making some motherboards, branding them, and encouraging many of its business partners to make similar designs. To be clear, Intel did this for a variety of reasons having to do with its own forecasts about what was most valuable in the PC market and how it could help the entire value chain improve around its products.[18] Long before the Centrino program occurred to anyone – that is, in the early to mid 1990s – enabling "wireless Ethernet" was not part of the grand Intel strategy in any explicit form, though it was not precluded either.

Intel hoped that its endorsement would increase demand for wireless capabilities within notebooks by, among other things, reducing weight and size, while offering users simplicity and technical assurances in a standardized function. It also anticipated that the branding would help sell notebooks using Intel chips and motherboard designs instead of using Advanced Micro Devices (AMDs). Furthermore, antenna and router equipment makers anticipated it might help raise demand for their goods.

Centrino diffused into a mix of support, ambivalence, and hostility in the value chain. Intel's motherboard designs increased the efficiencies of computers, but that benefit was not welcomed by every OEM who assembled PCs. As Intel's design became employed more frequently, it eliminated some differences between OEMs and other component providers. Many of these firms, including motherboard suppliers and card makers, in addition to the OEMs, resented losing both control over their designs and the ability to strategically differentiate with their own designs. Other OEMs liked the Intel design, since it allowed the firms to concentrate on other facets of their business.

Only Dell was able to put up any substantial resistance, however, insisting on selling its own branded Wi-Fi products right next to Intel's, thereby supporting some of the card makers. Despite Dell's resistance, the cooperation from antenna makers and (importantly) users helped Intel reach its goals. By embedding the standards in its products, Intel made Wi-Fi, or rather Centrino, easy to use, which proved popular with many users.

Although, Intel ran into several snafus at first, such as insufficient parts for the preferred design and a trademark dispute over the use of the butterfly, its preferred symbol for the program, Intel's management liked the outcome. Management learned many things

[18] For analysis of Intel's investments in different projects and why it chose to invest heavily in some complementary technologies and not others, see, e.g., Gawer and Henderson (2007).

from the experience and initiated several new projects as a result, such as contributing to writing upgrades in IEEE Committee 802.11 (to 802.11n) and writing an upgrade to a whole new wireless standard for longer ranges (to 802.16, a.k.a. Wi-Max, and related, 802.20).

The Centrino example illustrates the array of deliberate firm activities taken during a short period, building on top of learning from an earlier undirected economic experiment. The activities in IEEE Committee 802.11 ended up affecting the activities of many other firms, such as equipment manufacturers, laptop makers, chip makers, and coffee shops, which then shaped new activities at the committee as well. That change in purpose altered many business plans, such as investments in equipment design and distribution, as well as marketing campaigns.

More to the point, undirected economic experiments often can and do involve at least some directed experiments as well. In this case, an undirected economic experiment took an entirely new direction after a large firm decided that it could invest in shaping events in ways that served its commercial needs.

By traditional economic reasoning when this building involves more than one firm, as it did here, two externalities are present. There is an information externality *between* one firm's action and another at any point in time, as when one firm's directed experiment teaches another firm a lesson, or a set of actions interact in an undirected experiment and teach every industry participant a lesson. There is also an information externality over time, as when the lessons of prior experiments a participant lessons on which further experiments are built. Said another way, such externalities arise because there is no contract between firms for these lessons. This is so by definition when the lesson arises due to serendipity. More profoundly, it also arises for many other reasons, due to the myriad difficulties interfering with contracting between multiple parties for information. To understand these factors more deeply, we now explore the spreading of lessons.

SPREADING LESSONS AFTER EXPERIMENTS

We have seen from several examples that few lessons learned from the experiments stayed at a single firm. Rather, economic experiments generated lessons that spread, and additional experiments built on the prior ones. As we have also seen, the spreading of lessons can lead to large benefits to other firms who may not have participated in the earliest experiments. Although no conscious collective purpose guides the process at every step, there are many systematic features.

We now discuss different types of lessons and why they exhibit different patterns of spreading. There are three distinct types of lessons: First, *technical lessons* pertain to the design for a piece of equipment—for example, knowing how to create Wi-Fi. Second, *heuristic lessons* combine both technical knowledge and operational knowledge about how employees behave in firms and how customers react to firm behavior—for example, knowing how to use Wi-Fi. Third, *complex lessons* are marketing and operational lessons that involve many functions inside an organization—for example, knowing how to integrate the use of Wi-Fi into a wide variety of other processes. Virtually all technical lessons (and some heuristic ones) tend to spread quickly. In contrast, complex lessons tend to display a much wider variance of spreading speeds.

What happens as lessons spread to firms that did not conduct the original economic experiment? Two types of patterns ensue, depending on whether the lessons arose from directed or undirected economic experiments. First we discuss these two patterns, and in the next section we discuss how these overlap with differences between technical, heuristic and complex lessons.

The theory of spreading lessons

Consider the spread of directed experiments. There are many types of lessons: For example, there are those that guide firms to avoid mistakes in the future, that help firms invest in services with positive returns, or that inform firms about customer needs, and so on. Most such experiments help a firm understand the value of some unknown aspect of its business activities. Whether or not the same lesson could be applied to another firm is secondary to the private motivation to conduct the experiment.

A lesson increases its value by (1) generating more revenue through improvement of an existing service, (2) enhancing profits from lowering operation cost or avoiding higher investment expenses, or (3) enhancing pricing power through differentiating the firm from its nearest rivals. A lesson useful for one firm typically has features that make it valuable for others.

Sometimes its spread may have competitive implications, and sometimes not. Many lessons do not lose much value as they spread. For example, a lesson about how to lower the cost of service in a rural location may help another firm in another rural location, but have little if any short run competitive implications.

In contrast, some lessons are valuable for private purposes when only one firm makes use of it, so it loses some of its value as it becomes more common—that is, as many firms put it to use. In particular, it loses the part of value that made a firm unique, because spreading eliminates differences across firms. The loss of that type of value motivates firms to try to prevent some types of lessons from spreading. Typically, such efforts fail completely or work for only a short period, a topic we will discuss below.

For lessons learned from undirected economic experiments, many of the same observations hold as with directed experiments—with one major exception: Typically, there is no single firm conducting the economic experiment. Hence, no single firm may be acting to prevent the spread of lessons that alter comparative value, so spreading occurs almost by definition. The events involve actions at multiple firms, and, as one firm monitors the experience of another, these actions interplay with one another. In most of the practical circumstances when this occurs, multiple firms know the technical and heuristic lessons because all participating firms monitor market events or participate in them, whether it involves the demonstration of a new technology, or the rollout of a new service. While the participation of numerous firms is accepted as integral to an undirected experiment, the open question is, To how many other firms will those lessons spread? Generally, the answer is, All market participants who make efforts to learn the pertinent lessons.

Technical lessons spread into many locations and firms, because most computing and electronics markets in the United States display *dispersed technical leadership*.[19] That is, many firms have the ability to hire or employ any small- or medium-sized teams of skilled personnel who can quickly access the latest publicly available technical information in their

[19] See Bresnahan and Greenstein (1999) for a discussion of the role of dispersed commercial leadership in the development of platform strategies during the evolution of the computer industry.

industry and use the knowledge to comprehend technical issues and contribute to valuable activities. As a practical matter, existing firms either already possess such teams, or can assemble them by reassigning employees. If such employees are not yet employed, they are easily hired from labor markets.

Dispersed technical leadership cannot exist without many market participants informing each other. While industry conferences, consulting reports, and trade magazines have always informed market participants, today Web pages and community/industry forums supplement them. Any reasonably sized product market attracts an abundance of product reviewers and bloggers that track gossip about business initiatives and point out design flaws or triumphs.

Since the 1990s, in the United States many technically skilled people live in many places. Fast communication among such people about new technical developments can produce the same developments in many locales across wide geographic spaces, sometimes quickly. This means the lesson from an economic experiment in one location can become known quickly by other decision makers in other locations. It also means the accumulation of lessons involves learning done in a variety of locations.

Fast communication has one other consequence. Because firms monitor each other, they end up imitating one another, even when they are not in close competitive contact. It may even appear as if firms are acting in concert as they imitate one another—for example, as when many coffee shops in vastly different locations each installed hot spots. Such imitation also may take place over long distances as a result of firms in different locations monitoring one another, which small ISPs tended to do to one another.

Ultimately, for both direct and undirected economic experiments, the spreading of a lesson changes its role. When the lesson is codified into routines and embedded within an industry, when it spreads to a point that it is taken for granted, the lesson has become part of an industry's accumulated knowledge base, what Richard Nelson (2007) has called an industry's *know-how*. That is, the "flow" of many lessons adds to the "stock" of knowledge. An open question concerns the value of a lesson as part of this stock.

Many examples already hint at two answers. First, the entire knowledge base seeds and supports more experiments. In other words, an experiment generated a product or service that taught firms lessons, which then spread to the point that they became the industry know-how that will ultimately provide the basis for new experiments. At the same time, another notion of value also applies to know-how, a more comparative one. If there is no distinct difference between the know-how at one firm and another, then, in that sense, the know-how may be regarded as common, not supporting any comparative difference in value between firms.

Spreading different types of lessons

The previous discussion hints that dispersed technical leadership is important for another reason. If a lesson spreads, it has *somewhere else* to spread, that is, lessons learned in one location by one firm can become part of the know-how of many firms in many locations. Somewhere else often means *someone else* as well. In general, some types of lessons spread more easily than others and, as we shall see, that may also depend on the identities and variety of the firms involved.

Consider the identities of the firms involved in the early ISP industry. It is hard to provide a general explanation of why many firms began to experiment with commercial forms of Internet access. The first advertising for independent ISPs began in 1993 and grew mildly in 1994. Some of these firms, such as PSINet, IBM, and MCI, operated networks that were direct descendents of NSFNet (National Science Foundation Internet), and their commercial activities contained much continuity with what they had done for the NSF. Many of them, such as Netcom and countless regional ISPs, were descendents of bulletin-board firms. Many sought to satisfy their curiosity and some sought to make a profit. Yet, their initial motive is less significant than what happened next: Their experience quickly became known by bulletin-board operators and users everywhere else in the country.

The technical lessons were rather trivial for a former bulletin-board firm to learn, so initial steps toward offering Internet access were seemingly easy to implement. The technical steps between an ISP and bulletin-board firm were relatively incremental—many firms just added a connection to the newly privatized Internet backbone.[20] Generally, these technical skills were already common among those who operated bulletin boards.

Technical lessons tend to become codified into industry know-how quickly—especially when the technical lessons are put into a structured format (e.g., words, mathematic formulas, plans, pictures, or drawings) that a person other than the author can understand. It is almost tautological that such codification leads to easier transmission of the know-how. For example, lessons about the design for a modem bank, a server, or other modem equipment became codified almost immediately, and for good economic reasons. Most equipment suppliers in competitive markets would not consider selling equipment if information about it were not codified because most buyers demand it as a condition of purchase.

Others lessons pertain to heuristic knowledge about how to operate that equipment efficiently. For example, lessons about how to manage modem bank capacity at peak usage levels might not be known initially after a new piece of equipment became available for use, but such lessons would be learned through trial and error.

Several factors affect the speed at which heuristic lessons spread. On the one hand, some heuristic lessons spread slowly because, as sources of competitive advantage, they are guarded by the firms that first discovered them. For example, firms guard their strategies for how to deploy equipment efficiently. On the other hand, some firms, such as equipment providers, have strong incentives to spread lessons, since their spread contributes to further sales. In addition, the relevant software tools for monitoring use would show up in the discussion boards for an Open Source project, such as Apache (i.e., the most popular web server), and discussions about their use would transmit many of the key lessons. Alternatively, developers at many firms can relearn the same lessons independently, through their own directed experiments, and the lessons can become fodder for list-serves and industry trade publications.

Other factors can slow the codification of such heuristic lessons, however. First, one community of users may differ from another. For example, peak ISP usage occurs around the same time of day in different locations, but the similarities end there. Surfing habits and

[20] Most of these vendors already knew how to operate the basic building blocks for a point of presence (or POP) and support a basic service. The details of such a POP involved operating modem banks, servers, and managing traffic control.

behavior vary according to gender, family status, age, education, and income of the members of the household, the sum of which varies from one city to another, and even from one vendor to another within the same city. Such variety interferes with finding commonalities in, for example, marketing strategies (for a new feature) across locations or vendors.

In addition, solutions effective in one location might not work in another because a variety of heuristic operating rules established to resolve other operational issues might interfere with the functionality of a new lesson. For example, most ISPs wanted a way to limit overuse of capacity, especially when users failed to log off after ceasing or delaying use. Some ISPs instituted rules for automating log offs after short periods of nonuse, while others did not because users resented it (and, as a result, would leave for other vendors). Some vendors instituted special clauses into their contracts that eliminated "unlimited use," authorizing them to charge penalties for exceeding especially high monthly usage (e.g., over 100 hours). Modem capacity usage differed depending on these rules. Any heuristic lesson about how to operate new equipment at capacity would have to take into account such rules, but such variety interfered with uniform rules for all operators.

Not all lessons can be reduced to simple heuristics—some are complex lessons. These might emerge, for example, from lengthy investigations by firms seeking to lower cost or generate extra revenue. They often are interdependent, where one reinforces the other. In either case, complex lessons cannot be easily summarized by a simple heuristic rule-of-thumb or answer to a single question. Almost by definition, these lessons resist immediate codification and are the slowest to move from firm to firm.

As with heuristic lessons, ISPs were hesitant to share complex business lessons. For example, they would not lightly discuss with other firms which lines of business best complemented their access business. Firms also were hesitant to share information about what sort of costly activities built customer loyalty most effectively—for example, did users have greater willingness to pay incrementally for phone service or more free storage for e-mail, and which of these would users appreciate as a standard part of their contract? Similarly, ISPs were hesitant to share internal work practices that supported desired outcomes—for example, what was the appropriate work schedule and pay for someone who did phone support in addition to other duties?

As with heuristic lessons, the same factors interfered with codification and the spreading of complex lessons, namely, differences across communities and between other operating rules. That does not means complex business lessons never spread. Rather, they spread with more effort and at greater cost. In general, they spread more slowly and to fewer firms at any point in time.

As lessons spread they accumulate. In general, accumulated lessons contain the experience of many—both mistakes and triumphs. Moreover, because lessons develop within an interdependent discovery process, they are not a random mixture of insights about how to create value. Rather, this accumulated knowledge pool contains lessons from many firms and a variety of settings. Almost by definition, in a market with dispersed technical leadership, the accumulated set of lessons contains more lessons than any single firm could have learned on its own.

Theory of building know-how

Does accumulated knowledge exhibit a match or mismatch between cost and benefit? By traditional economic reasoning the cost and benefit do not align because of inter-temporal externalities: One party (in a directed economic experiment) or several parties (in an undirected economic experiment) assume the cost of generating lessons while many others gain the benefits later. More precisely, those who pay for lessons (in an early market) are not necessarily those who use them most profitably (in a later market), but no contract between them governed the early investment. Said another way: If there are very few restrictions on how accumulated lessons get used, and by whom, as part of industry-wide know-how, then lessons appear cheaper or inexpensive to later users, although no accountant would (or could) record their value in a ledger.

One other subtle factor shapes the wedge between total costs and benefits: There are asymmetries to the costs and benefits when generating lessons about commercial failure and success. Lessons about how to avoid commercial failure can be as valuable as those about success, but the firm whose failure illustrates the lesson for others rarely, if ever, does so for that purpose, and almost never under contract with the others who (later) gain the benefit of the lessons learned from the failure. In an extreme case, a firm may learn a lesson, teach others from its failure, but go into bankruptcy before it is able to use that lesson. Even though the lesson was expensive to the stockholders of the firm that initiated the experiment, it was inexpensive to the surviving users.

This mismatch never looks the same in any two instances, as each case involves a specific market structure with a specific set of firms. Nonetheless, the experience in ISP markets illustrates that the mismatch tends to arise in a variety of market structures. Specifically, this experience illustrates how two rather distinct industrial structures were compatible with a cycle of economic experiments and accumulations of know-how.

In one structure national firms compete with each other, each having many affiliate branches in many cities. In this structure, organizations are in the same location but with seemingly similar technical capabilities, as long as each focuses on different strategic approaches or customer bases and pursues distinct learning activities. Even in those circumstances, however, the success of one can induce imitation by another, leading the firms seem to have similar knowledge over time, and, hence, operate similar services. In other words, even though firms with national reach (e.g., Yahoo!, Excite, MSN, and AOL) came to the Internet from different backgrounds and approaches, by the late 1990s all of them had imitated each other and developed many of the same features.

Economic experiments also arise in a different kind of market structure, one where firms specialize in providing service for local markets, so their experiments focus on local conditions. Many firms with otherwise similar technical capabilities possess rather different business knowledge about different locations for short periods of time. That different business knowledge, in turn, supports seemingly similar business organizations that focus on learning the lessons affiliated with serving customers in different locations. That setting still induces firms to try to imitate the business lessons of others in different locations, so business lessons do not tend to stay unique for long. In other words, two local ISPs in two locations may look different for a while, but, over time, become similar to one another even if they do not compete directly.

Accumulation has an important affect on market structure, as it shapes the *variety* of firms, as it did, for example, among a variety of ISPs who covered many different local areas. *Variety* in this context means firms use different commercial assets in different locations, different personnel with distinct sets of skills, different financial support structures with different milestones for measuring progress, and even different conceptual beliefs about the technical possibilities. As a result, one firm's assessment of the returns from innovating does not need to be the same as another's. Different assessments result in different methods for achieving the same commercial goals, which may lead to different costs, or different commercial goals altogether, such as targeting different customers.

Accumulation of lessons over time tends to reduce variety. While the accumulated lessons may become larger than any single firm would have or could have developed on its own, the set of new lessons added by any firm tends not to change the base much. After this knowledge base develops and all firms learn it, firms may still be different because local economic conditions differ – those that affect costs, demand and market power, or because national assets differ – those that affect branding, or the ability to differentiate or cross market. However, because the knowledge base does not differ between firms, it does not act as an important source of variety.

It is often the mantra of studies of innovative industries that geographic clustering yields many benefits for innovative activity. The emphasis on economic experiments in this essay highlights a factor that pushed toward an opposite insight, the importance of having firms with similar know-how operate in different locations, where that difference fosters a variety of experiments. More to the point, in the face of the accumulation of economic experiments, it is the variation between geographically distant and separate markets that produces variation in economic experiments, variation that collectively accumulates to become industry know-how, a collection that exceeds what any individual firm could learn by itself.

This example is special in some respects, which should be acknowledged. Clustering was not possible because the delivery of service was local, and by definition, economic activity had to be geographically dispersed. In addition, geographic variation in a set of business circumstances, arising from either differences in conditions of supply and competition or differences of demand, did not hinder innovative activity for access markets, because experimentation by independent actors in multiple locations was comparatively cheap.

These special features are not unique to Internet access, however, suggesting the analysis may be more general. They are shared by a diverse set of technology markets which have an important local component. Those features can be found in, for example, computing facilities management services, equipment servicing and repair, software maintenance, industrial support activities, or custom computing software design. All such activities are important for the functioning of a large geographically dispersed high technology economy.

What industries achieve collectively

A goal to collectively generate innovative outcomes may not enter into a firm's strategic calculations. Nonetheless, in the best of circumstances, a group of firms in a market can support extraordinarily rapid technical progress in communities with many users and/or vendors at a societal level—as did participants in the dial-up ISP market between 1994 and 2000 and participants in the Wi-Fi equipment and service arenas between 1999 and 2004.

Such experimentation can also support rapid progress in something just as important – but more difficult to measure – progress in the commercialization of technology. That comes about from the building up of economic experiments in business models, pricing models, and other forms of commercialization – in this case, of Internet services.

These experiments can have large benefits for both consumers and firms. By helping market participants learn about the nature of demand in quickly evolving environments, companies can more effectively position their offerings and pricing structures. Similarly, consumers can benefit from a closer alignment of choices to their preferences.

Those benefits may accrue over time as well. If an early set of market participants learns sooner than it shifts all future learning forward as well; hence, everyone experiences benefits sooner. In addition, there may be a dynamic benefit if aligning preferences with offerings more quickly in an early period enables market participants to conduct more efficient and specialized search in a later time. In that case, on top of moving benefits forward, aligning more quickly in an early era leads to even faster learning later.

What can we learn from that experience about the factors that nurture the accumulation of industry know-how? The essay has already highlighted the role of (1) dispersed commercial leadership, a theme we reiterate below. Now we consider the role of (2) the growth in demand; (3) the maturation of an industry from knowledge accumulation;

(4) the conditions that shape rivalry and excludability of accumulated knowledge.

Perhaps first and most obviously, growth in demand supports economic experiments. Firms in both of these arenas expected high returns from their experiments, and those expectations arose from sensible readings of basic fundamental drivers of market value. In the case of ISPs, from 1995 to 2000 Internet access became adopted by U.S. households and businesses for the very first time. Indeed, most measurements of that trend indicate that the growth continued throughout into 1999 and only began to slow thereafter.[21] For Wi-Fi, comparable data is much harder to come by, but retail sales of related equipment continued to grow after the ratification of 802.11b in 1999 and, especially, after the unveiling of the Centrino program, as well as the ratification of 802.11g in 2003.

In both cases, more than growth of demand supported economic experiments. These markets began from conditions of dispersed technical leadership. Dispersed commercial leadership may be especially important during an industry's early years, while growth in demand supports robust economic experimentation among many firms. It contributes to more firms conducting experiments. Even if all face the same issues, the probability of success increases with the number of experimenters. In addition, it contributes to firms in different locations, i.e., facing a wider variety of circumstances, raising the possibility for one of them to a new problem or a different set of cost conditions that generates a lesson that then benefits them all.

In general, dispersed commercial leadership is valuable because a variety of firms may pursue a variety of distinct experiments. For example, in the case of the ISPs, an early open question concerned the best organizational form for exploiting the market opportunities. Many local firms tailored their actions to the needs of local customers, and depended on national portals and other firms to make up for what they could not do themselves. National ISPs, such as Earthlink, Juno and later, Netzero, looked for ways to brand a national service for access while also depending on others to fill user needs. Still other national ISPs, such as AOL, looked to standardize their delivery of content, organizing the Internet for their users. In principle, any firm could monitor any other and learn from any other, while each vied for a long term future.

[21] See NTIA (2003) for documentation of this diffusion to households during this time period. Similar data on diffusion to businesses is harder to come by, but the available evidence suggests that the adoption of access had already slowed by the end of 2000. See Forman, Goldfarb and Greenstein (2005).

This experience also illustrates that economic experiments vary systematically over time in light of a cycle of lesson generation and knowledge accumulation. Part of this is not surprising. Demand growth supports such experiments, and when growth in demand slows, one should expect the same of the number of economic experiments. However, there is also change in the incentives to conduct certain types of experiments firms conduct over time.

Experiments differ over time because users differ. Appealing to mass-market users differs from appealing to early users in a young market. Most early users, also known as *early adopters*, seeking a grand technical advance, tolerate technical difficulties. Economic experiments may focus on finding users who are willing to pay for a new good or service. In contrast, mass markets tend not to grow around a perfect technology, but, rather, grow around a reliable, inexpensive, and functional implementation of a technology that early adopters previously used. Mass markets may also involve users who desire reliable changes that are compatible with prior investments. Later experiments may need to address issues that either enhance revenue from existing users or generate changes in market share while accommodating prior investments.

Later economic experiments also differ because accumulation of know-how alters the conditions supporting experimentation. There is an inexorable accumulation of lessons that remove differences between the knowledge base of different firms. The value of new lessons is always compared against that base. When there are fewer new valuable lessons, the range of services and the routines for operations become unchanging, and, therefore, stable. After some time the economic experiments will have lower value.

Traditional economic analysis would suggest that the private incentives to engage in economic experimentation are low relative to the wider returns generated. This is so due to the information externalities inherent in conducting experiments in markets. Any participant may observe a directed experiment, and, quite possibly, learn the pertinent lesson. In addition, an undirected experiment involves the interplay of many firms who may not have any formal contracting arrangement governing their interplay.

More subtle, the accumulated knowledge base of technical and heuristic lessons had non-rivalrous features. That is, one firm’s use of the accumulated technical know-how did not reduce the amount available for any other firm also using it. There was no effective effort to exclude large numbers of firms from taking advantage of the accumulated industry know-how. The lack of excludability made it possible for non-rivalry to flourish. When no firm was excluded from using lessons, the lessons quickly became part of the non-rivalrous knowledge base. Consequently, there were (seemingly) no restrictions on how much of the accumulated technical lessons were used, so long as participants had access to technically skilled sources of information, which is common in markets with dispersed technical leadership.

The difference between the rivalrous features of some lessons is grounded in the type of lesson to which the features pertain. Specifically, this example does support a modified version of the commonly stated canard that "all ideas are public goods." Rather, *some* ideas are public goods, and, due to the market conditions for excludability, some are not. Complex business lessons, which spread slowly, did not exhibit the same link between non-rivalry and non-excludability that technical and heuristic lessons did. Some complex lessons were partially excludable for a short time. Even while technical information moved quickly between locations and firms, the ability of a firm to prevent direct rivals from imitating its business actions immediately slowed others from learning its business lessons. That slowed the speed with which the business lessons became part of the accumulated knowledge base.

Partial excludability has both benefits and drawbacks. Traditional economic analysis suggests that partial excludability nurtures economic experiments by increasing the returns from generating experiments. This analysis also illustrates an additional factor: excludability slows the spreading of lessons that supports further experiments, which, in turn, slows further experiments.

History does not allow one to learn what features of excludability would have nurtured the maximal rate of technical progress at a societal level. It is just not possible to know what would have happened had the situation been more extreme—with either full excludability or no excludability. As it was, this experience does demonstrate that during this period little or partial excludability can support quite rapid collective technical progress.

That historical accomplishment should not interfere with the key insight from examining benefits and drawbacks, however. On the one hand, by traditional economic reasoning, private incentives to engage in economic experiments were too low. There was no industry-wide market for the technical and heuristic industry-wide learning, certainly not for the lessons illustrated by failure, and occasionally not for many complex business lessons. That insight would support policies to encourage experimentation.

On the other hand, while that is so, it is does not necessarily support the introduction of formal intellectual property mechanisms for lessons affiliated with commercializing technology. It is tempting to make such a suggestion because in many circumstances contracting markets for economic experiments do not exist. However, while the introduction of such formal mechanisms may increase the ability of one party to appropriate returns from an idea, it also increases the extent of exclusionary behavior and, in turn, that would have slowed the spreading of lessons. Any gains in increased incentives on one margin might be removed from the losses from fewer lessons on which others build.

That open question about trade-offs suggests that policies for encouraging economic experiments must examine several margins simultaneously. To facilitate understanding of those margins we discuss next how several market and non-market institutions can encourage or discourage valuable experiments in markets with dispersed technical leadership. Specifically, we focus on episodes that arose in Internet access markets, and discuss several general lessons with the benefit of hindsight.

INSTITUTIONS THAT ENCOURAGE EXPERIMENTS

Contracting shapes the spread of lessons between different types of firms. Policy shapes contracting behavior in several different ways: by shaping the information available to those making a contracting agreement in advance of an experiment; by making it more difficult or easier to reach an agreement in advance even in the presence of good information; and by shaping behavior in the event that a successful experiment raises issues not otherwise covered by contract.

Such issues especially arise during standardization activities. As earlier noted, the very act of designing a standard can itself be an undirected experiment, as was the case with 802.11. This section highlights how standardization of a design may shape economic experiments in two other ways. Standards committees can provide a forum for different firms to present and argue for their product design features, thereby facilitating a confrontation between all the perspectives about where the value lies – prior to market experience that might reveal the veracity or falsehood of different perspectives. By then designing a standard, the committee has another effect: it alters the dimension along which firms will subsequently experiment. Once one aspect of a product is decided upon—once firms confront each other's views—firms must choose other ways to differentiate themselves from their competition, and they fashion their experiments accordingly.

Confrontation of views and standardization

In the first decade of the commercial Internet there were many institutions to facilitate standardization. Some were standards committees, such as those organized by the IEEE. Others took on that role as a primary activity, such as at the IETF (Internet Engineering Task Force), or W3C (World Wide Web Consortium). Still others were mandated by government regulatory action, such as actions at the Federal Communications Commission. Viewing these activities through the lens of economic experiments yield new perspective on how they contributed to the industry's growth and development.

For example, many of the economic experiments for ISPs occurred in the era when the FCC's (Federal Communications Commission) Computer II governed the relationship between telephone companies and third parties. In Computer II, the FCC drew a line between telephony and complementary services and standardized the technical interfaces between the regulated and unregulated parts of the network. It also classified some services as "enhanced," which freed these services from common carrier regulation and obligation, as well as freed the FCC from reviewing every new product design or new service proposal.[22]

The FCC concluded from their experience in competitive equipment markets that it needed to both (1) develop technical standardization of the interface between the regulated network and competitive market and (2) make this in a legally binding declaration rather than an informal policy with industry participants. In the competitive equipment markets, numerous legal and regulatory disputes slowed down the pace of entry and, by extension, the number and pace of economic experiments. By standardizing the interfaces between the

[22] The FCC initiated this regulatory framework in 1976 and set it in a (mostly) final form in 1982. As the commercial Internet began to blossom, the FCC was also beginning to put in place a regulatory framework known as Computer III, which allowed for more telephone company initiatives. For a history of these rules, see Cannon (2001), Goldstein (2005), or Neuchterlein and Weiser (2005).

regulated and unregulated parts of the network and freeing them of regulatory review, the FCC let multiple entrants pursue their economic experiments outside the frequent political considerations and legal fights inherent in regular regulatory activities.

In other words, the FCC nurtured economic experiments by committing to be *uninvolved* except in those disputes at the interface between the regulated monopolist and others. Hence, most firms did not involve regular intervention from decision makers in Washington D.C., as had been the case for entrepreneurial equipment initiatives decades earlier. Such standardization and development of Computer II enabled competitive activities to blossom, as in any competitive market, by limiting federal interference in some aspects of the industry. Computer II also had the subsequent consequence that supported robust economic experimentation in private equipment markets (e.g., servers, routers) and services (e.g., bulletin boards), which contributed to the innovative commercial Internet access industry in its earliest years. [23]

The passage of the 1996 Telecommunications Act borrowed many elements of the same framework, and initially the FCC and courts issued rulings kept the frameworks of Computer II and III in place. However, numerous other provisions in the Act introduced additional issues – over access charges, the rights for interconnection, and obligations of those supplying competitive alternatives. Resolving these issues eventually put Washington in every Internet access provider's radar screen, especially after late 1998.[24] These rulings over the next few years, combined with the end of the dot-com boom and a slowing in the growth in demand for access by new users, brought about a decline in entry of dial-up ISPs and a decline in the pace of learning.

It is also interesting to note the FCC's role in the birth of Wi-Fi and related wireless

[23] For further analysis of how these contributed to innovative behavior of market participants, see Greenstein (forthcoming).

[24] This statement necessarily simplifies a long and complex history. The first serious FCC rules concerned pricing for access of CLECs, so, arguably, the FCC was in every participant's radar screen immediately after the act passed. However, those decisions had huge consequences for competitive telephony, and affected the Internet to the extent that those policies supported CLEC growth. For ISPs and Internet access the first large change of federal policy at the FCC concerned the practice of "reciprical compensation" for CLECs, many of whom offered services to ISPs. This ruling was issued in early 1999, based on hearing held sooner than that. More broadly, other open issues concerned the extent to which the telecom meltdown of 1999 and the dot-com crash of 2000 were intertwined, and there are competing views about whether some or all of those events came about due to misrepresentation and fraud rather than errors in federal policy or court rulings. For various views, see e.g., Goldstein (2005), Sidek (2003), Neuchterlein and Weiser (2005).

products and services. These use unlicensed spectrum—one that is not designated for a single purpose when it is allocated, as is, for example, the television broadcasting spectrum. Once again, that standardization and legal declaration permitted experiments outside the range of plans and regulatory activities inside a federal agency.

Most forums for determining standards involved voluntary participation, and unlike government-issued standards, these committees issued standards that did not have the force of law behind them. These forums permitted firms with different views and forecasts (about the value of technology) to confront one another in advance of making expensive investments in new designs and the operations to support them. This included committees such as IEEE Committees or the IETF, where the writing of a standard required the writers to anticipate technical developments. Participation in these activities led skilled employees to learn about the activities of other employees at other firms.

Unrestricted communication between the academic observers and firms also facilitated these confrontations. The transparency of both the IETF and W3C facilitated much of this sharing. In addition, in the first decade of the commercial Internet many academics and managers at NSF retained an interest in fostering a healthy Internet access market, and, not having any reason to be secretive, shared their knowledge with others.

Notice that the emphasis is on transparency and non-exclusive access to knowledge, not on communal ownership, per se'. For example, Open Source projects, such as Apache, became established with the explicit purpose of helping firms share their technical advances with one another. In addition, these projects facilitated numerous informal channels through which users and vendors in different locales could share information—and thus the lessons they learned from economic experiments.

In a framework for economic experiments, the key features of these processes are (a) their transparency – where no decisions remain unexplained – and (b) their non-exclusive availability – where any person can access the results and repurpose the information for their own need. These facilitate the share of know-how between firms with dispersed motives for having that knowledge.[25]

[25] Sandvigs (2007) study of user-led innovation in wireless technologies further conditions that contribute, including (a) open, documented interfaces; and (b) a sub-culture of innovators. He also discusses several historical examples, compares them with contemporary examples, and looks at the contribution from other

Making policy for exclusion as lessons spread

Making policy for nurturing economic experiments after someone develops a key invention raises many challenges in practice. Consider the issues faced by the University of Illinois after it began a program of licensing the Mosaic browser in 1994. Placing an emphasis on economic experiments yields insights about why the diffusion of the browser could have evolved in many ways if policy about diffusion and excludability had taken different forms.

The University of Illinois could have chosen to diffuse the browser with a policy containing no exclusion. This could have involved not licensing at all, and letting the technology move out of the university at its own pace, as had been the norm at most universities decades earlier. Or, the university could have developed a licensing program with minimal fees and royalties and made it available to anyone, using the mechanisms of licensing to monitor use in a token way but not to make money. It also could have involved fostering an open source community around the browser. The earlier two policies had much precedence behind it, and the latter option arose a year later when Apache left the University.[26]

Instead, the university developed a licensing program aimed to make revenues off licensing this innovation to any taker. This program required the licensee to surrender some royalties in exchange for using Mosaic, and, indeed, as desired, it eventually generated several million dollars in fees. More to the point, the officially sanctioned channel was managed by a third party—a company known as Spyglass, also located in Champaign, which was given license to the technology and to the right to license the trademarked name "Mosaic."

The benefit to this format are not trivial: Spyglass had incentives to invest in

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facets, such as (a) rich or poor sets of data; (b) digital or analogue formats; (c) cheap or expensive communications, concluding that innovation arises even with the worse situation.

[26] "Arose" may be too strong a word. As the Apache founders make clear on their own web page, in February 1995 they sought to improve and coordinate further improvements to the NCSA server software, which had lost its key personnel. The NCSA tried to revive the software in April, but cooperated with the Apache effort. See http://httpd.apache.org/ABOUT_APACHE.html. Accessed March, 2007.

commercialization activities the NCSA (National Center for Super Computing Applications) – the center where it developed – would not undertake (or could not undertake, as they fell outside the scope of its mission), such as advertising, detailing, reprogramming, and active support for developers. The drawback was more subtle: it handed discretion to a single private firm about excluding others from using the knowledge through a license. While this drawback might seem minor on the surface, it was more of a potential problem here because the situation was not a green field setting. Millions of users had downloaded Mosaic by the spring of 1994, so the "idea" underlying a browser was already diffusing widely (for free), potentially inspiring many distinct experiments about how to alter it, use it, and, yes, even commercialize it.

Consequently, an issue arose when knowledge moved through an unofficial channel. As it happened, this second channel involved many of the student programmers—but none of the faculty or other administrators— who had conducted the experiments that led to the development of the Mosaic browser. Marc Andreeson, one of the students on the Mosaic project, had grabbed the attention of Jim Clark, known for starting Silicon-Graphics years earlier, and who had excellent established connections with the West Coast venture community. Their relationship coalesced into a business plan in the spring of 1994.

Spyglass decided they had to defend their intellectual property, principally the name *Mosaic*. Spyglass felt they had to discourage the unofficial channel, threatening to legally stop the new firm from calling itself *Mosaic Communications Company*. There was an additional question about whether the new firm was using original university property, such as the code written by the students at the university, though that question became mute due to a program of reengineering software from scratch.[27] These actions forced the new firm to change their name and in other respects alter their project, which distracted them from other issues the personnel wanted to urgently address. As it happened, the new firm changed their

[27] It appears that such reprogramming would have happened anyway, so it is unclear whether any ownership issues over code actually mattered for technical outcomes. For example, Spyglass also undertook such reprogamming because they believed it was necessary. It appears both parties wanted to reap benefits from creating a more efficient code, which contributed to long-term strategies. In practice, however, meeting such a requirement could have quite a hassle. See Cusumano and Yoffie (1998) or the account in Sink (2007).

name to Netscape, eventually went into direct competition with Spyglass,[28] and all the alumni from Illinois never lost their resentment for the legal hassles they managed during the early days of the firm.

On the one hand, these legal actions are understandable in light of having a licensing program: Prior licensees paid for the rights and future licensees – eventually, 120 in total – would have objected had the university/NCSA/Spyglass not tried to impose the same terms across the board on all licensees. That consideration would have held no matter who the licensee was, whether or not they were alumni. In addition, the setting was uncertain, so there was no obvious optimal strategy for favoring any licensee. In the late spring of 1994, it was not obvious which channel would yield the most value to society.

While those arguments have a grain of truth to them, they overlook the broader policy tension: the university did not have to commercialize its browser through this method in the first place. It could have simply let the browser diffuse and let any commercial firm imitate it. More to the point, by handing exclusive rights over to a third party the University and NCSA *de facto* gave Spyglass discretion to take action potentially at odds with one of the loftier grand missions of the University, namely, helping technology diffuse into society without exclusion. By protecting its licensees and its self-interest, Spyglass had to discourage another user for a new technology, albeit one that developed through a competing channel that eschewed use of the official university license.[29]

A retrospective bias sharpens the policy tension. Ultimately, Netscape's business model was wildly more successful than any other licensee's at catalyzing many other market participations. Hence, it appears the university's actions ended up raising obstacles and costs for the very project that catalyzed use of the technology more broadly in society. In other words, by choosing to license Mosaic to one sub-contractor, the university excluded some from experimenting with the technology. In this case that deterred rather than nurtured the

[28] As it turned out, both Spyglass and Netscape tried to engineer strategies in which they were "arms dealers" to others engaged in a war. However, each had a different conceptualization of how to build a platform with a browser at its core.

[29] As it turned out, Spyglass did license to any taker for the same terms, and this behavior ultimately led to the demise of the entire program. When Microsoft decided to make a browser, it licensed it through the formal channels from Spyglass for several million dollars, but later ran into an auditing dispute. Eventually the company paid Spyglass seven million dollars. Microsoft embedded the browser in its operating system and began multiple support activities for it, effectively killing the OEM business Spyglass had envisioned. In essense, therefore, Spyglass gained several million dollars but lost all its future business to one of its licensees. See Sink (2007).

very thing that helped society the most, running counter to the university's loftier mission.

This example illustrates the role that policy can have in shaping how lessons and know-how spread. The policy at the university caused the students to alter how they commercialized the know-how they had acquired from their own programming experiences at the university. In retrospect, society was fortunate that these actions turned out to be only a mild detour for Netscape and not a major blockade. In retrospect, it would have been in society's interest to pay the university far more than the revenue generated by Spyglass' licenses if the technology had been allowed to diffuse without any official licensing program and without impeding the student's' use of their know-how.

Policy for experiments involving incompatibilities

Many institutions attempt to resolve potential incompatibilities before they get embedded in commercial equipment. As was previously discussed, such issues played a large role in the events for wireless standards. Yet, despite such efforts, occasionally firms choose to conduct economic experiments with incompatible implementations of technologies. What, if anything, can policy makers do when this arises? Consider the policy lessons of the 56k modem war, a confrontation in which incompatibilities produced numerous costs and policy shaped outcomes in a favorable direction.[30]

The upgrade to 56K went through two phases. During the first phase, two branded technologies vied for use. Players in the modem industry fell into two camps, either with US Robotics which developed the X2[31], or with Rockwell Semiconductor which called their product K56Flex. Both camps signed up verbal "commitments" from a wide variety of ISPs and others. Both brought their product to market at essentially the same time, February 1997. Independent comparisons showed that the two technologies worked equally well, although there was significant variability across and between technologies depending on local

[30] Until early 1997, 33.6K was the fastest modem available for use with analog telephone lines. For numerous reasons it became technologically possible to raise modem speeds to 56K, which had a maximum of 53k in ideal conditions. Between 43k and 51k was more typical, depending on the quality of the line and switch. The concurrent development of the World Wide Web and the use of more graphics increased demand for faster Internet access, providing demand for 56K technology.
[31] This name referred to the fact that 56=28X2

connection characteristics. The two technologies were incompatible in the sense that a consumer with one standard that connected to an ISP with the other standard would receive data at only 28K or 33K.

The first phase lasted about a year and did not end well for anyone. The upgrade costs were much higher for some ISPs than for others, and the costs varied across standards. The ISPs often used complicated combinations of servers and consumer-grade modems from multiple vendors, so it was impossible to make a sweeping statement about the costs faced by every ISP. Many ISPs acted, but many chose not to upgrade at all. US Robotics had better name recognition among consumers, but this also was insufficient to determine the outcome. Users did not uniformly gravitate to one choice. Not only did the two technologies maintain relatively similar levels of ISP commitment, but overall sales were below what the market could have supported.

The second phase of deployment came after the intervention from the ITU, a quasi-government agency supported by the United Nations. User surveys and vendor surveys both showed that sales increased only after the ITU introduced a third standard, called the V.90. It was incompatible with both the X2 and Flex modems, though software patches allegedly permitted early adopters to upgrade. The new standard quickly gained market acceptance and industry sales grew, beginning to pick up around the winter of 1998.[32]

What did the ITU do? In this case the ITU's forums allowed parties to confront one another in a neutral setting. That permitted them to negotiate a settlement over a new design and over royalties. That did not guarantee an outcome would emerge, but by acting comparatively quickly—in record time, according to contemporary reports—the ITU nurtured a conversation that facilitated the compromise that moved events forward.

It is important to recognize why this compromise emerged and succeeded; it facilitated a confrontation between all the perspectives about where the value lies – after all, by this point parties had had some market experience. First, all parties learned from their market experience and were chastened by the prior failure to make sales as high as expected. That made management committed to working with the ITU to find a solution, which management believed (correctly, as it turned out) would help to generate more sales. In part this was because all participants anticipated that the ITU's endorsement would end confusion

[32] See Greenstein and Rysman (2007) for a full recounting.

in the US market. In part it had value for commercial prospects outside of U.S. markets, in which all the parties had an interest. Those markets had not yet grown. Second, the ITU employed the right people to negotiate between competing technical and commercial claims, forging an agreement that all parties could accept. Third, participants held a pessimistic view about the window for generating revenue. Everyone expected (incorrectly, as it turned out) that the market opportunity for 56k dial-up modems would disappear quickly in the face of rapidly diffusing broadband.[33]

This example shows how firms learned from different directed experiments, and the ITU's forum helped them resolve a dispute in light of what they learned. It let them share their learning, design a new product, and it changed the terms for competitive behavior. Indeed, there have several upgrades to the standard, reflecting additional learning since then, which is further evidence that all parties benefited from that agreement.

Contracting between interdependent services

Larger firms with more elastic budgets for product development and marketing can and do invest in a variety of experiments. For example, Intel's on-going investment in wireless standards is one of many investments in the wireless area. These investments come in several forms: Intel's direct support for employees who contribute to making new wireless designs; Intel's financial contributions to the organization that performs conformance testing; and Intel's financial backing of other firms (through its venture arm) that make use of the new designs in new equipment. Those investments come on top of pre-existing commitments to research in Intel's own laboratories to plan several generations of the wireless platform.

For related reasons, smaller and more entrepreneurial firms are more dependent on fluid markets for technical talent and on information from informal and formal channels for learning about comparatively accepted lessons among firms. Entrepreneurial firms have strong incentives to make alliances with the biggest and most successful venture capitalists when it enhances the ability to get access to informal channels. The best venture capitalists maintain access to short-term information about the rate and direction of technical change,

[33] For more on this, see Greenstein and Rysman (2007).

and they use that information to select among investments, shape their direction, and help small firms find buyers for their products or organizations.

Small firms also rely on many of the formal channels for information transmission. In that sense it is relevant that organizations differ in their reporting procedures from standards committees. For example, the ITU and the IEEE do not operate with the same procedures as those maintained by the IETF and W3C. It is well known that the presence of these later committees played a significant role in nurturing entrepreneurial entry in many Internet equipment and server markets, but what difference did their operating procedures make? According to this argument, small innovative firms benefited from the unprecedented transparency maintained by the IETF and W3C, which consequently encouraged the spread of know-how.

Where does that leave the question, What role can private contracting play in directing economic experiments? The answer hinges on two factors. Contracting is beneficial for those large firms with an array of directed economic experiments to undertake and for those small firms with access to intermediaries, such as venture capitalists, who can provide many of the same services. Both factors favor established firms. In some cases, the action of venture capitalists contributes to activities of a firm like Netscape, which aimed to compete directly with an incumbent firm, Microsoft. More often than not, however, the experimental aims of large and forward-looking firms are supported by the direction of experiments by small firms. Google, AOL, Microsoft, Yahoo!, and many other firms regularly consider buying small entrepreneurial firms with promising prototypes or demonstrated success.

This line of reasoning also suggests the setting in which contracting tends to have difficulties, which is an area where policy shapes outcomes. Specifically, it has difficulties in environments where contracting fails generally, as when there are many important externalities. The examples of this essay illustrated several such externalities. The most common externalities arose between providers of complements and it involved inter-temporal issues.

In a network where many participants make complementary services, as in the Internet, some externalities potentially arise because young firms conducting experiments cannot easily prearrange contracts with existing firms prior to their commercial success. Contracting in advance of these experiments may not be in the experimenter’s interest. The act of negotiating (with a carrier, another portal, a cache' firm such as Akamai, etc.) would give away too many secrets about what the firms were attempting to do. It may also involve lengthy and costly negotiation over many potential contingencies, either revealing too much to the large firm about a young firm's strategic thinking or simply lead to long delays that lower the viability strategies based on moving quickly.[34]

For example, You-Tube, MySpace, and Facebook all recently cut their teeth in the vast unorganized jungle of the Internet. Now each has tens of millions of users. Nobody saw that success coming except the owners, Webmasters, and a few lucky investors. None of those founders openly stated their plans in advance, and it would not have served their interest to do so, for fear that others would hear the idea and implement it earlier.

Now each of these firms faces numerous contracting issues with other stake-holders in Internet commerce. None of these issues would have, or could have been resolved with contracting in advance. Yet, post-innovation negotiation between parties now cannot be avoided. Most Internet access firms have to do business with one another in the network—in this case, because the experiment succeeded. In other words, once You-Tube began to grow, its success became intertwined with the interests of many other large firms, such as search engines, data carriers, and copyright holders. In summary, there would have been no way to contract in advance of these issues with all these parties.

In an era of common carrier regulation, managers could anticipate the set of rules to which disputes would default. It is interesting to note that the new era in the United States is defined by the *Brand-X* decision, in which common carrier regulation and obligations do not apply to operators of broadband facilities, as they did a decade earlier. It is much less clear what legal constraints, if any, apply to broadband firms and their negotiations with entrepreneurial firms. It is even less clear how this shapes the learning at entrepreneurial firms.

Stated broadly, there is an open question about factors encouraging entrepreneurship in the absence of a clear default for resolving disputes that arise after an entrepreneur has experienced success. This issue takes on importance because recent economic experiments continue to emerge from unexpected places, which suggests that the regulatory rules will

[34] For more on the types of difficulties that might shape negotiations before commercialization, see Gans and Stern (2003).

continue to matter in resolving those disputes. Moreover, after the Brand-X decision, it is no longer clear to any participant other than a few overconfident experts in telecommunications law what set of regulatory rules will—or, perhaps, even should—govern negotiation between regulated and unregulated firms in access markets.

Summary

The intertwining of directed and undirected economic experiments shaped the growth of the Internet access network in the United States. This market involved more than merely experiments with inventing technology and building on those inventions. Developing this market involved experiments in the commercialization of the technology, as firms tried discover value through attempts at a wide variety of combinations of pricing, product lines, and scales of operation. Many firms were motivated to undertake these experiments when they responded to new information about user demand, demonstrations of new applications, tangible market experience, vendor reactions to new market situations, and other events that they could not forecast but which yielded useful insights about the most efficient business actions to generate value.

Economic experiments pervaded a wide range of activities. Firms were learning about customer responses they could not fully imagine, using experiences to understand how to refine key business decisions, and deliberately learning through trial and error in market experience what could not be learned in a laboratory. In short, that learning led firms to change what they did. Economic experiments altered many business plans, such as investments in equipment design and distribution, as well as marketing campaigns. It supported rapid technical and commercial progress on an industry wide basis.

While this essay focused on a specific market during a specific time period, those events illustrate a broad array of concepts about how economic experiments shape behavior. Among the broad lessons are these: Both direct and undirected economic experiments yield lessons. The spreading of a lesson changes its role. When the lesson is codified into routines and embedded within an industry, the lesson has become part of an industry's accumulated knowledge base, a.k.a. its know-how. Firms take it for granted when it is part of know-how.

A lesson is still valuable in that second role because the entire knowledge base seeds and supports more experiments. Almost by definition, in a market with dispersed technical leadership, the accumulated set of lessons contains more lessons than any single firm could have learned on its own.

This viewpoint has implications for the design of policies for markets where economic experiments prevail. Regulatory rules, standardization activities, and open source communities shape the accumulation and spread of know-how, which, in turn, shapes the next level of experiments founded on the previous know-how. In a framework for economic experiments, transparency and lack of excludability are key features of institutions. These facilitate the sharing of know-how between firms. In addition, placing an emphasis on economic experiments yields insights about why the evolution of an industry could have evolved in many ways if policy about diffusion and excludability of new technology had taken different forms.

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