$$\pi_i = D(p)(p_i - c_i).$$

The first-order condition for firm i is given by

$$\frac{d\pi_i}{dp_i} = D(p) + D'(p)(p_i - c_i) = 0.$$

Adding up across all i gives

$$D(p)N + D'(p)\sum_{i=1}^{N}(p_i - c_i) = 0.$$

which can be rewritten as

$$\sum_{i=1}^{N}\frac{(p_i - c_i)}{p} = -\frac{D(p)}{pD'(p)}N.$$

Using the definition of the elasticity of demand, and the fact that $p = \alpha + \sum_{i=1}^{N} p_i$, we have

$$\frac{p - (\alpha + \sum_{i=1}^{N} c_i)}{p} = \frac{N}{\varepsilon}. \quad (1)$$

In other words, the percentage markup over cost for the product in question is equal to N times the inverse of the elasticity of demand. In contrast, the standard monopoly markup rule would be

$$\frac{p - (\alpha + \sum_{i=1}^{N} c_i)}{p} = \frac{1}{\varepsilon}. \quad (2)$$

The markup with N independent firms controlling key patents is equal to N times the monopoly markup.

It can be shown that the combined profits of the N firms under independent pricing is lower than would be earned by a monopolist selling all N components. This implies that the firms have an incentive to coordinate their pricing. A package license for all N components would lead to higher (combined) profits and lower prices for consumers.

5

Commercialization of the Internet: The Interaction of Public Policy and Private Choices or Why Introducing the Market Worked So Well

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Executive Summary

Why did commercialization of the Internet go so well? This paper examines events in the Internet access market as a window on this broad question. The study emphasizes four themes. First, commercializing Internet access did not give rise to many of the anticipated technical and operational challenges. Entrepreneurs quickly learned that the Internet access business was commercially feasible. Second, Internet access was malleable as a technology and as an economic unit. Third, privatization fostered attempts to adapt the technology in new uses, new locations, new market settings, new applications and in conjunction with other lines of business. These went beyond what anyone would have forecast by examining the uses for the technology prior to 1992. Fourth, and not trivially, the NSF was lucky in one specific sense. The Internet access industry commercialized at a propitious moment, at the same time as the growth of an enormous new technological opportunity, the World Wide Web. As it turned out, the web thrived under market oriented, decentralized, and independent decision making. The paper draws lessons for policies governing the commercialization of other government managed technologies and for the Internet access market moving forward.

I. Motivation

The "commercialization of the Internet" is shorthand for three nearly simultaneous events: the removal of restrictions by the National Science Foundation (NSF) over use of the Internet for commercial purposes, the browser wars initiated by the founding of Netscape, and the rapid entry of tens of thousands of firms into commercial ventures using technologies which employ the suite of TCP/IP standards. These events culminated years of work at NSF to transfer the Internet into commercial hands from its exclusive use for research activity in government funded laboratories and universities.

Sufficient time has passed to begin to evaluate how the market performed after commercialization. Such an evaluation is worth doing. Actual events have surpassed the forecasts of the most optimistic managers at NSF. Was this due to mere good fortune or something systematic whose lessons illuminate the market today? Other government managed technologies usually face vexing technical and commercial challenges that prevent the technology from diffusing quickly, if at all. Can we draw lessons from this episode for the commercialization of other government managed technologies?

In that spirit, this paper examines the Internet access market and one set of actors, Internet Service Providers (ISPs). ISPs provide Internet access for most of the households and business users in the country (NTIA 1999), usually for a fee or, more recently, in exchange for advertising. Depending on the user facilities, whether it is a business or a personal residence, access can involve dial-up to a local number or 1-800 number at different speeds, or direct access to the user's server employing one of several high speed access technologies. The largest ISP in the United States today is America-On-Line, to which approximately half the households in the U.S. subscribe. There also are many national ISPs with recognizable names, such as AT&T Worldnet, MCI WorldCom/UUNet, Mindspring/Earthlink, and PSINet, as well as thousands of smaller regional ISPs.

The Internet access market is a good case to examine. Facilities for similar activity existed prior to commercialization, but there was reason to expect a problematic migration into commercial use. This activity appeared to possess idiosyncratic technical features and uneconomic operational procedures which made it unsuitable in other settings. The Internet's exclusive use by academics and researchers fostered cautious predictions that unanticipated problems would abound and commercial demand might not materialize.

In sharp contrast to cautious expectations, however, the ISP market displayed three extraordinary features. For one, this market grew *rapidly*, attracting thousands of entrants and many users, quickly achieving mass-market status. Second, firms offering this service became *nearly geographically pervasive*, a diffusion pattern rarely found in new infrastructure markets. And third, firms *did not settle* on a standard menu of services to offer, indicative of new commercial opportunities and also a lack of consensus about the optimal business model for this opportunity. Aside from defying expectations, all three traits—rapid growth, geographic pervasiveness, and the absence of settlement—do not inherently go together in most markets. The presence of restructuring should have interfered with rapid growth and geographic expansion. So explaining this market experience is also interesting in its own right.

What happened to make commercialization go so well? This paper's examination reveals four themes. First, commercialization did not give rise to many of the anticipated technical and operational challenges. Entrepreneurs quickly learned that the Internet access business was commercially feasible. This happened for a variety of economic reasons. ISPs began offering commercial service after making only incremental changes to familiar operating procedures borrowed from the academic setting. It was technically easy to collect revenue at what used to be the gateway functions of academic modem pools. Moreover, the academic model of Internet access migrated into commercial operation without any additional new equipment suppliers.

Second, Internet access was malleable as a technology and as an economic unit. This is because the foundation for Internet interconnectivity, TCP/IP, is not a single invention, diffusing across time and space without changing form. Instead, it is embedded in equipment that uses a suite of communication technologies, protocols, and standards for networking between computers. This technology obtains economic value in combination with complementary invention, investment, and equipment. While commercialization did give rise to restructuring of Internet access to suit commercial users, the restructuring did not stand in the way of diffusion, nor interfere with the initial growth of demand.

Third, privatizing Internet access fostered customizing Internet access technology to a wide variety of locations, circumstances, and users. As it turned out, the predominant business model was feasible at small scale and, thus, at low levels of demand. This meant that the technology was commercially viable at low densities of population, whether or not it was part of a national branded service or a local geographically concentrated service. Thus, privatization transferred the operation of the technology to a new set of decision makers who had new ideas about what could be done with it. Since experimentation was not costly, this enabled attempts to adapt the technology in new uses, new locations, new market settings, new applications, and in conjunction with other lines of business. While many of these attempts failed, a large number of them also succeeded. These successes went well beyond what anyone would have forecast by examining the limited uses for the technology by noncommercial users prior to 1992.

Fourth, and not trivially, the NSF was lucky in a particular sense of the word. It enabled the commercialization of the Internet access industry at a propitious moment, at the same time as the growth of an enormous new technological opportunity, the World Wide Web. This invention motivated further experimentation to take advantage of the new opportunity, that, as it turned out, thrived under market oriented and decentralized decision making.

The paper first develops these themes. Then it describes recent experience. It ends by discussing how these themes continue to resonate today.

II. Challenges During Technology Transfer: An Overview

Conventional approaches to technological development led most observers in 1992 to be cautious about the commercialization of the Internet. To understand how this prediction went awry, it is important to understand its foundations.

Many studies of the commercialization of technology emphasize the situated nature of technological development. Technologies do not simply spring out of the ether; instead, learning processes and adaptation behavior shape them. Users and suppliers routinely tailor technologies to short term needs, making decisions that reflect temporary price schedules or idiosyncratic preferences, resulting in technological outcomes that can only be understood in terms of these unique circumstances and origins.[1] Such themes resonate throughout studies of technologies which develop under government management.[2]

Seen through this light, the most problematic feature of the Internet was its long exclusive use by military, government, or academic users. Prior to 1992 it had developed into the operations found at an academic modem pool or research center. These were small scale operations, typically serving no more than several hundred users, involving a mix of frontier and routine hardware and software. A small operation required a server to monitor traffic and act as a gatekeeper, a router to direct traffic between the Internet and users at PCs within a local-area-network (LAN) or calling center, and a connection to the Internet backbone or data exchange point operated by the NSF. These were often run by a small staff, either students or information technology professionals.

Revenues were not regularly collected in these arrangements and budgetary constraints were not representative of what might arise with

commercial operations and competitive pressures. Many small colleges had opened their Internet connections with NSF subsidies. The organizational arrangement within research computing centers also was idiosyncratic, usually with only loose ties, if any, to the professionally run administrative computing centers of a university or research organization. The array of services matched the needs of academic or research computing, which had only a partial overlap with the needs of commercial users.

Any student of technology transfer would have confidently predicted that the transition into commercial markets would give rise to challenges. Standing in 1992 and looking forward, it was uncertain whether these challenges would take a long time to solve and whether commercial users' needs would be difficult to address. In general, conventional analysis anticipates one of three challenges: *technical, commercial,* and *structural challenges.*

Technical challenges often arise during commercialization. Government users, government procurement, and government subsidies result in technology with many features mismatched to commercial needs. Products possessed features for which vendors or users have no need. Alternatively, commercial vendors and users do need other features. Thus, as a technical or engineering matter, a technology which is mature for exclusive noncommercial uses—such as a military application—may appear primitive in civilian use. It may require complementary inventions to become commercially viable. If these requirements are considerable, then commercialization may occur slowly.

For example, military users frequently require electronic components to meet specifications that suit the component to battle conditions. Extensive technical progress is needed to tailor a product design to meet these requirements. Yet, and this is difficult to anticipate prior to commercialization, an *additional* amount of invention is often needed to bring its manufacturing to a price/point with features that meet more cost-conscious or less technically stringent commercial requirements.

Commercial challenges arise when commercial markets require substantial adaptation of operation and business processes in order to put technologies into use. In other words, government users or users in a research environment often tolerate operational processes that do not translate profitably to commercial environments. After a technology transfers out of government sponsorship, it may not be clear how to balance costs and revenues for technologies that had developed under settings with substantial subsidies underwriting losses, and research goals justifying expenditures. Hence, many government managed technologies require considerable experimentation with business models before they begin to grow, if they grow at all.

For example, the supersonic transport actually met its engineering targets, but still failed to satisfy basic operational economics in most settings. Being technically sleek was insufficient to attract enough interest to generate the revenue to cover operating costs on any but a small set of routes. No amount of operational innovations and marketing campaigns were able to overcome these commercial problems.

New technologies are also vulnerable to *structural challenges* that impede pathways to commercialization. Commercial and structural challenges are not necessarily distinct, though the latter are typically more complex. Structural challenges are those that require change to the bundle of services offered, change to the boundary of the firms offering or using the new technology, or dramatic change to the operational structure of the service organization. These challenges arise because technologies developed under government auspices may presume implementation at a particular scale or with a set of technical standards, but require a different set of organizational arrangements to support commercial applications.

For example, while many organizations provided the technical advances necessary for scientific computing in academic settings during the 1950s, very few of these same firms migrated into supporting large customer bases among business users. As it turned out, the required changes were too dramatic for many companies to make. The structure of the support and sales organization were very different, and so too were the product designs. Of course, the few who successfully made the transition to commercial users, such as IBM, did quite well, but doing so required overcoming considerable obstacles.

In summary, conventional analysis forecasts that migrating Internet access into commercial use would engender technical, commercial, and structural challenges. Why did the migration proceed so different from what was expected?

III. The Absence of Challenge in the Internet Access Industry

An ISP is a commercial firm that provides access, maintains it for a fee, and develops related applications as users require. While sometimes this is all they do, with business users they often do much more. Sometimes ISPs do simple things such as filtering. Sometimes it involves managing and designing e-mail accounts, databases, and web pages. Some ISPs label this activity consulting and charge for it separately; others do not consider it distinct from the normal operation of the Internet access services.

On the surface the record of achievement for ISPs is quite remarkable. Most recent surveys show that no more than 10% of U.S. households get their Internet access from university sponsored Internet access providers, the predominant provider of such access prior to commercialization. Today almost all users go to a commercial provider (Clemente 1998, Nie and Ebring 2000). As of 1997, this ISP industry was somewhere between a three and five billion dollar industry (Maloff 1997), and it is projected to be much larger in a few years.

By the end of the century the ISP market had obtained a remarkable structure. One firm, America On-Line, provided access to close to half the households in the U.S. market, while several score of other ISPs provided access to millions of households and businesses on a nationwide basis. Thousands of ISPs also provided access for limited geographic areas, such as one city or region. Such small ISPs accounted for roughly a quarter of household use and another fraction of business use.

Technical Challenges Did Not Get in the Way

The Internet access market did suffer from some technical challenges, but not enough to prevent rapid diffusion. Commercialization induced considerable technical innovation in complementary inventive activities. Much of this innovative activity became associated with developing new applications for existing users and new users.

It is often forgotten that when the electronic commerce first developed based on TCP/IP standards, it was relatively mature in some applications, such as e-mail and file transfers, which were the most popular applications (these programs continue to be the most popular today, NTIA 1999). To be sure, TCP/IP based programs were weak in other areas, such as commercial database and software applications for business use, but those uses did not necessarily have to come immediately. The invention of the World Wide Web in the early 1990s further stretched the possibilities for potential applications and highlighted these weaknesses.

More important for the initial diffusion, little technical invention was required for commercial vendors to put this technology into initial mainstream use. Academic modem pools and computing centers tended to use technologies similar to their civilian counterparts—such as bulletin board operators—while buying most equipment from commercial suppliers. Moving this activity into the mainstream commercial sector did not necessitate building a whole new Internet equipment industry; it was already there, supplying goods and services to the universities and to home PC users. Similarly, much of the software continued to be useful—that is, Unix systems, the gatekeeping software, and the basic communication protocols. Indeed, every version of Unix software had been TPC/IP compatible for many years due to Department of Defense requirements. A simple commercial operation only needed to add a billing component to the gatekeeping software to turn an academic modem pool into a rudimentary commercial operation.

Technical information about these operations was easy to obtain if one had sufficient technical background; a BA in basic electrical engineering or computer science was far more than adequate. Many ISP entrepreneurs had used the technology as students or in related lines of business. Descriptions of some of the earliest access operations show that they did not employ any exotic hardware or rare technologies (Kalakota and Whinston 1996, Kolstad 1998). Many Internet bulletin boards quickly developed and Boardwatch Magazine, among others, expanded its focus from bulletin boards to ISP as early as 1994, also spreading information about how to operate such ventures. Several vendor associations, such as the Commercial Internet Exchange, were formed and also served as information sources.

Users with investments in networking technology, such as LANs or simple client/server architectures, also could adopt basic features with little further invention. Internet technologies associated with textual information had incubated for 20 years and were well past the necessary degree of technical maturity necessary for mainstream use. Telnet, FTP, and the basic protocols for e-mail were widely diffused and relatively easy to use. Some communication software already used TCP/IP and many of the common programs could easily adapt to it. There were already many similar technical activities taking place in commercial settings. TCP/IP compatibility was built into Windows 95, which further eased investments for users after 1995.

The basic commercial transaction for Internet access also did not raise prohibitive technical issues. Most often it involved repetitious and ongoing transactions between vendor and user. A singular transaction arose when the vendor performed one activity, setting up Internet access or attaching Internet access to an existing computing network. If the ISP also operated the access for the user, then this ongoing operation provided frequent contact between the user and vendor, and it provided frequent opportunity for the vendor to change the delivery of services in response to changes in technology and changes in user needs. This worked well because in many cases an ISP was better educated about the technological capabilities than the user. In effect, the ISP sold that general knowledge to the user in some form that customized it to the particular needs and requirements of the user. At its simplest level, this provided users with their first exposure to a new technological possibility while educating them about its potential.

Often access went beyond exposure to the Internet, especially with a business user, and included the installation, maintenance, and training, as well as application development. These types of transfers of knowledge typically involved a great deal of nuance, often escaped attention, and yet were essential to developing infrastructure markets as an ongoing and valuable economic activity. The basic technical know-how did not differ greatly from routine knowledge found in the computing services sector prior to commercialization.

Finally, some NSF decisions and legacy regulatory decisions also aided. When the NSF took over stewardship of the Internet backbone, it invested in developing a scalable system of address tables and IP-address systems. Subsequent growth tested those investments and inventions; no surprising problems were found, nor did any engineering problems hinder growth. Domain name registration also remained a gentle monopoly until recently. Data exchange points remained organized around the cooperative engineering principles used within the NSF days. A competitive data communications industry was beginning to reach adolescence at about the same time as commercialization and provided additional access points for new firms, particularly in urban areas. So as a technical matter, interconnection with the public switch network did not pose any significant engineering challenges (Werbach 1997).

Commercial Challenges Did Not Slow Diffusion

Internet access was built in an extremely decentralized market environment. Aside from the loosely coordinated use of a few de facto standards (such as the World Wide Web consortium) government mandates after commercialization were fairly minimal. ISPs had little guidance or restrictions. They were therefore able to tailor their offerings to local market conditions and to follow entrepreneurial hunches about growing demand.

As a technical matter, there were few barriers to entry in the provision of dial-up access. As a result, commercial factors, and not the distribution of technical knowledge among providers, largely determined the patterns of development of the basic dial-up access market immediately after commercialization. To the surprise of many, the operational procedures developed over two decades lent themselves to the early commercial implementations, fostering a foundation for commercial growth. As with many new markets which spawn in noncommercial environments (Ventresca et al. 1998), many features were borrowed wholesale and without question. In effect, entrepreneurs borrowed the organization of the academic modem pool and tried to put a revenue generating function on top of it. Billing software was added to the basic gateway component, and once this proved to be a feasible way to collect revenue, many entrepreneurs built on top of that commercial form.

Shortly after commercialization in 1994, only a few commercial enterprises offered national dial-up networks with Internet access, mostly targeting the major urban areas. Pricing was not standardized and varied widely (Boardwatch 1994–1995). Most of these ISPs were devoted to recreating the type of network found in academic settings or modifying a commercial bulletin board with the addition of backbone connections, so interconnection among these firms did not raise insoluble contracting or governance problems. These ISPs were devoted primarily to dial-up; few ISPs attempted sophisticated data transport over higher speed lines, where the regulatory issues could be more complex and where local exchange competitors were developing the nascent market.

Very quickly ISPs learned that low cost delivery required locating access facilities close to customers. This had to do with telephony pricing policies across the U.S. The U.S. telephone system has one pervasive feature; distance-sensitive pricing at the local level. In virtually every part of the country, phone calls over significant distances (i.e., more than 30 miles) engender per minute expenses, but local calls are usually free. Hence, Internet access providers had a strong interest in reducing expenses to users by providing local coverage. Unmet local demand was a commercial opportunity for an entrepreneurial ISP.

As it turned out, access over dial-up lent itself to small scale commercial implementations. Several hundred customers could generate enough revenue to support physical facilities and a high-speed backbone connection in one location, so scale economies were not very binding. The marginal costs of providing dial-up services were low and the marginal costs of expansion also fell quickly, as remote monitoring technology made it cheap to open remote facilities. The marginal costs to users of dial-up service were also low in response, involving only incremental changes for organizations that had experience with PC use or LAN technology. It was easy to generate revenue in subscription models, where a commercial firm withheld availability of access unless payment was made. Hence, the economic thresholds for commercial dial-up service turned out to be feasible on a very small scale, encouraging small firms and independent ISPs. To be sure, many firms also tried to implement access businesses on a large scale, but the economic advantage of large scale did not preclude the entry of small scale firms, at least not at first.

Finally, decades of debate in telephony had already clarified many regulatory rules for interconnection with the public switch network, eliminating some potential local delays in implementing this technology on a small scale. The FCC treated ISPs as an enhanced service, not passing on access charges to them as if they were competitive telephone companies, effectively making it cheaper and administratively easier to be an ISP. This decision did not receive much notice at the time since most insiders did not anticipate the extent of the growth that would arise. As ISPs have grown and as they threaten to become competitive voice carriers, these interconnection regulations have come under more scrutiny (Sidek and Spulber 1998, Weinberg 1999).[3]

In retrospect, two key events of 1995 set the stage for the commercial ISP market for the remainder of the decade. The first was the Netscape IPO in August 1995. The other was the entry of AT&T World Net.

The World Wide Web was known in the academic community in the early 1990s. It began to diffuse prior to commercialization and accelerated with Mosaic, a prototype browser developed at the University of Illinois. Many ISPs included Mosaic on their systems. Despite licensing the technology to many firms, the University of Illinois did not generate as much excitement as the Netscape IPO, which brought extensive publicity to the new technology (Cusumano and Yoffie 1998). The subsequent browser wars further heightened this awareness.

The emergence of the web changed the commercial opportunities for ISPs. ISPs found themselves both providing a traditional service in demand, text-based applications such as e-mail, and trying to position themselves for a new service, web applications. This new opportunity provided strong incentives to grow and experiment with new business models and new lines of service. It also induced considerable new entry. While not all markets experienced the same type of competitive choices, nor did all ISPs see the same opportunities, many private firms found ways to develop opportunities quickly, learning lessons that they then applied in other localities.

AT&T's entry was also important but its actions mattered because of what did not happen rather than what did. AT&T developed a nationwide Internet access service, which was available in much of the country, opening with as large a geographic spread as any other contemporary national provider. It also grew quickly, acquiring one million customers with heavy publicity and marketing. This growth depended on the strength of its promise to be reliable, competitively priced, and easy to use. It was deliberately aimed at households, and provided a mass-market service from a name brand. It was a commercial success, to be sure, but that was all. It was not a huge or dominant success, nor did it initiate a shakeout or restructuring of the market for ISP service.

Here was a branded, nationwide, professionally operated subscription model of ISP service, opening with as large a geographic spread as any other contemporary national provider. Yet, it did not end the growth of others, such as AOL, nor did it stop new entry of small firms, such as Mindspring, nor did it initiate a trend toward consolidation around a few national branded ISP services. In other words, even with its deep pockets AT&T did not dominate the offerings from all other firms, nor did it end the restructuring of the access business. This defied many predictions about how this market would be structured, further encouraging the decentralized growth and the emergence of independent ISPs.

Growth and entry brought about extraordinary results. Downes and Greenstein (1998) have constructed maps that illustrate the density of location of ISPs at the county level for the fall of 1996 and 1998; black and white versions of these are shown in figures 5.1 and 5.2.[4] For color versions see, respectively: http://www.kellogg.nwu.edu/faculty/greenstein/images/htm/Research/Maps/mapsep1.pdf and http://www.kellogg.nwu.edu/faculty/greenstein/images/htm/Research/Maps/mapoct98.pdf.

Colored areas are countries with providers. White areas have none. As the maps show, ISPs tend to locate in all the major population cen-

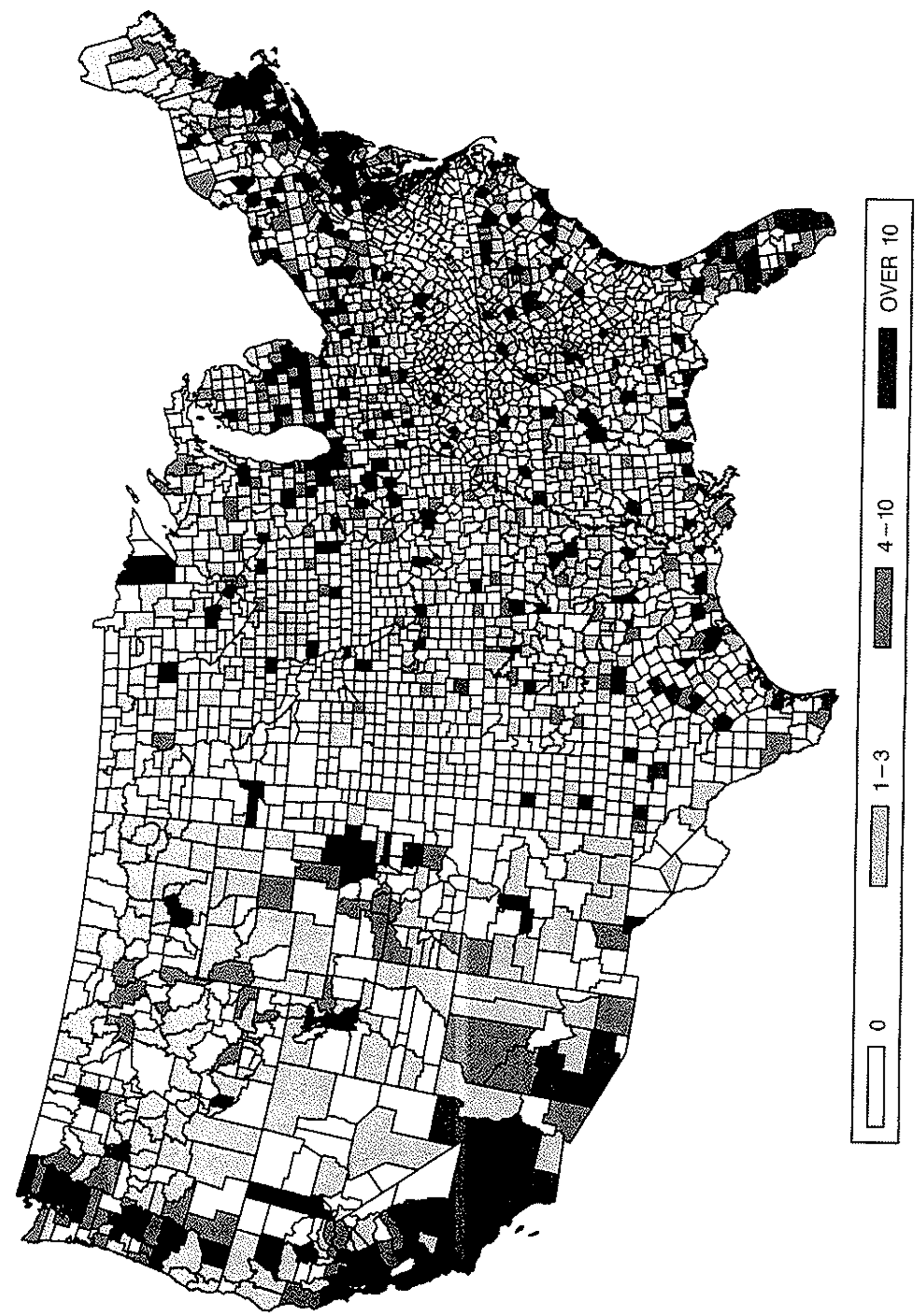

Figure 5.1
Distribution of ISPs September 1996

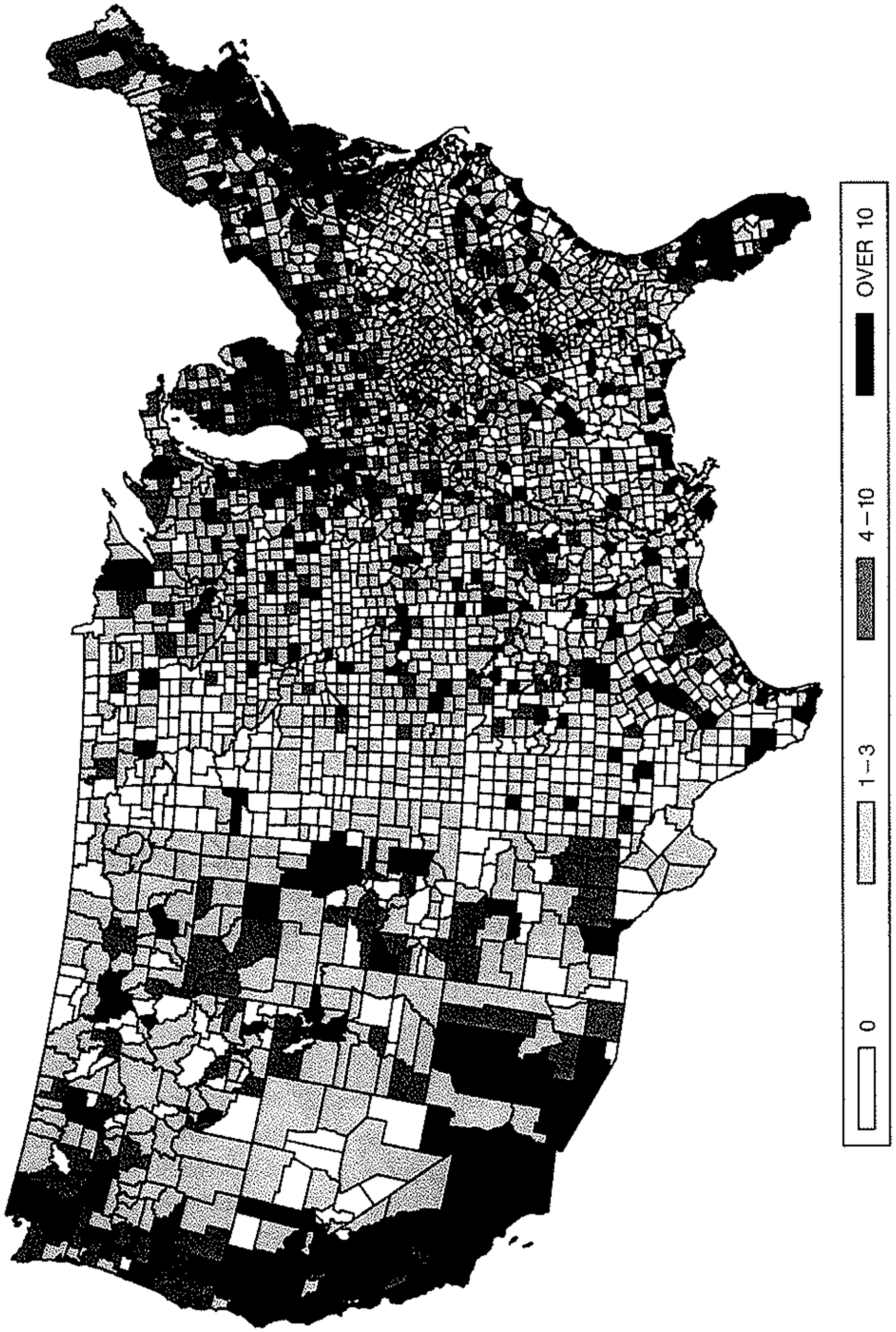

Figure 5.2
Distribution of ISPs October 1998
Copyright © 1998 Tom Downes and Shane Greenstein.

ters, but there are also plenty of providers in rural areas. The maps also illustrate the importance of changes over time. Many of the areas that had no coverage in the fall of 1996 were covered by the fall of 1998. Many of the areas that had competitive access markets in the early period were extraordinarily competitive in the latter period.

Downes and Greenstein (1998) show that more than 92% of the U.S. population had access by a short local phone call to seven or more ISPs by 1998. No more than 5% did not have any access. Almost certainly the true percentage of the population without access to a competitive dial-up market is much lower than 5%. In other words, with the notable exception of some low-density areas, ISP service was quickly available everywhere. To put it simply, among the vast majority of the U.S. population in urban and suburban areas, lack of use was primarily due to demand factors, not the absence of supply.

An unexpected pattern accompanied this rapid growth in geographic coverage. First, the number of firms maintaining national and regional networks increased over the 2 years. In 1996, most of the national firms were recognizable; they were such firms as IBM, AT&T, and other established firms who entered the ISP business as a secondary part of their existing services, such as providing data services to large corporate clients. AOL, CompuServe, and Prodigy all were in the process of converting their online service, previously run more like bulletin boards than ISPs, into Internet providers. By 1998, many entrepreneurial firms maintained national networks and few of these new firms were recognizable to anyone other than an industry expert.

There was also a clear dichotomy for growth paths of entrepreneurial firms who became national and regional firms. National firms grow geographically by starting with major cities across the country and then progressively moving to cities of smaller populations. Firms with a regional focus grow into geographically contiguous areas, seemingly irrespective of urban or rural features.[5]

Most of the coverage in rural areas comes from local firms. In 1996, the providers in rural counties with under 50,000 population were overwhelmingly local or regional. Only for populations of 50,000 or above do national firms begin to appear. In the fall of 1998, the equivalent figures were 30,000 or lower, indicating that some national firms had moved into slightly smaller areas and less dense geographic locations. In other words, Internet access in small rural towns is largely done by local or regional providers, with national firms only slowly expanding into similar territory.

It appears as if it does not pay for many large national providers to provide dial-up service for the rural areas whereas many small local firms in other lines of business (e.g., local PC retailing) can afford to add Internet access to their existing business. It may also be the case that the local firm may have an easier time customizing the Internet access business to the unique needs of a set of users in a rural setting.

What Structural Challenges Arose?

Commercialization of the Internet created an economic and business opportunity for providing access. The costs of entry into low quality dial-up access were low, and commercially oriented firms filled voids in specific places. For any firm with national ambitions, coverage of the top 50 to 100 cities in the U.S. was a fleeting advantage and quickly become a necessity for doing business. For any local or regional firm in an urban market, many competitors arose.

Yet, not long after the Netscape IPO the ISP industry began to enter a second phase. Profitability and survival involved more than geographic expansion. It involved bringing ISP service to the households and businesses with PCs, but without access. It also involved expanding into services which took advantage of new opportunities associated with the web.

Understanding this second phase requires an understanding of the services ISPs offer other than basic access and how those began to evolve. These new services include one of several activities: monitoring technical developments, distilling new information into components that are meaningful to unfamiliar users, and matching unique user needs to one of many new possible solutions enabled by advancing technical frontiers. Sometimes it includes heavy use of the technological frontier and sometimes not. In general, it depends on the users, their circumstances, their background, their capital investments, the costs of adjusting to new services, and other factors that influence the match between user needs and technological possibilities.

ISPs commercialized their adaptive role by offering new services that can be grouped into five broad categories: networking, hosting, web page design, basic access, and frontier access (see the appendix of Greenstein 1999 for precise definitions).

Networking involves activities associated with enabling Internet technology at a user's location. All ISPs do a minimal amount of this as

part of their basic service in establishing connectivity. However, an extensive array of these services, such as regular maintenance, assessment of facilities, emergency repair, and so on, are often essential to keeping and retaining business customers. Note, as well, that some of these services could have been in existence prior to the diffusion of Internet access.

Hosting is typically geared toward a business customer, especially those establishing virtual retailing sites. This requires the ISP to store and maintain information for its access customers on the ISP's servers. All ISPs do a minimal amount of hosting as part of basic service, even for residential customers (e.g., for e-mail). However, some ISPs differentiate themselves by providing an extensive array of hosting services, including credit card processing, site analysis tools, and so on.

Web design may be geared toward either the home or business user. Again, many ISPs offer some passive assistance or help pages on web page design and access. However, some offer additional extensive consulting services, design custom sites for their users, and provide services associated with design tools and web development programs. Most charge fees for the additional services.

Basic access constitutes any service as slow as or slower than a T-1 line. Many of the technologies inherited from the precommercial days became standard parts of basic access and were not regarded as a new service. A number of other new functions, such as audio streaming, filtering, and linking, also gradually became standard parts of most firms' offerings. Frontier access includes any access faster than a T-1 line, which is becoming the norm for business access. It also includes ISPs that offer direct access for resale to other ISPs or data carriers and ISPs that offer parts of their own backbone for resale to others.[6]

By 1998, different ISPs had chosen different approaches, offering distinct combinations of services and distinct geographic scopes. Table 5.1 shows the results of a survey of the business lines of 3,816 Internet service providers in the United States who advertise on *thelist*, an online directory of ISPs, in the summer of 1998 (see the appendix of Greenstein 1999). Virtually every firm in the sample provides some amount of dial-up or direct access and basic functionality, such as e-mail accounts, shell accounts, IP addresses, new links, FTP, and Telnet capabilities, but these 3,816 seem to underrepresent both very small and quasi public ISPs (e.g., rural telephone companies).

Table 5.1
Product Lines of ISPs

Category Definition	Most Common Phrases in Category	Original Sample
Providing and servicing access though different channels	28.8, 56 k, ISDN, web TV, wireless access, T-1, T-3, DSL, frame relay, e-mail, domain registration, new groups, real audio, FTP, quake server, IRC, chat, video conferencing, cybersitter TM	3,816 (100%)
Networking service and maintenance	Networking, intranet development, WAN, colocation server, network design, LAN equipment, network support, network service, disaster recovery, backup, database services, Novell Netware, SQL server	789 (20.6%)
Web site hosting	Web hosting, secure hosting, commercial site hosting, virtual FTP server, personal web space, web statistics, BBS access, catalog hosting	792 (20.7%)
Web page development and servicing	Web consulting, active server, web design, Java, perl, VRML, front page, secure server, firewalls, web business solutions, cybercash, shopping cart, Internet marketing, online marketing, electronic billing, database integration	1,385 (36.3%)
High speed access	T-3, DSL, xDSL, OC3, OC12, Access rate > 1056 k	1,059 (27.8%)

Of the 3,816 ISPs, 2,295 (60.1%) have at least one line of business other than basic dial-up or direct Internet access. Table 5.1 shows that 1,059 provide high speed access, 789 networking, 792 web hosting, and 1,385 web page design. There is some overlap: 1,869 do at least one of either networking, hosting, or web design; 984 do only one of these three; 105 do all three as well as frontier access. This reveals many different ways to combine nonaccess services with the access business.[7]

The Contours of Response to Structural Challenges

Structural issues were not resolved quickly and have not disappeared as of this writing. This occurred because these activities contain much more complexity and nuance than table 5.1 can display.

ISPs customize Internet technologies to the unique needs of users and their organizations, solving problems as they arise, and tailoring general solutions to idiosyncratic circumstances and their particular commercial strengths. Sometimes ISPs call this activity consulting, and charge for it separately; sometimes it is included as a normal business

practice. In either case, it involves the translation of general knowledge about Internet technologies into specific applications that yield economic benefits to end users.

What factors influenced vendors' attempts to construct viable and ongoing economic entities using new technology in an evolving market place? Is it possible to classify and analyze the determinants of coinvention? Why did some regions play host to ISP growth and others did not? There are many explanations, but these aggregate into two classes, one which emphasizes firm specific factors and another which emphasizes location specific factors.

Firm Specific Factors Firm specific factors shape the incentives to bring new technology into use (see, e.g., Demsetz 1988 or Nelson and Winter 1977 for a summary). ISPs came to the new opportunities with different skills, experiences, or commercial focus. In the face of considerable firm specific commercial uncertainty, ISPs purchased and installed their own capital equipment, publicized brand and service agreements, and made other long-lasting investments. Many of these investments could commit the ISP to particular services, even before market demand was realized or new commercial opportunities were recognized.

Strategies pursued by national firms can be viewed in this light. Most national ISPs covered the same geographic territories, so their strategies reflected either unique assets at the firm level, a firm's vision for where their service should fall relative to competitors, or some other firm specific feature. A more detailed look at each of IBM, AT&T, AOL, Earthlink/Mindspring, and PSINet will illustrate the variety of strategies each pursued.

IBM had been an early entrant into the ISP market, focusing primarily on business customers and secondarily on home users. Their service grew rapidly nationwide and globally, complementing their considerable other computer services. Yet, in a few years the firm decided to divest itself of its ISP backbone and facilities, eventually selling to the highest bidder, AT&T. The firm concluded that joint provision of access and other computer services was not a strategic advantage, and therefore focused its attention on computer operations in many firms. The full benefits from this refocusing will only be manifest in time.

AT&T entered into consideration in another way. As already noted, it added a dial-up service soon after commercialization. In 1998 it purchased TCI/@home, a cable company, and Excite, a web portal. These acquisitions position them for providing data service to the home with some content. With the recent agreement to purchase Media One, which was pending at the FCC as of this writing, AT&T became the largest cable provider in the country. The benefits from this are somewhat speculative, as the revenue stream justifying these purchases has not been realized. If voice telephony, streaming media, or any other of the host of new broadband services become viable over cable lines, AT&T is well positioned to provide them. Subscription fees for high speed access could also justify these purchases, if that technology becomes widely adopted.

AOL took a different approach. First, it grew its home user base through aggressive marketing to less technical users. In response to the proliferation of ISPs in the mid 1990s, it ended its tiered subscription model and introduced a flat-rate pricing model which mimics these other ISPs. Next it bought CompuServe, a failed competitor with a loyal customer base, and currently operates it as a separate branded entity. It also sold off its access facilities to UUNet, a subdivision of MCI/Worldcom, announcing concentration on the development of content. It has since pursued its walled garden strategy of making AOL proprietary content attractive and the primary focus of AOL users. The purchase of ICQ, an instant messaging service, and Time/Warner, among others, are consistent with this strategic approach. It is still an ISP, but a unique one, providing access to the Internet that its customer base infrequently uses. The full benefits of this approach are speculative as of this writing, as the revenues from it have not been fully realized.

Earthlink and Mindspring illustrate the issues facing new entrants on a national level. They market a low-cost reliable service which is also easy to use, successfully competing against AT&T with much the same appeal but a different branding. These firms also specialize in making the Internet easy to use for the nonAOL user, the web surfer who wants some but not too much help. Eventually these firms merged, partly to consolidate their resources for competition against AOL, and partly to compete more strongly in the nonAOL customer space. As one of the largest dial-up services in the country, there is a big question whether they can survive in their niche in the face of competitive substitutes from all sides.

Finally, PSINet illustrates the feasibility of embarking on a strategy of emphasizing infrastructure. They started as a consumer Internet service, but got out of that business in 1996. They had built out their own backbone, investing in high speed facilities across the country, focused on becoming a carrier's carrier for other ISPs and for businesses. Part of their strategy involves heavy investments in complementary services, such as hosting services or corporate software services, that can offer high speed service when located next to fast Internet backbone lines. They also focus on offering infrastructure services to businesses, and developing services such as VPNs, which take advantage of their technical capabilities and nationwide coverage. Once again, the full benefits of this approach are speculative, depending on realizing demand in the future.

There are, of course, many other national firms. As with the above examples, their strategies mix different elements of speculative investment, restructuring of organizations, and entrepreneurial guesses about future demand. In all cases, these experiments involve executives making investments under technical and commercial uncertainty, restructuring production and distribution assets on a grand scale, trying to bring new services to market, and only finding out if they meet market demand years after those investments.

It is also important to recognize the variance associated with local and regional ISPs, another and particularly interesting subset of ISPs, that provide service for approximately between a fifth and a quarter of the Internet users in the U.S. These firms locate in many different parts of the country; hence their firm specific strategies are also influenced by factors associated with their locations.

Location Specific Factors A well-known line of economic research, dating at least to Griliches (1957), has emphasized the geographic dispersion of incentives to adopt new technology. In this instance, while basic dial-up access is widely available in all urban areas and many rural areas (Downes and Greenstein 1998), there is great variance in market structure on a local level. Some areas contain many suppliers from a wide variety of backgrounds, while others contain few suppliers. From the standpoint of an ISP, many of these structural features of markets are exogenous, and shape the competitive pressures of the ISP. In addition, ISPs customize frontier technology to the needs of enterprises doing business at a specific time in a specific place. The costs of this may vary by region because infrastructure differs by region. The demand for higher speed service should also differ across regions if the users who find speed valuable are unevenly distributed across geographic regions—e.g., someone from San Francisco may be more willing to pay for speed than people from Poughkeepsie.

The contrast between firm specific and location specific questions are examined in Augereau and Greenstein (1999), who looked at small ISPs' investments in upgrades, and Greenstein (1999), who examined small ISPs' propensity to offer services beyond routine service associated with basic access. Both studies identify the importance of geographic factors by taking advantage of the variation between the locations of small ISPs.

These studies are motivated by two observations. First, as noted in Downes and Greenstein 1998, most large firms are located in the same (or largely overlapping) set of major cities. Hence, for the importance of location to be understood, the cause of variation between the small firms needs to be identified. Second, Greenstein (1999) and Strover (1999) document that ISPs in rural locations tend to provide fewer high quality services than those found in urban locations. Was this due to differences in infrastructure between urban and rural areas, differences in the type of customer found there, or differences in the types of entrepreneurs who locate in different regions?

These studies found that firm size, capacity, and financial strength were important determinants of behavior. There was also some evidence in Augereau and Greenstein 1999 that local infrastructure quality influenced investment behavior. Generally, variation in local demographic conditions or competitive conditions did not influence behavior. Both studies find much unmeasured variance in behavior, consistent with the presence of unmeasured location specific or firm specific determinants. Moreover, the factors which lead ISPs to offer new services, such as size, previous investments, and strategic focus, are disproportionately found in national firms and in local firms in urban areas.

These findings are consistent with the view that the scale of investment, the local infrastructure's quality, and the explicit costs shape investment decisions by young ISPs in emerging markets. It is also consistent with the view that there is too much commercial uncertainty in this market for firms to tailor the technical vintages of their capital stocks too closely to geographically local demand or competitive conditions. Finally, it is consistent with the view that most young firms with ambitious expansion plans initially locate in urban areas instead of rural areas, growing their base markets and expanding outward, if at all.

IV. Past Lessons and Future Challenges

As public discussion of electronic commerce has grown, a loose coalition of prophets for the new economy has come to dominate popular discussion. They write for such publications as *The Industry Standard, Business 2.0, Wired, Red Herring, Fast Company,* and more Webzines than anyone can list. It is only a slight exaggeration to say that all popular portrayals of the Internet contain two principal features. First, the prophets declare a business revolution in all information intensive activities—such as broadcasting, entertainment, retail marketing, supply chain management, other coordinative activity, and research. Second, and this is related, these same prophets proclaim that this technology's novelty dilutes standard lessons from the past. In other words, because this technology contains so many unique features, it is ushering in a new commercial era that operates according to new rules.

To be sure, there is probably a grain of truth to these declarations. However, momentary euphoria does not, nor should it, justify too simplistic a retrospective view of what actually happened, nor what is about to happen. Indeed, this paper showed that a traditional economic perspective does provide considerable insight into this new industry. In that spirit, we return to the questions that motivated the study and recap the findings.

The Commercialization of Internet Access Technology

Why Did the Internet Access Business Grow Quickly? Stated simply, exclusive use did not lead to isolated technical and operational developments. Hence, commercializing Internet access did not give rise to any difficult or insolvable technical and operational challenges. This was due in no small part to the way in which the defense department and the NSF incubated the technology. It grew among researchers and academics without being isolated from commercial suppliers. That is, the technology grew without generating a set of suppliers whose sole business activity involved the supply of uniquely designed goods for military or government users. Related to this was the fact that the basic needs of researchers and academics were not so different from early commercial users. Hence, simple applications of the Internet invented for academic users—such as e-mail and file transfer using phone lines—migrated to commercial uses without much technical modification.

Why Did Geographic Ubiquity Arise? To summarize, the Internet access business was commercially feasible at a small scale and, thus, at low levels of demand. This meant that the technology was commercially viable at low densities of population, whether or not it was part of a national branded service or a local geographically concentrated service. Again, this partly mimicked the academic experience, where the operations were also feasible on a small scale, but that statement alone does not capture all the factors at work. Internet access was feasible in a wide variety of organizational forms, large and small. Small scale business opportunities thrive with the help of entrepreneurial initiative that tends to be widespread throughout the U.S.—including many low density and isolated cities in otherwise rural areas that were largely not being served by national firms. Small scale implementation also depended on the presence of high quality complementary local infrastructure, such as digital telephony, and interconnection to existing communications infrastructure. These too were available throughout most of the U.S. due to national and local initiatives to keep the communications infrastructure modern.

Why Did the Internet Access Business Not Settle into a Common Pattern? Market forces did not impose uniformity in the use nor in the supply of access technology. Part of this was due to the absence of technical and commercial challenges, which allowed low cost experimentation of the technology in new uses, new locations, new market settings, new applications, and in conjunction with other lines of business. More generally, the technology was quite malleable as an economic unit. It could stand alone or become part of a wider and integrated set of functions under one organizational umbrella. Such malleability motivated experiments with new organizational forms for the delivery of access services, experiments which continue today. Finally, and unique to this example, the invention of the World Wide Web brought new promise to the technology. Not only did new business models arise to explore and develop its primitive capabilities and expand them into new uses, but it motivated firms to experiment with Internet access alongside new business lines.

Why Did Market Forces Lead to Such Extensive Growth? This case illustrates how market forces can customize new technologies to users and implement new ways of delivering technologies. These activities have immense social value when there is uncertainty about technical opportunities and complex issues associated with implementation. In addition, as the literature on general purpose technology would put it, coinvention problems are best situated with those who face them. In this case, those actors were ISPs who knew about the unique features of the user, the location, or the application. More generally, commercialization transferred development into an arena where decentralized and unregulated decision making took over. This was precisely what was needed to customize Internet access technology to a wide variety of locations, circumstances, and users. Removing the Internet from the exclusive domain of NSF administrators and employees at research computing centers brought in a large number of potential users and suppliers, all pursuing their own vision and applying it to unique circumstances. In addition, it allowed private firms to try new business models, employing primitive web technologies in ways that nobody at the NSF could have imagined.

In What Sense Did the NSF Get Lucky? As it turned out, the NSF commercialized the Internet access industry at a propitious moment, during the growth of an enormous new technological opportunity, the World Wide Web. Competitive forces sorted through new uses of this opportunity in particular places, enabling some businesses to grow and unsentimentally allowing unsuccessful implementations to fade. To be sure, some of these developments were heavily shaped by nonprofit institutions, such as the World Wide Web Consortium or the Engineering Internet Task Force, but profit motives still played a prominent role. Said another way, had NSF stewardship over the Internet continued there would have been some experimentation at computing centers found at universities and government laboratories, but it would not have been possible to replicate all the exploratory activity that did arise in commercial markets.

Disentangling the Systematic from the Merely Fortunate

While it was correct to forecast that commercial firms would restructure Internet access to suit commercial users, many users did not need such restructuring to make use of the technology. Internet access obtained widespread commercial appeal without restructuring of operations and other facets of supply. As noted, this occurred for many reasons, but two historically unique factors heavily shaped the story. First, the Internet was a demonstrably viable network prior to its commercialization, already used by many researchers, a fact that aided its migration into commercial use through incremental change. Second, the invention of the web fueled commercial growth above and beyond what probably would have happened in any event. Will broad lessons emerge in spite of these particular circumstances?

Said another way, while it is better to be lucky than right, it is always better to be both right and lucky. Would the NSF have been right if they were unlucky? What if the browser had not been invented? Would we still be lauding the NSF for pursuing policies friendly to commercialization? In that spirit, this section briefly considers two counterfactual questions: (1) Would outcomes have been similar in the absence of the browser? (2) Would outcomes have been similar in the presence of the browser, but in the absence of NSF policies friendly to commercialization?

The Importance of the Browser To answer a counterfactual question, it is important to ask: compared with what alternative set of events? This is difficult to answer in this instance because actual events had a certain inevitability to them. For example, consistent with its mandate as a public research institution, the University of Illinois encouraged diffusion of the browser through licensing (Cusumano and Yoffie 1998). To be sure, the Netscape browser of 1995 was a match thrown into a dry field, but parts of that field had already been set ablaze. After the University of Illinois began licensing Mosaic it was only a matter of time before the blaze became an inferno. In other words, if Netscape had not commercialized the technology somebody else would have done so soon. As another example, if Tim Berners-Lee had abandoned his project before completion, it appears that somebody else eventually would have invented something similar. Tim Berners-Lee's invention of hypertext (and then the World Wide Web) culminated decades of work associated with making computing easier to use, more networked and more visual instead of textual (Waldrop 2001).

Hence, the browser and hypertext appear to have a certain inevitability to them. In that light, the most conservative counterfactual is this: What if hypertext and the browser had been invented a few years later? Would the Internet have commercialized successfully?

The answer would appear to be yes, though events might not have been as dramatic. There are several reasons for that assessment. First, e-mail alone would have motivated considerable household adoption

of Internet access even without the browser. E-mail was among the most popular uses for the Internet in its early years, and also popular were many of the community bulletin boards, financial applications, news, and chat rooms. There were some substitutes for these activities even without the Internet, but e-mail (especially) would have been difficult to recreate in private networks on a national level and would have compelled some commercial activity. Both households and businesses found this application useful and all surveys of Internet use place it as the most popular application (Clemente 1998, Nie and Ebring 2000). While some of the more visual applications in the bulletin board industry, such as commercial pornography and probably much electronic retailing, would not have moved to the Internet without the browser, surveys such as Clemente (1998) have never shown these as anything more than a fraction of early Internet use.

On a business level it is also possible to imagine considerable demand for Internet access even in the absence of the browser. Many of the same applications just discussed, such as e-mail and news, motivated business demand. In addition, much of the online database industry would have found benefit from moving to TCP/IP based file transfer as a substitute for bulletin board based file transfers that were more cumbersome for users than a standard FTP or telnet download. With some challenges to overcome, commercial transactions that were forced into EDI-based data transfers also would have found TCP/IP technology useful. However, it would have taken considerable time to shift many other database applications into this mode, so one should not underestimate the difficulties (which were considerable even with the browser). So it is reasonable to expect the growth of TCP/IP connections within private industry even without the browser, but not at such a high rate.

Even with a later invention of the browser, many of the other institutions supporting the development of the Internet also would still have been in place. The creation of the Internet Engineering Task Force would have continued to have an impact on standards development and diffusion. There might not have been anything similar to the World Wide Web Consortium, but the shareware movement would have continued, a factor that made it easier to obtain software for setting up independent ISPs. The computing industry had become sufficiently vertically disintegrated by the early 1990s to prevent any single firm from blockading diffusion of TCP/IP;[8] neither IBM's proprietary networking offerings, nor DEC's, nor anyone else's could have dominated networking communications standards the way TCP/IP did once it began to commercialize.

Finally, even without the browser, one would have expected some migration of online capabilities into commercial use at some level. Migration would not have been unusual by historical standards. New computing capabilities often incubate among technically sophisticated users, building up functionality over long periods of time before migrating into mainstream use (Bresnahan and Greenstein 1999). In this instance, the situation was ripe for migration. All the prototypes for text based online activity existed among sophisticated users. Moreover, the new functionality associated with Internet technologies did not require radical investments on the part of users to be commercially viable. To be sure, there was one historical novelty to the pattern of migration in this instance. Due to NSF restrictions on use, the sophisticated users of Internet access technology were primarily concentrated in research positions and at universities, a subset of sophisticated users in the computing industry. Aside from this feature, the broad pattern of incubation and migration resembles other episodes of platform and technological growth in computing.

This is not to take away credit from those who took the actions and made them happen, nor to deemphasize the importance of these events for firms, regions, and individuals. The contours of events most certainly would have played out differently if the browser had diffused later. It would have resulted in very different outcomes for particular companies, stockholders, and, arguably, regions where these companies locate. Without the browser subscription model, Internet access might have had lower adoption rates at businesses and homes, growth might not have been as explosive, and a different structure of supply might have arisen. However, it is important to recognize the broad pattern that arises irrespective of the contours of how it plays out: even without the browser Internet technology would have migrated into commercial markets and demand would arise under any scenario, motivating the industry to continue to grow to a substantial level.

The Importance of NSF Policies Government employees deliberately let the baby bird out of the nest, encouraging its flight. NSF's policies enabled the entrepreneurial initiatives of commercial firms to influence migration of the technology. That said, migration of technology out of the research community into mainstream commercial markets might have happened under many government policies. So the question arises: Which government policies were critical? In light of later market events, the facet of NSF activities to highlight are those policies that did not turn exclusive use of the Internet into an idiosyncratic technology during its incubation.

There were many senses in which Internet technology was not isolated during its incubation. For example, after the NSF created the NSFNET in the mid 1980s there were no attempts to exclude researchers who had only mild research justifications for using the Internet, a policy decision that dated back to conflicts that arose when DARPA managed the precursor to the Internet. The diffusion of TCP/IP in the late 1980s further facilitated those goals, as it was an easy standard to use in virtually any computing network. The NSF also did not isolate the Internet from mainstream computing use or vendor supply, making contracts with firms such as IBM and MCI for operations, effectively subsidizing computing facilities at research facilities which did the same. In addition, the NSF developed and subsidized growth of the Internet at many locations, adopting a decentralized set of regional networks for its operation. This structure later facilitated private financing of Internet operations and further decentralization of investment decisions by organizations with commercial orientation.

It is possible to view other events in the late 1980s and early 1990s in a similar light. For one, NSF contracted with third parties, such as MERIT, for operations. These types of contracts prevented the network technology from being distant from mainstream engineering and technical standards. NSF permitted interconnection with private data communication firms, such as UUNet and PSI, a spin-off from one of the regional networks, well before commercial dial-up ISPs came into existence. These contracts also established precedents. Finally, NSF did not tightly police the use restriction, especially in the regional networks. Indeed, a number of staff worked toward a 1992 congressional law that officially lifted the use policy on NSFNET, providing more certainty that commerce could be conducted using assets that might have appeared (to a court) to be previously owned by the federal government.

Finally, it is important to note the absence of a particularly common error in large infrastructure development, the attitude of build it and they will come. That is, researchers and developers operating under government subsidies tend to fulfill their own vision of what to do with the technology instead of a user's. The NSF's actions effectively prevented this attitude from overwhelming development. As it turned out, the immediate use of Internet technology within academic research centers tended to put things to use quickly. It allowed researchers to find out what worked and why. Hence, some user desires influenced system design, operation, and growth—even prior to the emergence of organizations that have a commercial orientation and a direct incentive to take account of those desires.[9]

In summary, commercialization of government managed technology can fail because there is no incentive to anticipate technical, commercial, or structure challenges that may arise later in commercial markets. Since this failure can happen for a variety of reasons, it is not possible to point to any single NSF action as the policy that prevented such a failure or, alternatively, acted as the catalyst for commercialization. It is, however, accurate to say that the sum total of NSF's actions did not let exclusive use by researchers impose an irreversible idiosyncratic stamp on the Internet during formative periods of incubation. These policies did not generate an isolated technology nor foster creation of a nonmalleable operation around it. Instead, NSF incubated technology with features that could adapt to the demands of users who would later be in the majority. This is the broad goal worth emulating in policies for commercializing government managed technologies.

Challenges for the Near Future

The diffusion of broadband access, the widely forecast future for this industry, seems to be taking on a more typical pattern for new technology, where technical and commercial constraints shape the pattern of diffusion. It is unclear what the lowest cost method for the delivery of broadband services will be. It is also unclear what type of services will motivate mass adoption of costly high speed access to the home. There are technical limitations to retrofitting old cable systems and with developing DSL technology over long distances. It is unclear how many people will be willing to pay for such high speed services. These uncertainties cloud all forecasts. However, unlike in the past, there will not be 2 decades of incubation of broadband technology by only government sponsored researchers. Hence, there is no reason to anticipate anything like the speed of diffusion found in the dial-up market, nor take for granted that ubiquity will arise as easily (for more, see, e.g., Weinberg 1999, or Werbach 1997).

This observation would seem, at first blush, to suggest that this history sheds little light on the future—that past and future challenges are too unique to their time for comparison. However, that conclusion is a

bit hasty. Looking forward in the ISP industry, it is possible to identify some technical, commercial, and structural challenges that resemble those of the past and that will alter the contours of behavior and outcomes. I will discuss some of these, cognizant that restructuring is still taking place and changing sufficiently fast, so that any discussion runs the risk of becoming obsolete as soon as it is written.

Lesson 1: The Past Does Offer Guidance for Understanding Patterns of Restructuring The names of the firms may change and so too may the specifics of the strategies, but the absence of uniformity in the development of Internet access business models should persist into the future. New applications for web technology are still under development because the technology has potential beyond its present implementations. Not all local markets will experience the same type of competitive choices in access, nor should they. Not all vendors will see the same opportunities and these differences arise for sound economic reasons. Users with more experience still adopt applications closer to the frontier, while users with less experience still demand more refined applications. Web technology enables these differences to manifest in new directions and it is not obvious which implementation will succeed with either type of user. In other words, most of the economic fundamentals leading to structural challenges have not disappeared; hence, experimentation with new business models will probably continue.

Lesson 2: The Subscription Model of Internet Access Will Continue to Change Commercial markets inherited an organizational form from their academic ancestors, modifying it slightly for initial use. There is no reason to presume that it will maintain the same operational structure under competitive pressure. Indeed, it is presently under competition from a variety of alternate business models which use dial-up access to subsidize another activity. There are already hints of these potential changes as some ISPs charge very little for access and make up for the lost revenue with other services, such as networking, hosting, or web design. AOL has successfully combined access with its walled garden of content and AT&T appears intent on pursuing a unique approach of combining content and access. Other recent innovative firms include Netzero.com, which is the most successful to date of many firms that have tried to provide access for free and garner revenue through sales of advertising. There are also many other such experiments altering the explicit definition of basic service, embedding it with more than e-mail, but also with games, streaming, linking, and so on, that has the effect of changing the pricing structure too. It is not crazy to predict that access, by itself, could become absorbed into a bundle of many other complementary commercial services, slowly fading as the standalone service that existed in the academic domain.

Lesson 3: The Economics of Internet Diffusion Lie Behind Much of the Digital Divide Internet access diffused more easily to some users and in some locations. The margin between adoption and nonadoption has become popularly known as the digital divide. If some of these outcomes are understood as temporary results of a young diffusion process, then many of the differences between those with virtual experience and those without can be framed as the byproduct of the economic factors shaping this diffusion episode. Within business the important factors influencing adoption are the density of the location of the business, the availability of basic computer support services nearby, and a firm's previous investment in IT. At the home the important determinants are availability (which is influenced by density) as well as the same factors behind the diffusion of PCs: age, education, and income especially, and also race for some income levels. It follows, therefore, that policies aimed at digital divide issues, such as the E-rate program, should not address those factors which are only temporary and will resolve themselves through market forces without government intervention. Instead, government programs should target factors that are likely to be more durable over time and that lead to division in adoption behavior; such as density of location, income, education, and race.

Lesson 4: Geographic Pervasiveness Introduces New Economic Considerations There is one additional reason to expect the typical business model to remain unsettled. Geographic pervasiveness has entered into calculations today and it was not a relevant consideration at the outset of commercialization. The pervasiveness of the Internet across the country (and the developed world) changes the economic incentives to build applications on top of the backbone, and alters the learning process associated with its commercial development. All ISPs now depend on each other at a daily level in terms of their network security, reliability, and some dimensions of performance. Many new applications—e.g., virtual private networking, voice telephony over long distances, multiuser conferencing, some forms of instant messaging, and gaming—require coordinating quality of services across providers.

It is still unclear whether new business models are needed to take advantage of applications that presume geographic pervasiveness. If so, firms with national backbones and assets will have a commercial advantage. Pervasiveness also changes the activities below the backbone in the vertical chain. It has altered the scale of the market for supplying goods and services to the access industry, altering the incentives of upstream suppliers, equipment manufacturers, or middleware software providers, to bring out new services and inventive designs for the entire network. This factor was also not present in the academic network and it is unclear how it will influence the structure of the industry moving forward.

Lesson 5: Is There a Need for New Communications Policy for the New Millennium? Until recently, the place of technical change in most communications services was presumed to be slow and easily monitored from centralized administrative agencies at the state and federal level. It is well-known that such a presumption is dated, but it is unclear what conceptual paradigm should replace it. This paper illustrated how vexing the scope of the problem will be. In this instance, ISPs addressed a variety of commercial and structural challenges with little government interference, but under considerable technical and commercial uncertainty. This occurred because many legacy regulatory decisions had previously specified how commercial firms transact with the regulated public switch network. These legacy institutions acted in society's interest in this instance, fostering experimentation in technically intensive activities, enabling decentralized decision making to shape commercial restructuring in specific places and time periods. To put it simply, it was in society's interest to enhance the variety of approaches to new commercial opportunities and the existing set of regulations did just that. However, going forward it is unclear whether these legacy institutions are still appropriate for other basic staples of communications policies, such as whether a merger is in the public interest, whether incumbent cable firms should be mandated to provide open access, whether communications infrastructure should be subsidized in underserved areas, and whether Internet services should be classified as a special exemption, immune from taxation and other fiscal expenses. Hence, this industry is entering an era where market events and unceasing restructuring will place considerable tension on long-standing legal foundations and slow regulatory rule making procedures.

Notes

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1. The literature on general purpose technologies (Bresnahan and Trajtenberg 1995, Helpman 1998) also helps frame these themes by highlighting the role of coinvention, defined as the complementary inventions which make advances in general purpose technologies valuable for particular organizations in particular places at particular points in time.

2. For example, see studies of the supersonic transport (Cohen and Noll 1990), nuclear power (Cowan 1988), air frames (Mowery and Rosenberg 1992) and the early history of computing (Flamm 1989, Katz and Phillips 1982), among many such examples.

3. If anything, regulatory decisions for reciprocal compensation of competitive location exchange providers (CLECs) encouraged CLEC entry, which also partly encouraged ISP entry through interconnection with CLECs. Though important to incumbent local exchange carriers, however, one should not exaggerate this too much. The scale of this phenomenon grew tremendously in the late 1990s, but ISP entry started well before then. Moreover, since CLEC entry was primarily concentrated in dense urban areas, much of this effect was felt in urban areas, which would have experienced a great deal of ISP entry even without this implicit subsidy to CLECs.

4. For further documentation of these methods, see Downes and Greenstein 1999 or Greenstein 1999. The fall 1996 data covers over 14,000 phone numbers for over 3,200 ISPs. The fall 1998 data covers over 65,000 phone numbers for just under 6,000 ISPs.

5. Some ISPs have told me in interviews that this growth was initially in response to customer requests for local phone numbers for accessing networks (e-mail mostly at first) when these customers traveled outside their primary area. More recently, it is also common to have ISPs discuss the possibility of developing a large customer base for purposes of selling the base to a high bidder in some future industry consolidation.

6. Speed is the sole dimension for differentiating between frontier and basic access. This is a practical choice. There are a number of other access technologies just now becoming viable that are slow but technically difficult, such as wireless access. Only a small number of firms in this data offer these services and these firms also offer high speed access.

7. One of the most difficult phrases to classify was general "consulting." The vast majority of consulting activity is accounted for by the present classification methods as one of these three complementary activities, networking, hosting, and web design.

8. The direction of commercial events also would have continued to take the same directions. Important among them was the final dissolution of the working relationship between IBM and Microsoft, as well as the final triumph of Ethernet-based standards within the majority of networking equipment for LANs.

9. One might ask why NSF adopted these policies when they did and whether their consequences were anticipated. That is a longer story and beyond the scope of this paper,

which was simply to highlight those which were useful in light of later events. The account of Waldrop (2001), for example, begins that evaluation by arguing that NSF was making virtue out of necessity. He argues that there was no expectation that government agencies could operate a large scale data network indefinitely. This was particularly so at NSF, whose budget was periodically realigned by the whims and fads of political fashion. There also was no expectation that NSF could or would fund decades worth of large scale data communications research on the scale that DARPA had done. Hence, it was believed that a sustainable network would necessarily require private partnership on some level and, eventually, private financing.

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6

Numbers, Quality, and Entry: How Has the Bayh-Dole Act Affected U.S. University Patenting and Licensing?

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Executive Summary

This paper summarizes the results of empirical analyses of data on the characteristics of the pre- and post-1980 patents of three leading U.S. academic patenters—the University of California, Stanford University, and Columbia University. We complemented this analysis of these institutions with an analysis of the characteristics of the patents issued to all U.S. universities before and after 1980. Our analysis suggests that the effects of the Bayh-Dole Act on the content of academic research and patenting at Stanford and the University of California were modest. The most significant change in the content of research at these universities, one associated with increased patenting and licensing at both universities before and after 1980, was the rise of biomedical research and inventive activity, but Bayh-Dole had little to do with this growth. Indeed, the rise in biomedical research and inventions in both of these universities predates the passage of Bayh-Dole. Both UC and Stanford university administrators intensified their efforts to market faculty inventions in the wake of Bayh-Dole. This enlargement of the pool of marketed inventions appears to have reduced the average "yield" (defined as the share of license contracts yielding positive revenues) of this population at both universities. But we find no decline in the "importance" or "generality" of the post-1980 patents of these two universities. The analysis of overall U.S. university patenting suggests that the patents issued to institutions that entered into patenting and licensing after the effective date of the Bayh-Dole Act are indeed less important and less general than the patents issued before and after 1980 to U.S. universities with longer experience in patenting. Inexperienced academic patenters appear to have obtained patents that proved to be less significant (in terms of the rate and breadth of their subsequent citations) than those issuing to more experienced university patenters. Bayh-Dole's effects on entry therefore may be as important as any effects of the Act on the internal "research culture" of U.S. universities in explaining the widely remarked decline in the importance and generality of U.S. academic patents after 1980.