Chapter 1

THE EVOLUTION OF ADVANCED LARGE SCALE INFORMATION INFRASTRUCTURE IN THE UNITED STATES*

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I. INTRODUCTION

While studies have examined the regional development of information technology producers in the U.S.,[1] comparatively few have examined the regional diffusion of information technology to users. While a number of studies examine the returns from the use of information technology within organizations[2], little is known about the geographic concentration of those returns. This is a large gap in understanding how innovation translates into economic prosperity. Economic growth and advances in welfare arises from the use and adoption of technology in economic processes. Disparities between enterprises in the levels

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[1] For example, see Markusen et al [1986], Saxenian [1994], Steinmueller [1996], Forman, Goldfarb and Greenstein, [2002].

[2] For example, see Bresnahan and Greenstein [1997], and Brynolfsson and Hitt [1997].

and rate of adoption of new technology may lead to related disparities in regional economies, especially when different types of spillovers are limited by the proximity of economic activity.

In this study we empirically characterize the distribution of use of advanced information technology across the US. Here "advanced" means computing and communication technology near the technical frontier, whose increasing use in the 1980s enabled new goods and services and transformed downstream economic activity. We measure and analyze changes to the geographic distribution of advanced information technology (IT) in the late 1980s and early 1990s, the period just prior to the commercialization of the Internet. There was an explosion of commercial investment in information infrastructure in the late 1990s, but little is know about investment patterns prior to that.[3]

We first characterize the pattern of disparities between regions in the levels of advanced information infrastructure and access to it. We expect that economies of density in the provision and employment of many communication technologies give users strong incentives to locate these technologies in urban areas. Also, some industries are more intensive users of advanced information technology. Administrative-intensive work, such as banking, finance, insurance, real estate, or business services, tends to make heavy use of advanced computing and digital communications. Information infrastructure will tend to be found in the same places as these industries. Thus, we investigate how much of the location of information infrastructure can simply be explained by the density of human settlement and the location of industry.

We then investigate whether the diffusion of advanced IT follows an increasing "agglomeration" pattern or an increasing "dispersion" pattern over time. In an increasing agglomeration pattern, one or several geographically localized economic forces leads to increasing concentration of advanced infrastructure in a few places. In this situation the geographic areas that were early leaders continue to retain over time their relative lead over other regions and even build on it. In the increasing dispersion pattern, the opposite occurs. The geographic areas that were early leaders in technology lose their relative lead or cease to be leaders -- perhaps as part of a general re-ordering of the relative standing of regions.

Questions about the dispersion and agglomeration of investment are particularly interesting in light of the widespread investment in the late 1990s. In less than a decade after the commercialization of the Internet the supply and use of Internet infrastructure became nearly geographically ubiquitous.[4] Was this remarkable period of growth in infrastructure predeeded by dispersed investments in an earlier era?

We employ methods from the literature on economics of infrastructure in developing countries, suitably adapted to examine the regional distribution of advanced information infrastructure in a developed country. Our data on information technology capital at public and private enterprises come from surveys of users' information capital, which we aggregate to the smallest possible geographic unit. From these sub-indices we compute summaries of advanced IT and access to it. Following the spirit of the infrastructure literature, we interpret our indices as broad indicators of activities associated with building public and private digital IT networks in a region – i.e., development of labor markets for IT services, related

[3] For more on geography and growth of the Internet, see Cairncross [1997], Kolko [2002], Greenstein [2000], Kotkin [2000], Moss and Townsend [1997], Zooks [2000], and Forman, Goldfab and Greenstein [2002].

[4] See e.g., the analyses in Greenstein [2000], Downes and Greenstein [2002], Forman 2002], and Forman, Goldfarb and Greenstein [2002].

downstream applications, and localized inventive activity closely linked to advanced infrastructure.

We analyze three key ingredients of digital infrastructure: a) fiber optic deployment by local telephone companies, b) the number of large-scale computer users, and c) the processing capacity of large-scale computers (or "servers"). The growth in fiber optic cable at local telephone companies measures a region's ability to transmit data in digital form, while growth in large-scale computing capacity measures the ability of firms within the region to store and process large databases. As of 1992, the last year of our data, these were important indicators of both advanced computing and telecommunications capital stocks. This capital recently experienced rapid declines in price, increases in quality and rapid expansion nationwide. It has also been associated with transformations in downstream activities and the offering of many new goods and services. We examine the post-divestiture years 1986, 1989, and 1992 because these are years of rapid expansion and also for pragmatic reasons. These were the years for which we could construct a consistent index for all these capital stocks.

We emphasize several findings. First, the level of advanced information infrastructure is unevenly distributed. It locates in especially dense urban areas, rich areas and regions with large amounts of white collar work and related information-intensive industries. Second, advanced information infrastructure grew over time virtually everywhere. In six years the extent of growth has raised the relative standing of all but the worse areas to levels achieved by all but the best (by earlier standards). Third, over time advanced IT infrastructure became less concentrated in any specific region. This holds for the distribution of capital stock and for access to it. Fourth, there has been little shift in the relative standing of different regions, especially at the extremes. Many of the regions that were early leaders still continue to retain their leadership position, and many of the regions that were not leaders still continue to be behind. Fifth, the relative differences among regions have narrowed and many of the regions in the "middle" have changed their relative position.

We conclude that advanced IT did agglomerate in urban areas in any given year but the relative lead of urban areas narrowed over time. Moreover, these data do not support any argument that the distribution of advanced information infrastructure became increasingly more agglomerated in the late 1980s or early 1990s. These patterns are consistent with the diffusion of advanced IT to new uses outside of urban areas. These patterns also support the speculation that conditions were ripe for the rapid diffusion of the Internet. We offer several plausible conjectures about the reasons behind this spread. In addition, we conclude that these data do not support any argument that the diffusion of advanced IT exacerbated regional disparities in economic obtainment in the US.[5]

[5] The US pattern contrasts with other countries. For example, on information technology, see Capello [1994], or Roller and Waverman [2001].

II. AGGLOMERATION AND DISPERSION IN INFRASTRUCTURE

There is a voluminous literature on the relationship between economic growth and the location and growth of infrastructure in developed countries, where infrastructure refers to the traditional utilities, roads, educational institutions, and so on.[6] There is also a growing literature on the growth of information infrastructure in developed countries, where this refers to telecommunications networks, computing equipment, the Internet, knowledge-intensive industries and related backbone technology.[7] Finally, there is also a somewhat older debate over the appropriate definition of "universal access" in an age of technological change; some aspects of this debate touch on regional disparities in infrastructure.[8] All these discussions would be aided by statistical studies of the regional distribution of the use of advanced information infrastructure.

Below we provide a short summary of the conventional analysis of the forces leading to agglomeration and dispersion of infrastructure. We show how this conventional summary needs to be altered to apply to the spread of advanced information infrastructure. We also briefly discuss why its geographic spread is important for understanding regional economic growth.

1. Advanced Information Infrastructure and Economic Growth

In its most common usage "information infrastructure" is synonymous with communication and computing equipment, software, and related activities associated with information technology. More concretely, this common and broad definition of "information infrastructure" encompasses capital equipment, such as mainframes, minicomputers, PCs, LANs, WANs, local and long distance telephone equipment, private and quasi-public switching equipment and software, both packaged and customized. It also encompasses the results of complementary activities at user enterprises such as training, maintenance and operation. It also involves the flows of tacit and explicit knowledge among enterprises about the technological frontier thorough user groups, trade publications and industry associations.

The term "advanced" – as in "advanced information infrastructure" -- also refers to a similar broad definition, but also to specific recent developments. It partly refers to the use of new technologies in communications networks, where the dramatic leap to digital equipment from legacy analog equipment enabled many new applications and services. In particular, the upgrading of the existing telecommunications networks to digital technology in transmission, switching and other equipment, both in the public switched network and privately operated facilities, accelerated considerably in the 1980s.

The term "advanced" has a slightly different meaning in computing, though it is also associated with new technology. In its common usage "advanced" largely refers to software, peripheral and processing technology near the technical frontier. There was no single

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[6] See e.g., Munell [1992] or Teubal et al [1996] for a review.

[7] For examples, see National Academy of Engineering [1995], National Information Infrastructure Advisory Council [1995], NTIA [1995], the Information Infrastructure Task Force [1993, 1994], Kahin [1991], Kahin and Keller [1995], National Research Council [1996] and Teske [1995].

[8] For discussions of recent issues and trends, see, for example, Teubal et al [1996], Mueller [1993], Mueller [1997] or Moss and Townsend [1997], Downes and Greenstein [2000].

dramatic technical change comparable to the digital/analog switch in communication; in computing there have been several notable "technical revolutions" (see Friedman and Cornford [1991]). In the 1980s and 1990s these include the PC revolution (associated with thousands of decentralized applications), the departmental computing revolution (associated with super-minicomputers), the on-line-transaction processing revolution (associated with making large databases accessible in real time at large scale computing facilities), the networking revolution (from growth of local area networks to the growth of the Internet), the client/server networking revolution (still on going) and, most recently, the Internet.[9] More generally, the large multiplicity of advances in so many facets of computing creates the perception to users of an ever shifting technical frontier and an ever changing menu of applications.

Broadly speaking, these technical changes bring about economic changes through several related mechanisms. First, there may be declines in the costs of doing an existing activity. This decline in costs should bring about a substitution away from more expensive alternative inputs, expansion in the use of complementary inputs (such as skilled labor), and expansion in enterprises that are information intensive. Second, information technology may enable adopters to perform new activities, potentially associated with the offering of new goods and services. Typically the benefits associated with this type of innovation are realized quite slowly if complementary developments are the least bit complex -- often requiring costly adaptation by using organizations as well as complementary invention by related peripheral and component suppliers.[10] Finally, there is a third mechanism associated with technological competition -- i.e., when many firms innovate in order to match their competitors. When many using organizations adopt an innovation the rents associated with these gains may be competed away. Then the users of goods from information-intensive organizations realize benefits either through decline in prices or increases in new types of applications, which are then passed on to their customers.

All three mechanisms operated in advanced information infrastructure. The change in communication equipment reduced both the costs of maintaining the existing public network and increased the services associated with it.[11] Users also found that they could build greater capabilities into their private communications and computing networks if the local public switch network was of a higher quality.[12] In large scale centralized computing facilities, which are the backbones of most enterprise computing and networking, advanced infrastructure is installed as part of a new system or along with upgrading, retrofitting, and improving existing systems. These changes both reduced the costs of performing existing tasks and enabled the development of entirely new functions.[13]

[9] For a history of the structure of the computing industry and its relationship to these technical revolutions, see Bresnahan and Greenstein [1999] and Greenstein [2000].

[10] For a theory of this see Bresnahan and Trajtenberg [1995]. For an application to computing in large organizations, see Bresnahan and Greenstein [1995, 1997] or Brynolfsson and Hitt [1997].

[11] For example, many more services built by local phone companies on top of the existing system -- voice mail, caller-id, remote control of call forwarding, automated paging, alarm monitoring, call-waiting and other enhanced service -- were aided by the advanced infrastructure within the network (Lavoie [1988], Reese [1988]).

[12] For example, higher quality backbone enabled users to invest in less expensive facsimile machines, computer modems, paging services, and other high quality digital communication equipment (Brody[1988], Radford [1989]).

[13] For example, in the 1980s these investments were associated with dramatic improvements in inventory management, decentralization of information applications such as financial analysis and word-processing,

Many of these mechanisms have an important regional dimension to them. For example, the benefits from improvement in local telephone service principally accrue to the local telephone company and local organizations who use these new goods and services. There may also be important regional dimensions to these developments; support services for software and maintenance grow up to service local needs and idiosyncratic problems, contributing to the development of a thick local labor market for advanced IT personnel.

2. The Location of Advanced Information Infrastructure

Advanced IT will tend to agglomerate in urban areas for a variety of reasons. First, in telecommunications networks there are economies of density in the provision and employment of many new services. Second, as long as advanced technology remains relatively unstandardized and difficult to use, the labor market for servicing and operation will tend to favor urban areas.[14] This arises endogenously because it increases the liquidity of labor markets for enterprises that use specialized engineering talent. Similarly, close proximity facilitates learning through user-groups, facilitating the development of complementary service markets for maintenance and engineering services, the delivery of parts and so on.

These agglomeration economies may persist over time for a variety of reasons. Technical frontiers shift frequently, requiring constant experimentation, favoring the users in areas where these experiments are less costly. This would also tend to favor the experienced users in urban areas, and not incidentally, potentially accelerate the relative differences in economic welfare between the leaders and losing areas. More generally, as any of the above factors become even more binding over time, the degree of agglomeration increases.

Agglomeration may not persist as advanced technology becomes less exotic to a greater number of users, which occurs as its features become standardized and its price declines. Then IT diffuses to lower-value uses, to a wider class of users and to many new applications. Many of these new uses and users may not necessarily be located near the first adopters, producing geographic dispersion over time away from the areas of early experimentation. This potentially leads to a decrease in the relative disparity of economic welfare between the late and early adopters. Similarly, as advanced technology becomes less exotic and more standardized, it is also more easily serviced in outlying areas, again contributing to its geographic dispersion.

Political factors may also play a role. In the US, in particular, government policies will mitigate somewhat against the persistence of agglomeration over time, especially when agglomeration results in a notable disparity of economic growth between regions. Competition among localities to attract the key technologies and infrastructure linked to economic growth may lead to direct subsidies of public enterprises or indirect subsidies to enterprises that operate quasi-public infrastructure (e.g., through local public utility policies). There are also national political pressures to reduce regional inequities, especially between urban and rural areas. Several federal agencies have historically pursued policies associated

initiation of automated customer interaction in retailing, and development of applications associated with access to enterprise-wide data and ease of use (Friedman and Cornford [1989]).

[14] For example, labor markets for specialized engineering talent tend to concentrate in a few locations, such as Silicon Valley, Route 128, the research triangle and so on.

with "universal service", which may lead to mandates against regional inequality in access to advanced technology (e.g., apply pressure for the adoption of digital switches in rural areas).

More concretely, several factors arose in the 1980s that could push towards either increasing agglomeration or dispersion of advanced information infrastructure. Here we mention two important ones. First, some industries are more information intensive than others. The geographic dispersion of modern infrastructure will partly depend on whether the information-intensive industries tend to be more geographically concentrated than the less information-intensive industries. Over time changes to this distribution will depend on whether one type of industry tended to grow more in the 1980s and whether the technical changes to information technology induced geographic relocation of information intensive users. Second, networking technology in computing underwent significant changes in the 1980s. For example, the diffusion of on-line transactions processing became linked to the development of many new business services. This encouraged the growth of centralized computing facilities in major enterprises. This could lead to capital deepening at existing users (which may have agglomerated more advanced IT in existing facilities in urban areas) or it could lead to diffusion of more computing locations to new uses in new locations (which may be outside of existing facilities).[15]

While some of these explanations are mutually exclusive, many of them overlap or reinforce one another. Thus, we attempt a modest and feasible research aim which informs understanding in this area. We focus on the following questions:

- What determines the geographic dispersion or agglomeration of advanced information technology across the US?
- How should we characterize the distribution of infrastructure?
- Has the relative degree of disparity between different regions changed in a period of rapid growth in advanced information technology? If so, how?

III. DATA

For purposes of this empirical study we confine attention to a few key components of advanced information infrastructure. We do this for two reasons. First, investment in advanced infrastructure is positively correlated across components within regions. Accurate measurement of a few components gives an excellent indication about the remainder. For example, upgrading to larger CPU capacity on existing computing systems is associated with taking advantage of technical improvements embedded in new systems or taking advantage of technical change in complementary components. Similarly, large investments in digital telecommunications equipment are associated with taking advantage of technical improvements in all digital equipment. Second, there are practical constraints in assembling data. It is simply infeasible to compile comprehensive data of information infrastructure across a wide variety of activities or product markets for the entire US. Accordingly, our

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[15] Similarly, the growth of client/server technology encouraged a decentralization of computing activities in the mid 1990s, but extensive experimentation at legacy operations at centralized facilities. While this trend was still incipient at the very end of our sample period (Bresnahan and Greenstein, 1997), it may still have influenced forward-looking investment in the late 1980s.

indices focus on a few components that correlate with advanced technology in digital communications equipment and frontier computing.

Our data set consists of information about local exchange companies (LECs) and large-scale computer users in the U.S. in 1986, 1989, and 1992. It combines data first introduced in Greenstein, McMaster and Spiller [1995] (GMS), in Bresnahan and Greenstein [1995, 1997] (BG), and in Hart, Nave, Raskob and Thomason [1982] (HNRT). Further documentation can be found in the appendices of these papers and of Greenstein, Lizardo and Spiller [1997] (GLS) and Greenstein and Spiller [1997].

1. Sources for Data on Advanced Telecommunications and Computing

Our unit of observation is the territory covered by a local exchange company (LEC) at the sub-state level. This choice is made out of necessity, as no smaller geographic unit is reported to the FCC, and the FCC is the source of our data on telecommunications infrastructure. The shape of these regions within a state depends on how the state divides up local telephone service franchises among different companies. Some states divide up their territory among many companies and some do not divide it at all. Most of these decisions were made years before. The appendix to GLS [1997] includes a list of all these territories, the division of different states, and the major cities within each LEC.

LECs' fiber optic deployment data, as well as demographic and economic data of the counties served by the carriers, come from GMS, while territorial extension data are from GMS and HNRT.[16] There are 101 LECs that annually report their fiber deployment to the FCC.[17] Demographic, economic, and territorial data of the counties served by each LEC, which are used in the regressions, are aggregated to the company level within each state.[18] While some small independent companies do not report to the FCC, the GMS data cover virtually all of the fiber optic cable used by local telephone companies.[19] Figure 1 shows a visual approximation of the geographic area corresponding to the 101 LECs reporting to the FCC (it is approximated at the county level, not the LEC territory level). This area covers almost all the U.S. territory and over 90% of the US population.

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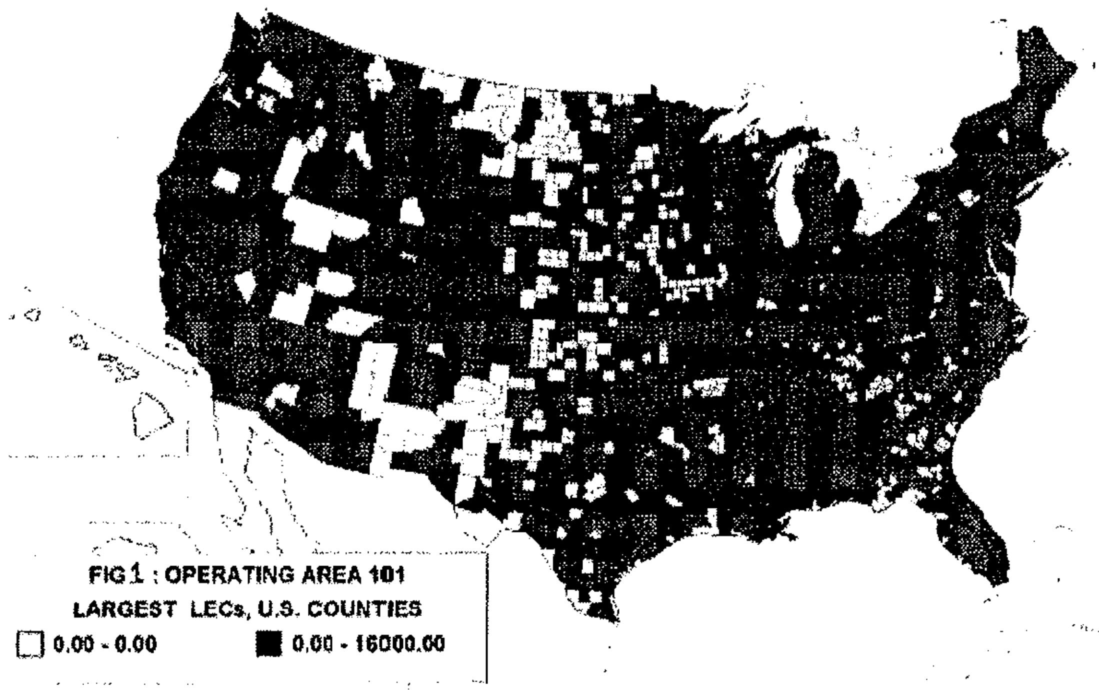
[16] The land areas from HNRT are for LEC square mileage in 1981. There may have been slight changes over time due to mergers and other transactions.

[17] If a LEC generates more than 100 million dollars in revenue a year, it must report its infrastructure data to the FCC. Fiber deployment is reported using M and ARMIS 43-07 forms. The total revenue associated with the local telephone firms deploying the fiber in our index exceeds seventy billion dollars in 1992.

[18] The sources of the demographic data are the "Annual Estimates" of the U.S. Bureau of Economic Analysis, Department of Commerce, and "Regional Economic Information System Annual CD." The information is gathered for 48 states and the District of Columbia. Alaska and Hawaii are excluded. See GMS for detail.

[19] It includes the vast majority of cable at local telephone companies in the US. Many of these areas are geographically small or, by definition, do not concern populous areas. In addition, this data does not include investment in fiber optics by competitive access providers such as Teleport or MFS, not does it include rural independent LECS, neither of whom are required to report their capital stocks to the FCC. As of 1992, this was not a large percentage of any region's fiber network. Including these providers might be an important component of a region's fiber if this data were updated to the present.

Figure 1. Operating Area 101



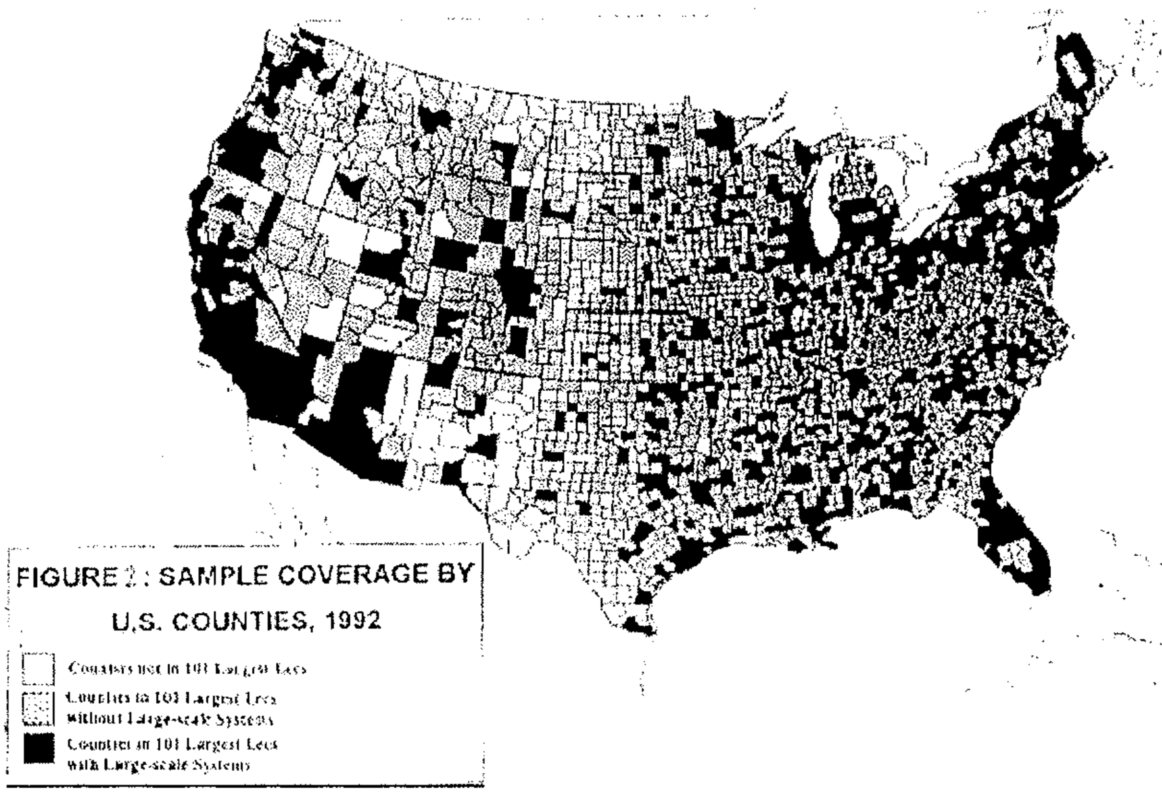
Information about large-scale computer users' locations and computing capacities overlaps with that found in BG. These data are collected by the Computer Intelligence Infocorp (CII), a division of Harte Hankes, a market survey firm based in La Jolla, California, that regularly calls computer users in businesses to document their computer use patterns. We use the survey results from the end of each calendar year. The magnitude of the sample of large-scale systems users in each year is 13,788 sites in 1986, 13,553 sites in 1989, and 12,386 sites in 1992. Each of these users had at least one mainframe or large supermini computer at their site when they were surveyed. CII claims to cover 70% of all large-scale users in the U.S. These users cut across the entire spectrum of US industries, with some slightly better coverage of the Fortune 500 and facilities of major corporate computing facilities.[20] Since there is also extensive coverage of thousands of firms outside this group, there seems to be no reason to expect the error in CII's sampling of large-scale users to correlate with the geographic location of users.

We matched the CII data against the FCC data through the use of zip codes (primarily), city codes (secondarily), and county codes when available (rarely), relying on GMS when no other information was available. We have found that virtually all the large-scale systems users are located in the geographic areas served by the 101 largest LECs that report fiber optic deployment to the FCC. In each year, less than 4.5% of sites included in the CII sample belong to territories that are served by LECs which do not file with the FCC. Further, the proportion of overall computer capacity, as defined below, located in these territories is less than 2.7% of the total amount in each year. Thus, except in Table 5, all our analysis is based on information for those LECs that report annually to the FCC and for the computer users

[20] BG [1996] found that for sites that contained identifiers approximately 15% of the observations came from Fortune 500 firms and that over 85% of the Fortune 500 have at least one representative in this sample.

within those LECs. Figure 2 shows the geographic distribution of computer users relative to our coverage of LECs, visually approximated in the same way as Figure 1.

Figure 2. Sample Coverage by U.S. Counties, 1992



2. Indicators of Advanced Information Infrastructure

We use three indicators of the stock of information technology infrastructure: the number of sites using large-scale computing, their associated computing capacity, and the miles of fiber optic cable used by the LEC within a region. We now explain these choices.

The number of sites using large-scale computing is one simple indicator of the presence of sophisticated users in a region. Another related indicator of infrastructure is the computing capacity existing within a region, which we measure by the sum of Mips (millions of instructions per second) of all processors within computers systems existing in a region's sites. We also include all the client/server hardware investment at these sites, reflecting the spread of the networking revolution to large-scale computing in the 1990s. Precise definitions for the computing models included and excluded may be found in BG [1997].[21]

In the early years of our sample either of these indices measures the bulk of large-scale computing capacity in a region. BG [1996] and [1997] show that the vast majority of these

[21] This includes all mainframe and non-mainframe computing hardware except PCs at all the sites operating within the region boundaries. We found in preliminary analysis that there was a strong correlation between aggregate mainframe MIPS and aggregate non-mainframe MIPS within a LEC in a year. Thus, for the purposes of this study, there was no benefit to distinguishing between the two different types of capacity or weighting them differently. We present the unweighted total.

sites are associated with white collar administrative work at central computing facilities. A smaller, and slightly declining, fraction is associated with engineering or manufacturing work. Thus, the only systematic bias is associated with sites which left the sample. BG [1996] show that the diffusion of client/server networking up until 1992 primarily occurred at engineering oriented sites and that most non-random exits, which were still small as of 1992, were concentrated at these engineering sites.[22] Hence, our measure of a region's computing capacity slightly emphasizes computing at administrative sites in 1992; We think this emphasis will be small since we also add non-mainframe MIPS -- i.e. the MIPS associated with servers in client/server configurations -- into our total measure.

The presence of a site or the extent of MIPS in a region indicates some significant developments of advanced IT. There is no way for most of these facilities to operate smoothly without the presence of many complementary technologies, without users with technical skills, nor without the presence of a support organization or other related infrastructure. These are simply too big an investment to live in isolation of other technical advances. Large scale systems cost approximately half-a-million dollars for the hardware on average. At most large facilities, the software, training, installation and maintenance expenses are three to four times the hardware expenses on an annualized basis (BG).[23]

Our last indicator is the number of miles of fiber cable installed by local telephone companies within a region, where "miles" has been adjusted to reflect the number of strands of fiber. Fiber optic cable enables high-volume transmission of data and is widely considered to be an essential part of the modern digital telephone system. The limits on its capacity are determined by the available terminal and repeater technology. Due to all the complementary factors that must be in place to make it effective, this too is an excellent measure of advanced communication infrastructure. Further digital technologies, deployed in conjunction with fiber, enable a variety of services. Fiber enhances the reliability as well as the quality of data services over phone lines. (See, e.g., Brody [1988], Lavoie [1988], Minoli [1991], chapter 7, Reese [1988]).

Although the miles of fiber optic cable used by the LEC within a region includes neither fiber deployed by long distance telephone companies nor that deployed by private providers and users of local fiber optic cable, our measure reflects the bulk of fiber devoted to local telephone networks and/or data transfer over the public network phone lines. It reflects tens of billions of dollars invested in capital stock using digital technology. Much of this investment received publicity when announced and may have been the focus of negotiation between local regulators and utilities (see GMS [1995]).[24]

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[22] As with the diffusion of most advanced technologies, there was resistence among users of legacy technologies to completely ceasing use of the old systems. There were many reasons for this, including worries about losing site-specific investments, uncertainty over future technologies, and so on. As a result, the demonstration of many working prototype client/server systems in 1992 did not induce much immediate retirement of legacy systems. See Bresnahan and Greenstein [1997, 1997].

[23] Spread over 12,000 sites in 1992 and more sites in the earlier years, the total value of the capital going into the computing site of our index must be in the tens of billions of dollars. As shown in BG [1997], the value of hardware associated with large scale systems continued to grow into the 1990s. Its fraction of the total computing capital stock did not dramatically change until the mid 1990s.

[24] We are also leaving out investment in fiber optics by small rural telephone exchanges, most of whom are located in small cities and towns scattered throughout the US. To the extent that this investment represents real economic advance and not just gold-plating investment under regulatory distortions, it will only enhance our findings below that there has been a spread of fiber from urban to rural areas. However, many of these small cities will not have large investment in large scale computing, so we think it is unlikely that our measurement

3. Measuring Access to Infrastructure

To measure the level of access to advanced information technologies we borrow from the established methods for measuring access to infrastructure in developing countries (Cowell [1995]). In this literature researchers examine changes in the "density" of infrastructure. We experimented with a variety of methods for measuring "density." As it turned out, all our experiments pointed toward the same qualitative answer, so the composite measure will be the best single index for a region's standing. These indices are:

- *Number of Sites/Population*[25] measures whether a worker living in a region with a high number of Sites/Population ratio has more chances to be exposed to computer technology.
- *All Systems Mips/Population* measures the exposure to computing power of large-scale systems existing in the region.
- *Fiber/Land,* which equals Miles of Fiber Optic Cable Deployed/Miles of Land Extension, measures the deployment of fiber optic across geographic regions. A LEC with a high Fiber/Land ratio has a greater capacity to supply advanced telecommunication services than one with a low ratio.[26]
- *Networking Capacity Index*, which equals (Fiber/Land)*(MIPS/Population), is a composite index that measures the potential capacity of a geographic area for storing information and transmitting it among computers in the region using the public telecommunication infrastructure provided by the local exchange company.[27] It is analogous to transportation infrastructure indices of roadway and vehicle carrying capacity per capita and per square mile.

In our exploratory research of these data (GLS [1997]) we found that all of these measures of access are highly correlated on a regional basis. Thus, in general, we will focus primarily on one summary measure, the networking capacity index.[28]

4. Infrastructure Statistics: An Overview

The geographic distribution of advanced large-scale computer and fiber infrastructures in the U.S. is deceptively skewed. Many geographic areas contain few large-scale computer

framework and qualitative results would be greatly influenced by their inclusion. We await further evidence of diffusion of advanced IT to small rural towns before reaching a definitive conclusion.

25 The numerator in the indices Number of Sites/Population and All Systems Mips/Population corresponds to 1,000 people.

26 For this calculation we use the square miles of the LEC within the state relative to its fiber from HNRT.

27 A region without fiber optic deployed, but with a high processing capacity of information, has a Networking Capacity Index of zero. So too does a region with fiber and no computing.

28 We also explored another standard composite index used by economic geographers to measure the amenities associated with different locations (See Nissan [1994] for a full explanation). This index combines the information provided by the first three aforementioned sub-indices, Number of Sites/Population, All Systems Mips/Population, andFiber/Land. It normalizes each sub-index and then for each region sums a weighted index of the difference between the maximum value reached in the sample and each normalized value in any given year. The larger the distance from the maximum the smaller the index. It is well known that this index is inappropriate with skewed data. Since the distribution of infrastructure is highly skewed, this procedure is flawed here. See GLS [1997] for these calculations.

users, low or no computing capacity, and low or no deployment of fiber optic cable in relation to geographic areas in the top of the distribution. However, most of the U.S. population lives within the territories that are advanced in their IT deployment. This is because most of the US population is located in a small number of regions, most of which are advanced. Table 1 contains the descriptive statistics for the distribution of advanced information infrastructure in the late 1980s and early 1990s.

Table 1: Descriptive Statistics of Computer and Fiber Optic Infrastructures LEC Level

Descriptive	No. Sites			All Systems MIPs			Fiber Optic (Miles)		
Statistics	1986	1989	1992	1986	1989	1992	1986	1989	1992
Total	13257	12988	11836	112,476.2	258,666.6	553,093.5	265472	2443449	6316436
MEAN	131.3	128.6	117.2	1,113.6	2,561.1	5,476.2	2,628.4	24,192.6	62,539.0
MEDIAN	47	48	41	270.2	678.1	1,373.4	151	9138	22371
STD	218.2	208.9	184.9	2,030.7	4,477.0	9,497.3	7,148.3	37,972.0	89,721.6
CV	166.2	162.4	157.8	182.3	174.8	173.4	272.0	157.0	143.5
MIN	0	0	0	0	0	0	0	0	0
MAX	1291	1261	1071	12,980.4	27,042.2	59,630.1	50553	203561	451356

In Table 1 we see that our three indicators of the stock of information infrastructure experienced changes in the distribution during the period 1986-1992. The number of sites that used large-scale computers decreased during the period, while the computer processing capacity and the deployment of fiber optic grew remarkably fast. The total number of millions of instructions per second (All Systems Mips) was almost five times larger in 1992 than in 1986. The miles of fiber optic deployed by the 101 largest LECs was nearly 24 times larger in 1992 than in 1986. The situation in 1986, when around 28% of the 101 LECs did not have fiber optic deployed in their operating areas, contrasts dramatically with the situation in 1992, when just around 4% did not. This advanced IT capital has diffused at an extraordinarily rapid rate. The only comparable historical precedents for this kind of growth are the well-known massive efforts behind the building of other communication or transportation infrastructure -- i.e., the building of miles of post-civil war rail, pre-civil war telegraph lines, turn-of-the-century telephone and (slightly later) electrical lines, and miles of post world-war II national highways.

The percentage of population living in regions with relatively low stock of information infrastructure is small. Less than 15% of the population of the 101 largest LECs are served by LECs that have less than the median Number of Sites, All Systems Mips and Fiber Optic. In the case of fiber, the fraction of population that is served by the LECs that belong to the top ten percentile has increased from 15.4% in 1986 to 44.25% in 1992.

In the descriptive statistics we see hints that the geographic dispersion of the three variables increased during 1986-1992. The coefficient of variation of the geographic distribution of large-scale computer users, Mips and Fiber Optic is consistently lower across the years. The largest changes in the coefficient of variation of the geographic distributions of Mips and Fiber Optic occurred during the period 1986-1989.

In Table 2 we present the descriptive statistics of access indices in two different forms. One includes Washington D.C. in the sample and one does not.[29] Clearly, there is variance in the level of access to advanced IT across the U.S. While it is difficult to evaluate whether these differences are large or small, as there is no natural baseline against which to compare them, the degree of access increases over the time in three of the indices -- fiber/mile, MIPS/pop, and the networking index. We note that there is little to be inferred from declines in site/pop, since the total number of sites is declining nationwide, potentially due to the client/server revolution, while the total number of MIPS/pop grows dramatically.

Table 2: Indices of Access to Computer and Fiber Optic Infrastructures Descriptive Statistics: LEC Level

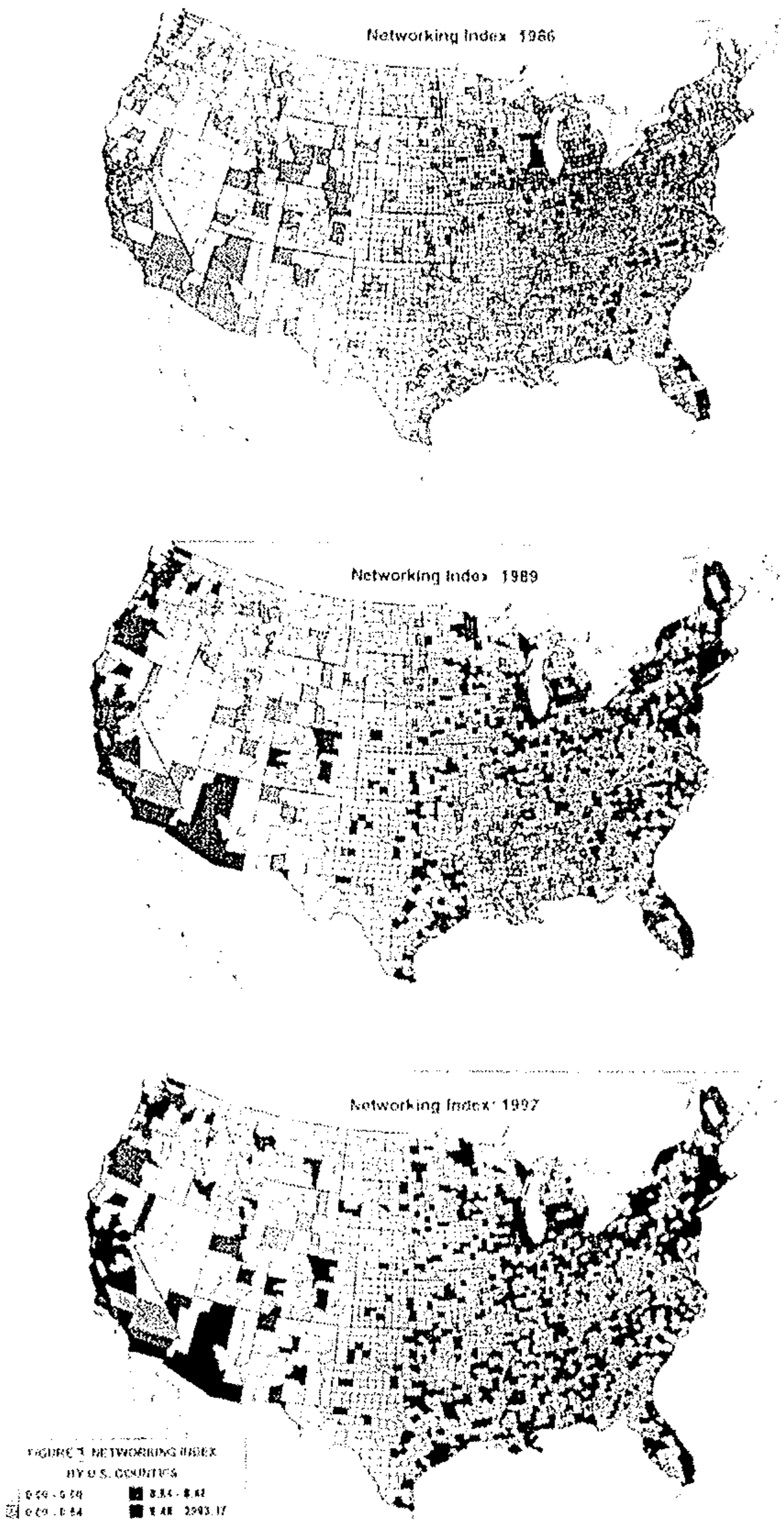
	Fiber Optic /Land			**All Systems MIPs /Pop**			**Number of Sites /Pop**			**Net-Working Index**		
	1986	**1989**	**1992**	**1986**	**1989**	**1992**	**1986**	**1989**	**1992**	**1986**	**1989**	**1992**
Washington D.C. Included												
MEAN	0.153	3.363	7.628	0.408	1.007	2.066	0.059	0.059	0.052	0.117	10.969	43.317
STD	0.424	14.942	31.725	0.424	1.328	2.259	0.102	0.102	0.078	0.552	79.895	298.049
CV	277.700	444.400	415.900	103.750	131.800	109.330	172.400	173.980	151.400	470.244	728.365	688.068
MIN	0	0	0	0	0	0	0	0	0	0	0	0
MAX	2.564	148.800	312.522	2.593	10.782	15.130	1.026	1.256	0.779	5.240	800.180	2983.170
Washington D.C. Excluded												
MEAN	0.134	1.908	4.579	0.386	0.964	1.991	0.058	0.057	0.050	0.066	3.077	13.918
STD	0.382	3.119	8.262	0.364	1.259	2.141	0.101	0.101	0.077	0.201	9.663	39.461
CV	285.190	163.459	180.440	94.202	130.634	107.511	175.855	177.516	153.734	304.024	314.047	283.522
MIN	0	0	0	0	0	0	0	0	0	0	0	0
MAX	2.564	15.601	63.143	2.577	10.782	15.130	1.026	1.256	0.779	1.274	85.934	326.132

Finally, Figure 3 summarizes the network capacity index in a picture. It classifies the LECs' geographic areas by the level of their networking indices in 1986, 1989, and 1992. The darkest group corresponds to those areas with a networking index in the top decile of the distribution for 1989. The second darkest group (dark grey) represents the areas with a networking index above the median but below the top decile in 1989. The next lightest shade (of gray) is for those areas with a networking index above zero and below the median in 1989. Areas with nothing are white.[30] We apply the same cardinal levels for determining the shades to the maps for 1986 and 1992.

[29] Washington D.C. is the only major urban hub of such a small geographic size to be so dense, to have its own telephone regulator and report separate statistics to the FCC. Washington D.C. is a dense urban area comprised of much administrative work and low residential population and small geographic area. As a result, it reports extraordinarily high per/capita and per/mile statistics for all our infrastructure data. This one observation strongly skews the distribution of any access statistic we construct. We are fairly certain that similar statistics would result if we could collect them for a comparable area of downtown Manhattan, Boston's financial district, Chicago's business loop, downtown San Francisco, or any other major urban hub. However, all these other urban areas are combined with much of the residential outlying regions to form the LEC territory.

[30] Though our rankings come from networking indices computed at the LEC level, we white out all counties where we do not find any large-scale computer users (even if the local telephone company primarily responsible for

Figure 3. Networking Index by U.S. Counties



that county has fiber optics in other parts of itsregion). This is an approximation and, yet, a more accurate visualization of the distribution of access since it also reflects the distribution of industry and population. Fiber optics in the local exchange are unlikely to be located where there is no industry.

As we can see from the maps, in any given year, advanced IT agglomerates in a few regions. The highest levels of information infrastructure are located in the big urban centers of the U.S. No single region or small number of cities, with the possible exception of Washington DC (as noted above), dominates the country. Overall, the distribution follows the U.S. population, and it appears from the picture that the major urban centers have the most advanced infrastructure. In 1992, the top areas include LECs that cover San Francisco, San Diego, and Los Angeles, Seattle, Tucson and Phoenix, Denver, Houston, Dallas, Minneapolis, Chicago, St. Louis, Detroit, Indianapolis, Cincinnati and Cleveland, Pittsburgh and Philadelphia, Buffalo, New York City and environs in Connecticut and New Jersey, Boston, Washington D.C. and its environs, Raleigh-Durham, Atlanta, Miami, St. Petersburg and Tampa.

Second, much has changed over time as there is investment in advanced IT infrastructure. All three maps together illustrate growth over time (as they get darker over more and more regions). In 1986 only six LECs had a networking index above the 1989 median. In contrast, in 1992 there were 33 LECs with a networking index above the 1989 top decile. Looking at the evolution over time, differences between regions never completely disappear. Yet, we also observe changes in those areas that occupy the different ranks.

IV. EXPLAINING THE CROSS SECTIONAL DISTRIBUTION

The location of information infrastructure in a region depends on the supply and demand for investment, which depends on particular characteristics of the region and many other complex factors. Below we offer a summary of the factors that influence the agglomeration of infrastructure in some regions and not others. A simple regression describes the cross-sectional pattern of information infrastructure during 1986, 1989, and 1992. Our main point is that the density of human settlement and the location of industry alone explain much of the geographic pattern of advanced information infrastructure, though certainly not all of it. In addition, we also show that the pattern of IT capital is less concentrated in regions specialized in information technology intensive activities than in regions specialized in less IT intensive activities. This suggests that dispersion of IT-using industries contributed to increasing the dispersion of advanced IT in the 1990s.

1. A Descriptive Regression

We estimate a reduced form equation for the networking index existing in a region as a function of a set of demographic and economic variables of the region. The data correspond to the 101 local exchange companies over the years 1986, 1989, and 1992.

We explain advanced information infrastructure by the local per capita income, population density, the fraction of the local employment devoted to finance, insurance, and real state (FIRE), the size of urbanized and rural populations, and a set of dummy variables that describe the characteristics of the region's main cities.[31]

[31] An explanation for the construction of these variables can be found in Greenstein and Spiller [1997].

Local per capita income directly measures the earnings of the local population, but it is also correlated with other factors, such as tax revenues, high-value-added businesses in the region and so on. Population density, urbanized population, and rural population are key factors in the decision to deploy fiber optic cable and advanced computing. Urbanized population represents the population served by the LEC in cities with a population of 50,000 or more, while rural population represents rural settlements with less than 5,000 people. The fraction of local employment in FIRE identifies the importance in the local economy of a group of activities intensive in data processing and transmission. All these variables, except rural population, should have a positive impact on the location of information infrastructure.

We also include a set of dummies to identify the characteristics of the cities included within the boundaries of the local exchange company. One of these dummy variables measures whether the LEC contains within its boundary a city with a population over a quarter million inhabitants in 1990. This variable captures the existence of a critical mass of potential business users of information infrastructure located in an urban hub. Another dummy variable specifies whether the LEC covers an area considered (by the U.S. census) as one of the fifty fastest growing areas in the U.S. between 1980 and 1990. Most of the fast growing areas in the 1980s were extensions of suburban communities, rather than concentrated urban hubs; this variable could predict under-deployment of advanced information technologies or the opposite, depending on whether recent growth makes deployment of advanced information technology easier or more difficult.

Descriptive statistics for the variables in the regression are presented in Table 3, and the regression results are in Table 4. A test of structural change shows that we can reject the hypothesis that the regression parameters are the same not only in the three years taken together, but also in either of the sub-samples of 1986-1989, 1986-1992, and 1989-1992. Thus, we report a separate regression equation for each year. In these the explanatory power of the regression increases over time (the R-squared increases), suggesting that the distribution becomes easier to predict as cumulative investment resulted in large unchanging capital stocks in many places. Yet, the elasticities of the important variables also change from one year to another, suggesting overall that the relationship between advanced infrastructure and exogenous factors is changing over time.

We see that density predicts advanced infrastructure location. In 1986, a 10% increase in population density led to a 0.8% increase in the networking index, while in 1992 it led to 3.8%. Variation in population density across regions induces substantial differences in the networking indices prevailing in those regions. In 1986, when evaluating the impact of other regressors at their mean level, one standard deviation around the mean of log of population density showed that the networking index fluctuated from 0 to 0.20. During that year approximately 90% of the sample had a networking index in this range. A similar calculation at the mean of log of population density in 1992 would have created a fluctuation in the networking index from 2.362 to 7.939. This interval includes the middle 20% of the sample in 1992.

Infrastructure also appears to be a complex function of density. While the fraction of urban population in a county increases the amount of infrastructure, the presence of a city with population over a quarter million within the boundaries of an LEC makes a difference in the level of the networking index too. Holding constant the influence of other variables, the presence of a relatively large city increases the expected value of the networking index by 65%. The variable FASTGROW decreases the expected value of the networking index by

63% in 1992. These results suggest that the largest agglomerations of advanced infrastructure are found in dense urban areas with established cities in the US -- the traditional financial centers -- not those growing rapidly with suburban sprawl.

Table 3: Descriptive Statistics Endogenous and Exogenous Variables

	MEAN	STD. DEV	MEDIAN	MIN	MAX	NUM. OBS
ENDOGENOUS VARIABLE						
LOG (1+NETWORKING INDEX)						
1986	0.070	0.226	0.003	0.000	1.831	101
1989	0.781	1.089	0.348	0.000	6.686	101
1992	1.612	1.489	1.322	0.000	8.001	101
EXOGENOUS VARIABLES						
LOG PERCAPITA INCOME						
1986	9.544	0.155	9.537	9.229	9.919	101
1989	9.600	0.161	9.579	9.283	10.027	101
1992	9.630	0.147	9.616	9.298	10.045	101
LOG POPULATION DENSITY						
1986	4.460	1.303	4.397	1.442	9.249	101
1989	4.482	1.310	4.439	1.442	9.227	101
1992	4.515	1.305	4.480	1.429	9.162	101
FRAC POP EMPLOYED IN FIRE						
1986	0.067	0.017	0.067	0.034	0.117	101
1989	0.066	0.018	0.065	0.034	0.118	101
1992	0.064	0.017	0.062	0.032	0.116	101
CITY OF HALF MILLION	0.178	0.385	0.000	0.000	1.000	303
CITY OF QUARTER MILLION	0.376	0.487	0.000	0.000	1.000	303
FAST GROWING AREA	0.149	0.357	0.000	0.000	1.000	303

Table 4: Log Networking Index OLS Regression Results

Regressors	All Years	1986-1989	1989-1992	1986	1989	1992
Dummy 1986	-7.399 -(1.348)	-5.504 -(1.245)		1.572 (0.965)		
Dummy 1989	-6.710 -(1.216)	-4.815 -(1.089)	-11.926 ** -(1.760)		-10.393 -(1.557)	
Dummy 1992	-5.879 -(1.064)		-11.104 -(1.635)			-14.914 -(1.293)
LNPERCAP	0.506 (0.846)	0.409 (0.858)	0.952 (1.294)	-0.190 -(1.085)	0.861 (1.192)	1.293 (1.038)
HALFMIL	-0.058 -(0.322)	0.008 (0.004)	-0.133 -(0.636)	0.117 (1.516)	-0.094 -(0.365)	-0.173 -(0.562)
QUARTMIL	0.272 * (2.009)	0.127 (0.957)	0.443 * (2.522)	0.018 (0.530)	0.287 (1.341)	0.603 * (2.235)
FASTGROW	-0.283 * -(2.603)	-0.161 -(1.629)	-0.408 * -(3.141)	0.027 (0.487)	0.324 -(2.376)	-0.475 * -(2.334)
FIREEMP	13.485 * (2.430)	6.554 (1.386)	17.800 * (2.549)	-0.448 -(0.288)	11.741 (1.618) *	22.630 ** (1.975)
LNPOPDEN	0.379 * (6.940)	0.272 * (4.487)	0.518 * (8.035)	0.070 ** (1.850)	0.467 * (5.117)	0.557 * (6.292)
Adj. R-squared	59.485	46.662	66.872	17.300	61.452	66.783
Number Observed	303	202	202	101	101	101
Residual Sum of Squares	183.652	76.789	119.919	3.970	42.934	69.237

Numbers in parentheses are t-statistics. All standard errors and associated t-statistics in the table were computed using White's covariance matrix estimator and are heteroskedastic-consistent.
* Significant at 5%
** Significant at 10%

We see evidence that industry and income matter. This is provided by the importance of FIRE. A larger fraction of employment in FIRE represents a large financial and white-collar sector. This increases the information infrastructure index. Broadly interpreted, it is not surprising that administrative work and infrastructure move together, but it is difficult to infer causality from this in the long run. Also, per capita income becomes important in the last two years of the sample. The implied elasticity on income in 1992, which is 1.9, suggests that rich regions tend to have more infrastructure.

Finally, we note a puzzling pattern over time. In the restricted regression, where all coefficients except the time dummies are set equal, the implies rates of growth are enormous. The difference in the time dummies imply an average of 70 percent growth in information infrastructure across all the observations between 1986 and 1989, holding constant for other factors. Similarly, we see a 100% growth between 1989 and 1992. Yet, when the coefficients are allowed to differ across years, much of these differences over time show up as differences in the relationship between infrastructure and its predictors. This suggests that the distribution of infrastructure may be changing over time as the relationship between infrastructure andexogenous factors change. These changes may reflect a resettling of post-divestiture investment patterns in telecommunications and a change in computing investment in response to the networking revolution. Since several factors simultaneously influence this result, further work will need to disentangle its components.

In sum, densely populated areas tend to have more access to infrastructure, with the most densely populated cities having the most advanced infrastructure. Yet, agglomeration reflects more than just density. It helps to be a rich area, as well as one with a larger white-collar sector, and it does not help to be one experiencing recent rapid growth in population. In addition to these cross-sectional features, there is more advanced infrastructure everywhere over time, a trend which resulted in virtually all areas deepening their advanced information capital at extraordinarily rapid rates.[32] The relationship between exogenous factors and advanced IT also seems to be changing over time; this motivates further analysis of the changes to the distribution.

2. Location of Information Technology Intensive Economic Activities

In this section, we take advantage of additional information found in the computer user surveys to characterize the role of white-collar activity in determining the location of information infrastructure. CII reports the primary industry for each computer using site. We use this information to analyze the contribution of the distribution of different information-intensive activities to the observed distribution of infrastructure.

Table 5 shows that the economic activities with the larger number of sites using large-scale computers were, in 1992, business services, wholesale trade, education services, depositary institutions, insurance carriers, health services, and computers and related equipment.[33] These activities accounted for 46% of the total number of sites. The question we investigate is this: if these intensive users of information technology did not alter their location in response to more investment in advanced IT, would more investment lead to more or less agglomeration of advanced IT? We can get some evidence by looking at the geographic distribution of information-intensive users.

[32] Because of the skewness of the data and the presence of outliers, we were concerned that OLS does not properly model the determinants of infrastructure. In Greenstein and Lizardo [1997] we perform quantile regressions (Koenker and Bassett [1978]) that allow us to estimate different points of the conditional distribution of the networking index. Our inferences did not substantially change, so we only report the OLS results here.

[33] This excludes federal/state/local government.

Table 5: Characteristics of the Distribution of All Systems MIPs by Group of Economic Activities, 1992

Economic Activities	SIC Groups	Econ. Activ. Share All Sys MIPs	Num LECs w/Bus in Econ. Activ.	GINI Coefficient Distrib. of Capacity Specializ. Index
Federal/State/Local Government	91-97	14.85	85	0.593
Business Services	73	11.93	79	0.604
Wholesale Trade	50-51	2.64	73	0.695
Education Services	82	6.63	83	0.647
Depositary Institutions	60	5.30	81	0.716
Insurance Carriers	63	7.95	66	0.618
Health Services	80	4.09	77	0.638
Computers and Related	35, 365-368	5.44	67	0.720
Legal, Social, Engin. Serv., Museums	81,83,84-89	3.50	55	0.764
Misc. Retail	52,55-59	1.83	58	0.782
Printing and Publishing	27	1.46	57	0.717
Manufacturing	21-25, 29	1.74	59	0.871
Chemicals	28	2.38	44	0.862
Misc. Manufacturing	30-32, 39	0.91	60	0.865
Transportation Services	40-47	2.99	47	0.785
Insurance Brokers and Real Estate	64-69	2.27	48	0.787
Fabricated Metals	34	0.46	49	0.831
Electrical Apparatus	361-364, 369	1.08	45	0.894
Food Products	20	0.96	48	0.909
Gas and Sanitary Services	492-495	1.61	52	0.796
Other Transportation Equip.	372-379	2.67	46	0.858
Instruments	38	0.95	42	0.872
Motor Vehicles and Equip.	371	1.31	39	0.876
Primary Metals	33	0.52	46	0.934
Security and Commercial Brokers	62	1.94	27	0.891
Electric Services	491	1.49	55	0.785
Food Stores	54	0.49	40	0.863
General Merchandise Stores	53	1.71	42	0.883
Non-Depositary Institutions	61	1.24	43	0.852
Paper and Allied Products	26	0.57	42	0.847
Telephone Communication	481	3.09	44	0.765
Hotel, Personal Services	70-72,75-79	0.62	30	0.903
Mining and Construction	10-12, 14-17	0.64	37	0.922
Other Communication Services	482-489	0.31	28	0.906
Oil and Gas Extraction	13	2.35	13	0.950
Agric, Forestry, Fish., and Hunting	1,2,7,8,9	0.08	17	0.964
Descriptive Statistics				
Mean		2.78	50.67	0.810
Std. Dev.		3.19	17.65	0.103
Median		1.72	47.50	0.850
Min		0.08	13.00	0.593
Max		14.85	85.00	0.964

Economic Activities are presented in descending order of Share of Sites.

$$\text{Index} = \frac{\text{Mips in Region i used in Activity j/Mips in Region i}}{\text{National Mips used in Activity j/ National Mips}}$$

We employ an index of geographic specialization in computer intensive economic activities that follows Krugman [1991]. We construct an index that measures the degree of specialization of the computing capacity existing in a region in a particular economic activity. For each group of economic activities we construct the index as follows:

If, for a given economic activity j, a region shows a ratio greater than one, we say that the computing capacity existing in this region is more specialized in the generation of activity j than is the computing capacity existing in the rest of the regions that present a ratio less or equal to one.

Table 5 shows a high inequality of computing capacity across information-intensive sites relative to less information technology intensive economic activities. The distribution of the computing capacity across regions is relatively less concentrated in the former group of activities than in the latter. Moreover, economic activities included in the former group are developed in a much larger number of regions.

For those activities less intensively using information technology, the geographic distribution of the specialization index of computer capacity looks like the locational pattern of industrial employment discussed in Krugman. Many industries in the U.S. are highly geographically concentrated and most of these industries are not high tech sectors. Table 5 suggests, therefore, that the agglomeration (or lack thereof) of advanced information infrastructure is partially a function of the growth of information intensive industries, which, themselves, are more dispersed than the average industry.

We must state these conclusions carefully. At most we can say that the geographic distribution of white-collar industries contributes to a greater spread of advanced information infrastructure than would be typically found for an important input in non-information intensive industries, such as manufacturing. As a greater fraction of the economy moves into these information-intensive industries, this movement could contribute to the spread of information infrastructure. As yet, this evidence does not allow us to assign any causality. Does the cheaper input cause the information intensive activities to expand or does the expansion of these industries cause the spread of advanced IT? These are simultaneous events and the present methods can only allow us to make the association between them. To make further inferences about the contribution of white-collar work to the geographic diffusion of advanced information technology, we need further evidence on the changing geographic distribution of information-intensive work over time.

V. CHANGES TO THE DISTRIBUTION OF INFRASTRUCTURE

We now summarize changes to the distribution of advanced information infrastructure. We use a standard set of measures found in the study of income inequality and the study of infrastructure in developing countries: quantile ratios, the decile distribution ratio, and the Gini coefficient. We use all three to show that our results are not sensitive to method; using all three we find that advanced IT became less agglomerated over this period.

The analysis of quantile ratios allows us to compare the proportionate movement of the different quantiles of the distribution of the variable of interest. The quantile ratio is defined as the ratio Qth-quantile/Median. The comparison over time of these ratios illustrates whether the quantiles are moving closer to each other or if they are moving apart over time. A simpler and related measure is the Decile Distribution Ratio (DDR), which is the ratio of the share of the bottom 40% in relation to the share of the top 20%. When inequality decreases, this ratio increases. Finally, the Gini coefficient is defined as:

$$G = \frac{1}{2n^2 \overline{y}} \sum_{i=1}^{n} \sum_{j=1}^{n} | y_i - y_j |$$

where y_i and y_j are the values taken by the variable in regions i and j, and n is the total number of regions. The definition corresponds to the average difference between all possible pairs of the variable among the regions, expressed as a proportion of the total sum of the variable. The Gini coefficient takes values in the interval [0,1], 0 representing total equality, and 1 representing the maximal inequality.

1. Changes to Information Infrastructure

The quantile ratios (Table 6) show that the information infrastructure rich do not seem to be getting richer, and the poor are improving their relative position. The bottom halves of the geographic distributions of MIPs, Sites and Fiber are getting closer to their medians. In the case of MIPs and Sites, there is no clear tendency in the movement of the quantile in the upper half of the distribution. In the case of Fiber, there is a tendency toward equalization of the amount of fiber deployed by the upper half of the distribution in relation to the median.

Table 6: Quantiles and Quantile Ratios Geographic Distribution of Computer and Fiber Optic Infrastructures

	No. Sites			All Systems MIPs			Fiber Optic (Miles)		
	1986	1989	1992	1986	1989	1992	1986	1989	1992
Quantiles									
10th	2	2	2	6.2	14.0	61.9	0	487	1,397
20th	13	13	13	52.3	109.9	274.5	0	2,053	5,442
30th	20	23	22	116.7	254.4	637.3	13	3,248	8,227
40th	32	34	30	206.9	471.6	963.4	89	4,830	15,344
50th	47	48	41	270.2	678.1	1,417.7	151	9,138	22,371
60th	69	63	60	492.8	1,261.9	3,023.2	365	14,798	42,111
70th	114	116	108	874.4	1,942.6	4,506.8	557	23,611	62,067
80th	197	194	173	1,774.9	3,536.4	7,931.6	1,390	33,848	93,111
90th	301	310	291	2,879.7	7,007.3	15,365.3	9,027	70,505	189,508
99th	942	873	796	8,816.4	18,709.7	44,205.7	33,837	184,734	385,781
Quantile Ratios									
10th	0.029	0.032	0.033	0.013	0.011	0.020	0.000	0.033	0.033
20th	0.188	0.206	0.217	0.106	0.087	0.091	0.000	0.139	0.129
30th	0.290	0.365	0.367	0.237	0.202	0.211	0.036	0.219	0.195
40th	0.464	0.540	0.500	0.420	0.374	0.319	0.244	0.326	0.364
50th	0.681	0.762	0.683	0.548	0.537	0.469	0.414	0.618	0.531
60th	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
70th	1.652	1.841	1.800	1.774	1.539	1.491	1.526	1.596	1.474
80th	2.855	3.079	2.883	3.602	2.802	2.624	3.808	2.287	2.211
90th	4.362	4.921	4.850	5.844	5.553	5.082	24.732	4.764	4.500
99th	13.652	13.857	13.267	17.890	14.827	14.622	92.704	12.484	9.161

Quantile Ratios = Qth-Quantile/Median

Table 7 shows that the ranking patterns of geographic areas according to the number of sites and total amount of MIPs seems to be quite stable over time. This is easy to explain since the unit of observation is not scale free. That is, despite rapid rates of growth overall, the bigger areas are still bigger and the smaller areas still smaller. Hence, this is some evidence that the networking revolution did not alter the geographic distribution of computing stocks in any dramatic way.

Table 7 : Spearman Correlation Matrix Geographic Distribution Computer and Fiber Optic Infrastructures

		No. of Sites			All Systems Mips			Fiber Optic Cable		
		1986	1989	1992	1986	1989	1992	1986	1989	1992
No. of Sites	1986	1.00	1.00	1.00	0.97	0.97	0.97	0.72	0.86	0.85
	1989		1.00	1.00	0.97	0.97	1.00	0.73	0.87	0.86
	1992			1.00	0.97	0.97	0.97	0.73	0.86	0.86
All Systems Mips	1986				1.00	0.99	0.98	0.73	0.85	0.85
	1989					1.00	0.99	0.72	0.85	0.84
	1992						1.00	0.74	0.86	0.85
Fiber Optic Cable	1986							1.00	0.83	0.83
	1989								1.00	0.94
	1992									1.00

* All coefficients have a p-value of 0.0001

Fiber optics, however, do not show an identical pattern. The ranking pattern of geographic areas has changed between 1986 and 1989. Closer examination, not shown in the tables but revealed by the raw numbers in the appendix of GLS [1997], shows that the changes in the ranking pattern are due to changes in the deployment of fiber in the geographic areas that occupy the mid-size positions, and not in the areas that occupy the extreme positions of the ranking pattern. That is, areas that had a very small or a very large deployment of fiber optic in 1986 continue holding their position in the 1992 ranking pattern, but there was much growth among LECs with middle size fiber deployments. We conjecture that a rearrangement of investment patterns in the post-divestiture era altered in the ranking of regions in infrastructure.

The Gini coefficient and the Decile Distribution Ratio, shown in Table 8, reveal that the level of the two computer infrastructure variables show a slight reduction in inequality among regions.[34] The Decile Distribution Ratio corresponding to Number of Sites is almost twice the ratio for All Systems Mips, implying that the presence of users of large-scale computers has become more concentrated in regions where the presence had been low, but these users are basically small capacity users.

[34] The Gini coefficient of the geographic distribution of number of sites decreased from 0.678 in 1986 to 0.662 in 1992, while the Gini coefficient of the distribution of All Systems MIPs decreased from 0.718 in 1986 to 0.702 in 1992.

Table 8: Measures of Inequality of the Geographic Distribution Computer and Fiber Optic Infrastructures

	1986	1989	1992
GINI COEFFICIENTS			
Number of Sites	0.667	0.669	0.661
All Systems Mips	0.718	0.708	0.702
Fiber optic	0.856	0.671	0.651
DECIL DISTRIBUTION RATIOS			
Number of Sites	0.056	0.060	0.066
All Systems Mips	0.031	0.035	0.037
Fiber optic	0.003	0.049	0.054

The changes in the distribution of computing capacity at the regional level are surprising, considering the increasing skewness of computing capacity at large-scale computing sites. That is, the sites themselves are becoming more concentrated even though regions are not.[35,36] The Decile Distribution Ratio shows the same pattern. Further, there is a reduction in inequality of Fiber Optic cable. Although the major changes occurred from 1986 to 1989, the reduction of the inequality in the geographic distribution of fiber optic deployment continued to 1992.[37]

In summary, advanced IT grew tremendously over this time period. The degree of agglomeration declined along with that growth (though IT infrastructure did continue to agglomerate in urban areas at any point in time). Much of this change in the degree of agglomeration is due to growth in fiber at many localities, but some of it also appears to be due to the geographic spread of computing capital (despite the reduction in the number of sites). Since these are not scale-free observations, we are cautious about inferring much about changes to the access to advanced IT, which we analyze below. However, we note that the large decline of any areas with "no fiber," principally among smaller rural areas, suggests that we will find an increase in access to infrastructure at the lower end of the distribution.

2. Changes to the Distribution of Access to Information Infrastructure

We turn now to our analysis of changes to the access to information infrastructure, a more scale-free measure of the distribution. Table 9 compares the quantile ratios in 1992, 1989 and 1986. We find that for all indices almost all of the quantiles are getting closer to the

[35] A smaller fraction of the sites is holding a large percentage of total MIPS. The Gini coefficient of the site distribution of All Systems MIPs (across all sites), presented in Table 5, was 0.729, 0.733, and 0.750 in 1986, 1989, and 1992, respectively.

[36] Just 25 local exchange operating areas show a reduction of the Gini coefficient of the site distribution of All Systems Mips from 1986 to 1992, 34 from 1986 to 1989, and 33 from 1989 to 1992. In only 8 local exchange operating areas the Gini coefficient of the site distribution of Total Mips systematically decreased during the years 1986, 1989 and 1992. These places were United in Florida, Cincinnati Bell in Kentucky, United in Missouri, North western Bell in Nebraska, New Jersey Bell, United in Pennsylvania, United in Tennessee, and US WEST in Wyoming.

[37] The Gini coefficient decreased from 0.855 in 1986 to 0.67 and 0.65 in 1989 and 1992, respectively.

median in 1992. Much of this is due to greater diffusion of information technology in geographic areas where the access to this technology used to be low, but some is also due to declines in the relative lead of areas where infrastructure is high.

Table 9: Quantiles and Quantile Ratios Geographic Distribution Indices of Access to Computer and Fiber Optic Infrastructure

	Fiber Optic / Land			All Systems MIPS / POP			Number of Sites / POP			Net-Working Index		
	1986	1989	1992	1986	1989	1992	1986	1989	1992	1986	1989	1992
Quantiles												
10TH	0.000	0.044	0.253	0.032	0.084	0.137	0.016	0.017	0.014	0.000	0.006	0.017
20TH	0.000	0.184	0.660	0.094	0.248	0.525	0.024	0.026	0.022	0.000	0.043	0.416
30TH	0.001	0.340	1.117	0.138	0.375	0.887	0.031	0.035	0.030	0.000	0.123	0.679
40TH	0.009	0.455	1.404	0.229	0.491	1.253	0.040	0.041	0.039	0.001	0.214	1.336
50TH	0.014	0.643	1.775	0.320	0.749	1.661	0.048	0.047	0.044	0.003	0.406	2.678
60TH	0.024	0.854	2.409	0.423	0.949	2.065	0.055	0.053	0.050	0.009	0.578	4.142
70TH	0.044	1.401	3.477	0.505	1.163	2.415	0.062	0.060	0.055	0.023	1.146	7.784
80TH	0.085	2.749	6.194	0.624	1.440	3.036	0.071	0.067	0.059	0.049	2.801	15.173
90TH	0.250	5.367	11.186	0.733	1.771	3.605	0.079	0.078	0.069	0.109	7.485	32.702
99TH	2.161	14.679	47.038	2.036	8.145	14.049	0.593	0.588	0.464	1.172	59.077	260.784
Quantile Ratios												
10TH	0.000	0.016	0.041	0.051	0.058	0.045	0.223	0.252	0.236	0.000	0.002	0.001
20TH	0.000	0.067	0.106	0.151	0.172	0.173	0.344	0.381	0.371	0.000	0.015	0.027
30TH	0.009	0.124	0.180	0.221	0.261	0.292	0.437	0.513	0.513	0.001	0.044	0.045
40TH	0.104	0.165	0.227	0.367	0.341	0.413	0.559	0.607	0.657	0.023	0.076	0.088
50TH	0.160	0.234	0.287	0.513	0.520	0.547	0.679	0.702	0.741	0.056	0.145	0.176
60TH	0.275	0.311	0.389	0.678	0.659	0.680	0.773	0.781	0.851	0.189	0.206	0.273
70TH	0.513	0.510	0.561	0.810	0.808	0.796	0.869	0.893	0.932	0.468	0.409	0.513
80TH	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
90TH	2.932	1.953	1.806	1.175	1.230	1.187	1.117	1.156	1.174	2.232	2.673	2.155
99TH	25.298	5.340	7.594	3.265	5.656	4.628	8.347	8.742	7.867	24.066	21.094	17.187

*Washington D.C. is excluded.

In Table 10 we observe a high correlation among the index of access to computing technology and the index of power of computing capacity (0.92, 0.90, and 0.88 in 1986, 1989, and 1992, respectively). Similarly, the correlation over time of Number of Sites/ Population shows that for this access index the ranking of geographic areas stayed basically the same over the years. The small changes that have occurred in the ranking pattern of All Systems MIPs/Population are due to changes in the rank of those regions that are between the 20^{th} and 80^{th} percentile of the distribution. That is, the position of the smallest stays the same over time, as well as the ranking of the largest. Only the middle rankings have changed significantly.

Table 10: Spearman Correlation Matrix of Indices of Access to Computer and Fiber Optic Infrastructures

		Total Mips/ Pop			No. of Sites/ Pop			Fiber Optic/ Land			Net-working Index		
		1986	1989	1992	1986	1989	1992	1986	1989	1992	1986	1989	1992
Total Mips/ Pop	1986	1.00	0.97	0.92	0.92	0.91	0.86	0.48	0.50	0.56	0.60	0.77	0.80
	1989		1.00	0.94	0.92	0.90	0.87	0.45	0.49	0.54	0.56	0.77	0.80
	1992			1.00	0.87	0.88	0.88	0.44	0.43	0.47	0.54	0.71	0.78
No. Sites/ Pop	1986				1.00	0.98	0.93	0.43	0.50	0.55	0.54	0.73	0.77
	1989					1.00	0.96	0.44	0.50	0.55	0.55	0.73	0.77
	1992						1.00	0.39	0.45	0.49	0.49	0.67	0.73
Fiber / Land	1986							1.00	0.64	0.66	0.97	0.67	0.68
	1989								1.00	0.94	0.65	0.89	0.22
	1992									1.00	0.68	0.88	0.86
Net-working Index	1986										1.00	0.74	0.75
	1989											1.00	0.96
	1992												1.00

*All coefficients have a p-value of 0.0001.

Now we examine the Fiber/Land access index. The ranking in 1986 is different from the ranking pattern at the end of the period. Table 10 also shows that the places that have higher levels of Fiber/Land tend to be, in general, places with higher levels of Number of Sites/Population and All Systems MIPs/Population.[38] Thus, it is not surprising that the networking index shows that over time many regions contain a larger level of access to information infrastructure. Furthermore, the networking index indicates that the differences between regions are getting smaller.

Table 11 shows that most of the indices seem to have become more equally distributed across the period. As with our analysis above, the skewness in these data are somewhat deceptive. Going back to Table 2, we observe that most of the U.S. population lives within territories that are in the upper quartile. Most of the under-performing territories are also relatively unpopulated.

[38] In particular, the correlation among the Number of Sites/Population and Fiber/Land are 0.43, 0.52, and 0.48 in 1986, 1989, and 1992, respectively. The correlation among All Systems MIPs and Fiber/Land is around 0.48 in the three years.

Table 11: Measures of Inequality of the Geographic Distribution Indices of Access to Computer and Fiber Optic Infrastructures

	1986	1989	1992
GINI COEFFICIENTS			
No. Sites/Population	0.419	0.404	0.389
All Systems Mips/Population	0.459	0.494	0.464
Fiber/Land	0.851	0.680	0.657
Networking Index	0.868	0.826	0.796
Relative Information Infrastructure Index	0.033	0.036	0.035
DECIL DISTRIBUTION RATIOS			
No. Sites/Population	0.354	0.388	0.408
All Systems Mips/Population	0.222	0.200	0.237
Fiber/Land	0.005	0.059	0.084
Networking Index	0.001	0.010	0.144
Relative Information Infrastructure Index	1.844	1.829	1.831

In summary, there is less agglomeration over time in access to advanced information technology capital. This change in access is due to changes in the dispersion of fiber optics and computing. The changes to fiber are a post-divestiture phenomenon, so these results raise questions about the determinants of LEC investment in the post-divestiture era. The changes to computing occurred in spite of a gradual decline in the number of sites using large scale computing. This raises issues about the influence of the networking revolution on the regional dispersion of advanced IT. Finally, the high correlation in the location of these two components of infrastructure motivates a further examination of the co-determinants of these complementary inputs.

VI. Conclusion

In this study, we have examined the geographic distribution of advanced information infrastructure in computing and telecommunication between 1986 and 1992, a period of rapid growth. In all our estimates, we interpret the level of capital stock as a proxy for a broad variety of activities associated with building public and private digital IT networks in a region. Our findings may be summarized as follows:

- Advanced infrastructure grew at a tremendous rate in the late 1980s and early 1990s across all regions. Virtually every region experienced growth in advanced infrastructure and increasing access to it.
- Advanced IT grows rapidly in dense urban areas. Yet, density alone does not explain the location patterns of advanced IT.
- Areas with larger white-collar sectors also have more advanced information infrastructure. Information intensive industries also tend to be more geographically

dispersed than less information intensive industries, potentially contributing to the spread of advanced IT.

- Higher income areas and areas experiencing recent growth in urban population do not have more agglomeration of advanced IT.
- The US experienced changes in the distribution of infrastructure capital during a period of rapid growth. The large changes did not alter the relative rankings of the "richest" or the "poorest" regions, but did alter the relative disparity between them. It also altered many of the rankings of regions in the middle.
- During this period, increasing equality of access to advanced information infrastructure was not due to extreme changes in the ranking of regions. It was due primarily to the increase in the relative standing of regions on the bottom and relative declines in the regions at the top.

These conclusions need to be stated carefully. We cannot argue on the basis of available evidence that the distribution of advanced IT capital matches some policy-relevant notion of an appropriate distribution. Indeed, no such distribution can be precisely defined for concrete data since there are inherent ambiguities in measuring the distribution of infrastructure and access to it. However, we can conclude that the period prior to the commercialization of the Internet was one of rapid growth in advanced IT in the U.S. Furthermore, we can conclude that this period did not lead to an increased agglomeration of advanced IT capital. To the contrary, the evidence suggests increased dispersion. That is, all regions, rural and urban, whether initially ahead or behind, became more alike over time. By virtually any ideal, this movement is a good thing.

Other economic changes follow the growth in advanced information infrastructure, its standardization and its decline in price. Independent service providers, broadband access, forms of electronic commerce, and support services for digital communications and networking, for example, all work better with advanced telecommunications networks. Many business services tied to local labor markets for technical help will also be aided. On-line-transaction-processing of large data bases, such as credit checking, automated inventory restocking and reservation systems, all require advanced large-scale computing facilities to run well. Our analysis gives a positive conclusion to concerns about regional disparities in the backbone to advanced IT. Our findings suggest that only a small number of areas, in particular small and less densely populated regions, may not have direct access to advanced IT capital. Furthermore, most areas have improved over time, easing the diffusion of nationwide services and reducing the degree of disparities across regions.

Our results call for a more careful modulation of the debate regarding the redefinition of universal service in the new information infrastructure. The agglomeration of advanced IT followed a somewhat predictable economic logic -- locating in areas in relation to a few features of those areas, such as the presence of IT intensive industries, high income and density. The relative lead of the earliest investors did not seem to last for very long. It also seems that in this instance investment has decreased the concentration of advanced IT over the period. Further research of these patterns needs to understand the micro-economic determinants of investment in post-divestiture telecommunications and networking. Further work may also need to carefully focus on specific geographic areas of low access or specific populations whose experiences cannot be reflected in the data analyzed in this study.

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