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Excessive(?) entry of national telecom networks, 1990–2001

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ABSTRACT

This paper documents entry and capacity expansion in US long-distance fiber–optic networks before and during the "telecom boom." It disentangles the many swaps and leases between networks in order to measure owned route miles versus route miles shared with other carriers. Entry is still extensive, but more moderate when these shared miles are not counted. It concludes that entry was excessive primarily with regard to swaps and leases, but less so with regard to the physical building of the networks.

1. Introduction

During the late 1990s there was tremendous investment and entry of new firms in the North American long-haul telecommunications industry. These expansions were driven by very fast demand growth for Internet and other data-oriented telecom services and by exponential decreases in the cost per bit transmitted using fiber optic communications equipment. But by 2001, competition and slowing demand growth were squeezing the profits of these carriers, and an equally unprecedented slowdown in spending occurred. The problems in the telecommunications sector were blamed for slowing growth in the entire U.S. economy.

As the expansion turned to bust, discussion of "excessive entry" and a "fiber glut" became increasingly common. Generally the fiber glut story revolves around three premises. First, Internet growth was not as fast as expected, and in particular, not as fast as Worldcom claimed (Odlyzko, 2003a). Second, the still-high growth rate of data traffic was "…not nearly fast enough to use all of the millions of miles of fiber-optic lines that were buried beneath streets and oceans in the late-1990s frenzy." (Dreazen, 2002, p. B1). Third, the equipment used to send data over fiber optic cable improved dramatically so that each strand of fiber could carry many more gigabits of data: "Perhaps never before has the efficiency of an industry's technology gotten so far ahead of demand." (Berman, 2002, p. B1)

These gloomy statements have become the conventional wisdom: there was excessive entry of fiber–optic networks based on overoptimism and strategic behavior. This paper presents two important caveats to the fiber glut story, one conceptual and one empirical.

The conceptual caveat relates to applying railroad history to fiber networks. Both are long-distance transport infrastructure with expensive rights of way, and both have experienced boom and busts, but the economics only partially overlap. In fiber networks there is a big difference between sunk investments – actual miles of right of way – and non-sunk investments that create "virtual networks" through relatively fungible swaps and leases of conduit space and fiber. There was nothing equivalent to virtual networks in railroading, and that makes the fiber case very different.

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The empirical caveat is that many observers have assumed that stated route miles of fiber indicate the total length of the fiber–optic networks. This is only partially correct, because most public data mix real and virtual networks, creating confusion about the actual amount of sunk investment in facilities. This paper presents newly collected data that distinguishes the two types of networks, and finds that more than half of 1990–2001 investment was non-sunk. This makes the fiber boom easier to explain, and it also means there was less ‘‘capacity overhang’’ than many people thought.

Before moving further, it is important to clarify the industry segment under discussion. The national fiber–optic networks connect major cities using cable laid along railroad, gas pipeline, and other rights of way. This industry segment is not regulated by the FCC or other government agencies, except to the extent that there may be environmental and safety restrictions regarding rights of way. National networks sell high capacity links between specific cities and nationwide coverage to all cities. They are *not* the long-distance telephone companies or the Internet backbones; instead these two are their largest types of customers, and in several cases they are vertically integrated into these downstream segments. The most famous example is AT&T which during the period of this study also offered long distance telephone service; other firms like Level 3 offer their own Internet backbones. This paper focuses on the most basic level only—the physical infrastructure. These firms have additional interest because many of them were involved in scandals, including Worldcom, Global Crossing, Qwest, and Enron.

There are several complementary types of infrastructure that are not studied here. These include regional and metropolitan fiber–optic networks and local access networks such as telephone and cable television—the latter two are surveyed by Woroch (2002). Most of the traffic on the national networks has to traverse these other networks as well, but they operate in distinct markets—distinct in part because of the break-up of AT&T into national and regional components. It is not practical to provide national service by combinations of regional networks, nor is it practical to provide more than very limited regional service on a portion of a national network. While all types of networks experienced major investment in the late 1990s, it was the national fiber–optic networks that appeared to be the most ‘‘overbuilt’’ and were most implicated in the collapse.

The literature on long-haul telecom networks has primarily focused on economic geography. Rutherford, Gillespie, and Richardson (2004) discuss the topology of European long-haul networks and focus on the continued importance of national boundaries. Malecki (2002) shows that the Internet backbones (and by extension the long-haul networks they run on) mirror preexisting urban geographical relationships, and Gorman and Malecki (2000) show that different backbone networks have very different topologies which they change over time. The geographic distribution of U.S. Internet infrastructure is discussed in Greenstein (2005).

Several papers address oligopolistic capacity choices in Internet backbone markets; among these are Economides (2005) and Prüfer and Jahn (2007). Both of these papers discuss how competition in national fiber networks made entry quite easy in the backbone market. Little data have been collected on which firms entered when and where. Until 1998, Jonathan Kraushaar of the Federal Communications Commission published a yearly update on long distance fiber optic networks, but this was discontinued just as industry investment took off. This paper presents newly collected data that merges Kraushaar’s (1999) work with publicly available information on firms’ entry decisions up to the end of 2001.

Section 2 discusses the relevant theory of firm entry, investment, and sunk costs and applies it to the national fiber–optic network industry. It also compares the telecom crisis to the problems of late nineteenth century railroads. Section 3 describes data sources and methods of data collection. Analysis of the pattern of entry and the decrease in industry concentration is in Section 4. Section 5 concludes.

2. Sunk costs and fiber–optic networks

The building of the national fiber–optic networks is another chapter in the peculiar history of U.S. infrastructure industries. This history started with the canal boom of the early nineteenth century, reached its most dramatic episode in the railroad booms and busts of the late nineteenth century, and has continued since then with electricity transmission, trucking and Interstate highways, and long-distance telephone among others. All of these industries have been politically as well as economically important, and all have been characterized by financial instability and/or heavy government regulation.

In particular, the telecom boom and bust has been compared to the nineteenth century railroad experience, and the two do have many similarities (Miller, 2005; Odlyzko, 2010). In both cases, a large number of firms gained access to rights-of-way between major cities, built multiple parallel routes, and then engaged in intense competition that left many of them bankrupt. But even though the real-world characteristics of fiber–optic networks are similar to other infrastructure, the networks can be operated in a way that virtualizes them and confuses how extensive the real infrastructure is. These methods are detailed below.

Sunk costs can be described more precisely by looking at the game-theoretic literature in industrial organization. Sutton (1998) has argued that for any technology-intensive industry, entry can be modeled in two stages. In Stage 1, firms make irreversible investments that determine their characteristics, such as product variety or quality or geographic reach. These investments are industry-specific sunk costs, so the firms do not exit the market later in the game. In Stage 2, the firms compete according to Cournot, differentiated Bertrand, or some other type of competition. The terms of this competition are affected by the Stage 1 decisions. Sutton suggests that a very loose requirement for a solution to this game is a criterion of "viability." That is, firms will not make Stage 1 investments that they cannot recoup as operating profit in Stage 2. So one question here concerns the viability of the initial, sunk investments in fiber–optic networks.

Conceptualizing these two stages in telecom is difficult because of the complexity of the technology. In the related area of local broadband networks, Faulhaber and Hogendorn (2000) argue that the basic game structure can be refined: in Stage 1, firms invest in *network scope* that determines where they can offer service in geographical space. Then Stage 2 can be divided into two parts. In Stage 2a, firms invest in *traffic capacity* that determines how much they can produce in each area that they serve, and in Stage 2b they compete in each area subject to these traffic capacity constraints. The key to this interpretation is that network scope is a sunk cost because investments like rights-of-way, conduits, and utility poles have no alternative use and are not fungible. But traffic capacity is not sunk because investments like telephone switches and fiber–optic terminals can be resold or redeployed and are therefore fungible.

Under this interpretation, the key to competition between infrastructure firms is geography, since the sunk network scope investments mean that once a firm enters a territory it can commit not to leave. Traffic capacity, on the other hand, may affect short-run competitive outcomes (for example, it might lead to Cournot outcomes in the manner of Kreps & Scheinkman (1983)), but it does not carry long-run commitment value.

Thus, when people speak of "excessive" entry in infrastructure, they typically mean some form of redundancy—two or more facilities serving the same geography. Greenstein (2005) notes that such redundancy was not a feature of either the regulated telephone industry or the original NSFNet Internet backbone, and by those standards even two parallel networks might seem excessive. On the other hand, many competitive industries have duplicative facilities, and in most business ventures some "building ahead of demand is a calculated gamble," (Greenstein, 2005, p. 40) especially when future customers are expected to remain with one network and not switch. In this understanding, "excessive" does not simply mean duplication, but so much competition at any one geographic point that the Stage 2 operating profits cannot cover the risk-adjusted Stage 1 capital costs.

2.1. Real and virtual networks

All networks, whether railroad, long-distance telephone, or fiber-optic are "real" in the sense that in Stage 1 the network provider must gain access to a right-of-way and build facilities. In a fiber network this involves burying protective conduits in the right-of-way, building "huts" to house equipment at intervals along the route, and placing fiber–optic cable inside the conduit.[1] Each strand of fiber has very large data capacity, each cable contains many strands of fiber, and many fiber–optic networks are built with multiple conduits.[2] This is not so different from building a railroad or building a terrestrial long-distance telephone network. In fact, they are so similar that they often directly overlap: the oldest network in our sample is AT&T's, which goes back to the era of regulated telephone. During the fiber boom, it was prohibitively expensive to acquire new rights-of-way, so the newer networks generally follow highways, railroads, and natural gas pipelines. In fact, several of the major networks are associated with companies that own these rights-of-way. Williams, for example, was a natural gas pipeline owner, while Qwest was originally a division of the Southern Pacific Railroad. There is irony in the comparison with nineteenth century railroads because in many cases the very same rights of way were used during the fiber boom.

The capacity that carries traffic over the networks is also "real." For a railroad it involves locomotives, signals, and so on, while for long-distance telephone switches are the most important real capital. In a fiber–optic network, terminal equipment takes electronic data from many sources, switches and combines it into channels, and converts it to optical signals using lasers. This is called "lighting" the fiber in the industry jargon. Terminal equipment is expensive, but it can be moved, resold, expanded, and contracted given sufficient lead time. There are some sunk costs involved, so the quantity of lit fiber has some short-run commitment value. But the key is that the amount of traffic capacity is not closely tied to the sunk network scope, since more or fewer conduits can be used, and more or fewer fibers can be lit.

The key question for this paper is how the scope of the resulting "real" network is conveyed to the customers. For the case of railroads, it is a fairly simple matter—the railroad advertises where its tracks go, which cities it serves, and so forth. It is generally quite clear how many route-miles a railroad has. It is true that railroads often advertise their ability to interconnect with other railroads, or even with trucking companies, to reach more destinations, but this usually does not seem to imply that the railroad actually owns additional track beyond its real scope.

The same was generally true for long-distance telephone. Langdale (1983) discusses competition in the early deregulation-era long-distance telephone industry. In addition to AT&T, there were four major national "competitive carriers" that built and operated their own microwave networks between major cities. (Again, one of these was associated with the Southern Pacific Railroad!) The ability of these carriers to carry traffic beyond their point-to-point networks was important to them and contentious. Langdale (1983) describes how the 1978 Execunet decision allowed MCI to interconnect with AT&T's network and expand its reach. After that, more and more leased-line and interconnection-based services were offered by the competitive carriers. However, the basic real scope of their underlying microwave infrastructure was still apparent.

[1] Planning of these networks is described and modeled in Lanning, Mitra, Wang, and Wright (2000).

[2] There are periodically advances in the quality of fiber–optic strands, so systems in which it is easier to install new fiber have an advantage in the long run.

In the case of fiber–optic networks, the amount of capacity on each route, and the modularity of the terminal equipment allowed for operators to share capacity in a more fundamental way than mere interconnection. Owners of fiber–optic networks sold ''indefeasible rights of use'' (IRUs) by means of which firms could obtain either space in conduits or dark fiber (fiber–optic cable with no terminal equipment attached at the ends). Since most networks contain several conduits and many fibers, it was possible to sell IRUs to the same route several times. For example, two major networks, Frontier and GTE, obtained IRUs covering most of the route miles in Qwest's network in 1997 and 1998.

IRUs convey many of the rights of ownership, but they are typically limited to 20 years, can be dissolved by mutual agreement, and are frequently terminated (with less than the originally anticipated compensation) by bankruptcy courts. Furthermore, despite the careful language of IRU agreements, in an industry with rapidly changing technology there are likely to be many noncontractables that could render an IRU economically obsolete earlier than its legal expiration.

This allowed fiber–optic network to be made up of two quite different types of ''route miles.'' To define the two types of network scope more precisely:

Definition: *Real network scope* consists of the actual ownership of rights-of-way, conduits, and buildings that support a fiber–optic network.

Definition: *Virtual network scope* consists of indefeasible rights of use that allow a carrier to install fiber and/or electronics within the real network of another carrier.

This, then is the key difference that makes fiber route miles difficult to compare with route miles of other infrastructures: many fiber–optic networks are based on IRUs, so total *real* network scope is much less than the number of national networks would suggest. Firms that go bankrupt and hold IRUs are likely to exit the industry once and for all. Only those firms that actually own real networks are committed to continuing employment of their assets even in the face of bankruptcy reorganization. Since 2001, the owners of real network scope have recognized hundreds of millions of dollars in ''termination revenue'' when IRUs are returned to the networks. Examples include 360networks handing back all IRUs to Level 3 in 2005 and Touch America handing back its IRUs to Qwest in a 2003 bankruptcy settlement.[3]

This means that the ''unwinding'' of the fiber boom is quite different from the nineteenth century railroad booms. Hadley (1968) discussed how the sunk-cost nature of railroad rights-of-way created many periods of instability in the railroad industry. When competition on a route (New York to Chicago was particularly competitive) was too great to support all the lines on the route, some railroads went bankrupt. But their hard investment in right-of-way had no alternative use, so the insolvent line simply emerged from bankruptcy with its debt reduced, and the number of competitors remained the same. Some locomotives and rolling stock might be redeployed elsewhere, so the number of trains might be less, but the number of competing, oligopolistic firms was held fixed by the number of parallel routes. This pattern, and the companies' collusive attempts to combat it, eventually led to regulation of the industry.

2.2. Policy issues

The difference between real and virtual network scope relates to government policy at two levels. At the broadest level, there is the question of whether private infrastructure markets are efficient or whether they produce destabilizing booms and busts. In particular, the real/virtual distinction bears on the question of whether such volatility (and potential remedies for it) is more about the overuse of real resources in construction or more about information problems regarding contracts that may not create value overall. Both real resources and contractual sharing were involved in the fiber boom, and this paper suggests that the contractual excesses caused most of the ensuing bust.

At a narrower level, and of concern to communications policy, is the future trajectory of the US long-haul fiber networks. From an *ex post* perspective, it may not matter if entry was excessive, as long as sufficient long-haul capacity continues to be available. Indeed, Odlyzko (2003b) says the fiber can be viewed as an expensive ''gift.'' Prüfer and Jahn (2007) have drawn attention to a ''capacity paradox'' whereby the very high capacity of the fiber–optic communications is precisely the source of its success at generating innovation. As long as high capacity causes losses, it is unlikely to be augmented, and eventually market pressures can be expected to create some combination of a less-competitive, more-discriminating, and more-congested infrastructure. This raises the question of how much excess capacity there is, and when to expect and try to mitigate these outcomes.

3. Data

Given the characteristics of the fiber industry, the goal of this research was to collect data that carefully differentiate between *real route miles* which measure real network scope versus *virtual route miles* which reflect virtual network scope based on IRUs. The sum of these, *total route miles,* gives a measure of short-run industry concentration, while real route miles alone gives an upper limit on concentration if all IRUs were dissolved.

[3] See Level 3 (2007, p. F-28) and Qwest (2004, p. 25–26). Qwest (2005, p. 47) provides a nice description of the termination revenue: ''In 2003 we recorded gains totaling $82 million related to the early termination of services contracts and IRU arrangements with certain customers. Under these arrangements, we received cash up-front and we were recognizing revenue over the multi-year terms of the related agreements. In these cases where the customers elected to terminate the agreements prior to their contractual end and we had no continuing obligations, we recognized the remaining portion of the deferred revenue as other income as of the termination date.''

During the period 1986–1998, the FCC collected route-mileage data from the inter-exchange (long distance) telephone companies. These data were compiled and analyzed by Jonathan Kraushaar in what was then the Commission's Common Carrier Bureau, and the reports continue to be available at the FCC's web site. The FCC data collection proceeded through voluntary questionnaires and telephone calls, and they received a high response rate. The decision to stop collecting the data was based in part on the proliferation of new types of fiber networks and sharing of ownership that are discussed in this paper. Toward the end of the sample period, Kraushaar (1999) expressed concern in his reports that fiber route miles might be double-counted.

It is important to note that each route mile typically contains many strands of fiber–optic cable, so measures of "fiber miles" or "strand miles" are usually many times larger than route miles. Further, each strand of fiber may be dark, or lit using a variety of equipment types with different data rates. Thus, one route mile of, say, Level 3's network does not have the same data capacity as one route mile Sprint's network. Nevertheless, this paper focuses on route miles for three reasons. First, route mile data are the most available and comparable across networks, since information like the number of strands of fiber and the type of equipment used is usually confidential. Second, route miles are the most prone to double-counting, since the same mile can contain fiber strands of several carriers. Third, route miles give the best measure of industry concentration, because they proxy for the *number* of firms serving a typical route. In a simple traffic capacity game (Cournot being the prime example), the presence of a facility in which to install capacity is more important than the overall size of the facility, provided that the upper size limit is never reached. The rapid development of fiber optic terminal equipment during the period under study meant that *none* of the networks studied was capacity-constrained in the sense of needing to lay new fiber in order to transmit more data.

3.1. Which firms were in the industry?

The first step is to define the universe of firms involved in national fiber–optic networks. An important source is the map "North American National and Regional Fiberoptic Long-Haul Routes Planned and In Place" published by KMI Research and dated May 2002.[4] The following U.S. national carriers are listed on this map and also incorporated in the data:

Of these, 360networks is the only Canadian carrier with a U.S. national network. Several of the carriers (DTI, EPIK, Metromedia, Pathnet, and Touch America) are essentially regional networks that expanded to national reach through IRUs. Because of their national profile, they are included in the data. Two other U.S. national carriers are listed on the KMI Map but not included in the data. The first is Aerie Networks, which was proposed but never built. The second is Business Telecom which was a North Carolina regional carrier with some IRU capacity on the east coast of the United States.

The sample is limited to firms that either achieved national reach or had announced aspirations to national reach. Regional networks (which include the local telephone companies) are not counted. They actually include the majority of fiber in the United States, but they do not compete in the same national market. Providing national coverage by piecing together circuits from regional networks is too expensive and unreliable to be competitive. Regional networks listed on the KMI Map but excluded from our data are Alltel, Black Hills Fibercom, C3 Networks, Columbia Transcom, Connectiv, Dominion Telecom, Dukenet, El Paso Global Networks, Electric Lightwave, Entergy, Florida Fiber Network, FPL Fibernet, GPU Telecom, Iowa Network Services, ITC Deltacom, Kentucky Data Link, Logix Communications, MP Telecom, NEON, Norlight, Onvoy, Palmetonet, Progress Telecom, SON Communications, Telergy, Time Warner Telecom, and Valleynet. Also excluded are firms that purchased access to national networks but did not own any mileage of their own and did not participate in any swaps of IRUs; these were customers, not peers, of the carriers listed.

The research on the firms listed in Table 1 revealed IRU transactions with three additional carriers, which were added to the data. They are listed in Table 2.

Dynegy is an energy company which purchased a single, large IRU from Level 3 in 2001. XO is a telecom services firm which purchased IRUs from a nationwide network in 2000. Genuity was based on a national virtual network acquired by GTE in 1997–1998. It also did not own its own national fiber, but it did purchase a Midwest regional network that included real route miles. This regional network was not counted as part of Genuity's national network totals in their own documents nor in this paper's data. In 2002, Level 3 acquired Genuity.

3.2. Route mile data

For each network, a network map was obtained, either from the company's web site (in most cases) or from an Internet service provider reseller (for Qwest, MCIWorldcom, McLeodUSA, and ENRON). These maps were checked against the KMI Map discussed above, and there were only minor inconsistencies which related to routes planned but not actually constructed. These are generally shown on the KMI Map but not on the networks' own maps.

To understand when route miles were added, the maps were compared with the firms' annual reports and investment prospectuses as filed with the Securities and Exchange Commission and available through the online EDGAR database

[4] Rutherford et al. (2004) use the European version of this map in their analysis of European long-haul networks.

Table 1
National fiber–optic networks on KMI map and included in sample.

Name	Former name(s)
360networks	Worldwide Fiber
AT& T	
Broadwing	IXC
Digital Teleport (DTI)	
ENRON	
EPIK	Florida East Coast RR
Global Crossing	Frontier
Level 3	
McLeod USA	CapRock
Metromedia	
Pathnet	
Qwest	Southern Pacific RR, LCI
Sprint	
Touch America	Montana Power
Velocita	PF.net
Williams	WilTel
Worldcom	MCI, LDDS

Table 2
National fiber–optic networks not listed on KMI map.

Name	Former name(s)
Dynegy	
Genuity	GTE
XO	NEXTLINK

(primarily forms 10-K and S-4). Some companies included very meticulous network data with these filings, while others simply mentioned route miles in passing.

For AT&T, Sprint, and MCI, the networks were substantially complete in 1990, the company reports matched the FCC figures, and there is no evidence that these companies engaged in any trades involving IRUs prior to 1998. Thus, the FCC figures for these networks were used up until 1998. For all other networks the process of building the network was reconstructed on a route-by-route basis, matching location and route-mile data from company reports against the route maps and cross-checking with the FCC data where applicable. Note that route-mileages were not computed from the maps; the maps were simply used to be sure that all pieces of the network were accounted for in the company reports.

In nearly all cases, the promotional and technical materials made available by telecom firms do not differentiate between the two types of route miles. But building up the data on each network allowed for determination of which routes were based on IRUs and which on real right of way. In some cases, routes are jointly owned, in which case the database counts one-half the miles for each of two owners and one-third for each of three. Jointly owned routes are a much smaller portion of total mileage than are IRUs and do not greatly affect the totals.

To supplement the maps and company reports, the companies' press releases were searched using the archives on LEXIS/NEXIS. In many cases, firms obtained routes by swapping IRUs to their own right of way for IRUs to the right of way of their competitors. The firms often announced and promoted these swaps as an inexpensive way to build their network quickly. In several cases, firms swapped access to a preexisting IRU for a preexisting IRU on another firm's route, so that the swaps could be more than one layer deep. Because of this, it is frequently possible to determine that a route is based on an IRU but not the source of that IRU. Fortunately, this problem does not affect the computation of virtual versus real route miles.

Although the routes identified as shared are all documented, there are probably additional IRUs and swaps that were not reported. As such, the database is conservative since it attributes all other miles as owned. Data on Sprint is less complete than the other networks. All sources suggest that Sprint's network was largely completed before the sample period and not significantly expanded thereafter. For years in which no data were available for Sprint, the database assumes no expansion and simply repeats the previous year's figure.

4. Entry and investment

This section documents the pattern of entry and shows that a large proportion of investment is virtual miles. When only owned miles are considered, entry appears more moderate and industry concentration more typical of a high-sunk-cost industry.

Table 3 shows total network route miles (owned plus shared) by firm for the period 1990–2001. It includes both "lit" and "dark" miles since the dark miles would still be expected to exert competitive pressures in the long run. During the

Table 3
Total route miles, 1990–2001.

Network	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
360networks (Worldwide Fiber)									1181	7971	11,976	14,176
AT& T	32,398	32,500	33,500	35,000	36,022	37,419	38,704	38,704	39,576	39,576	42,551	46,500
Broadwing (IXC)	914	914	914	1257	1357	1365	2025	5500	9300	15,700	18,500	18,500
DTI								927	1500	7250	14,360	17,835
Dynegy												16,000
ENRON									3400	16,281	16,281	16,281
EPIK (Florida East Coast RR)										3801	11,500	1244
Genuity (GTE)								5283	12,000	17,500	17,500	20,800
Global Crossing (Frontier)								4932	9620	13,000	20,000	20,000
Level 3									410	9084	15,236	15,639
MCI	16,000	16,700	17,040	19,793	21,460	21,049	23,096	25,234				
McLeodUSA (+CapRock)	332	332	332	332	519	519	621	866	5052	8036	16,600	26,000
Metromedia									3099	18,000	18,000	18,000
Pathnet										478	1500	
Qwest (Southern Pacific RR, +LCI)	1210	1406	1406	1406	1408	1408	3977	7101	15,000	25,500	25,500	23,700
Sprint (limited data)	22,093	22,725	22,799	22,996	22,996	22,996	23,432	23,574	23,574	23,574	23,574	23,574
Touch America (Montana Power)								2770	9770	10,466	17,370	21,370
Velocita (PF.net)												4000
WilTel	9700	9700	9700	9700	9700							
Williams									9300	17,000	20,800	28,700
Worldcom/MCIWorldcom (LDDS)					1300	11,000	12,589	19,619	47,529	47,806	47,806	47,806
XO (NEXTLINK)											16,000	16,000
Total	82,647	84,277	85,691	90,484	94,762	95,756	104,444	134,510	190,311	281,023	355,054	396,125
% Change		2.0%	1.7%	5.6%	4.7%	1.0%	9.1%	28.8%	41.5%	47.7%	26.3%	11.6%

early 1990s, three large long distance companies, AT&T, MCI, and Sprint, had been joined by Williams, a natural gas pipeline company that built a nationwide fiber optic network called WilTel. Williams sold this network to Worldcom in 1995.[5] Beginning in 1998, Williams built an entirely new network under the name "Williams."

In 1997—2 years after the Netscape initial public offering launched the Internet as a major commercial force and 1 year after passage of the Telecommunications Act—growth in route miles increased rapidly. This was a combination of expansion by existing networks and *de novo* entry. By 2001, there were 19 national networks, but profits were low and Pathnet had exited the market, while EPIK contracted back to its Florida base. In 2002, almost all of these firms were in bankruptcy.

EPIK's sudden contraction from national to regional network demonstrates that the network scope of some of these companies did not consist of sunk assets. Tables 4 and 5 show *real* route miles of each firm in each of the years and the percentage of total route miles that were real (again these are both "lit" and "dark" miles).

At the beginning of the 1990s, all networks were owned outright by the carriers. But entry in the later 1990s involved so many swaps and IRUs that many "national" carriers owned only a small percent of their rights of way, and in a few cases owned none at all. The IRU strategy does not appear to have been a temporary expedient to expand network reach, since most carriers were decreasing their percentage owned even as they served more route miles.

The bulk of total investment in network route miles came during 1998, 1999, and 2000. The majority of the new miles in this period were shared. New right of way built in this period is mostly accounted for by upgrades to the old AT&T and MCIWorldcom networks and the entry of three new major networks, Qwest, Level 3, and Williams (see Fig. 1). One way to interpret this is that three incumbents were joined by three entrants and fringe firms that were partially dependent on the six major networks.

These data suggest that the industry did not experience overbuilding and ruinous competition along the same lines as the railroads of the late 1800s. Rather, actual construction of new rights of way represented more modest entry, but the swaps of IRUs created a very competitive environment in which prices fell. (One could certainly argue, however, that even six firms is a lot for an industry experiencing rapid technological change that increases traffic capacity.)

4.1. Measuring concentration

One goal of this paper is to answer the question of whether too many national networks were built. A first cut at this answer comes from simply looking at the total number of firms in the industry. The first column of Table 6 shows the number of networks with a positive number of total route miles for each year. These numbers are quite high even in 1990, and rise to a very competitive industry of 19 firms by 2001. As discussed, however, many of these networks were based on virtual route miles, so the second column of Table 6 shows the lower number of networks that had positive *real* route miles. The number is still very large for a very high fixed cost industry.

Clearly not all of the networks were equal, and route miles can be used as a measure of geographical coverage and market power. The sample of networks is confined to those that publicly aspired to national network coverage. Pathnet and Velocita did not actually achieve such coverage during the sample period, while all the others served all major American cities. (Pathnet announced a larger network but went bankrupt while building it, and Velocita completed such a network after 2001.)

Other than incumbents AT&T, MCI, and Sprint, the earliest entrant network was WilTel, which reached 9700 route miles in 1989 and was sold to Worldcom in 1995. This network served 78 US cities, including New York, Washington, DC, Atlanta, Chicago, Minneapolis, St. Louis, Dallas, Houston, Denver, Los Angeles, and San Francisco (Gonze, 1987). Based on this, let 9700 route miles be used as a threshold for national presence.[6] The remaining columns in Table 6 show the number of firms with networks above this threshold, using both total and real route miles as measures. Applying the threshold does not change the numbers much using total miles, but for real miles the number of firms falls drastically.

Another important aspect of fiber–optic networks is *route diversity*. Data networks depend on extremely high reliability, and even outages of less than 1 s can cause significant financial damage to customers because systems may crash, take time to reboot, and important pieces of data may be lost. To prevent these problems, networks strive to develop multiple routes between all cities and employ switching systems that can reroute traffic within milliseconds if a link is cut. In the process of developing route diversity, more small cities can also be served, adding to the competitive strength of the network.

As a result, networks of various sizes can serve different types of traffic. Prior to attaining national coverage, a network can serve a limited set of city-pairs. A sparse national network can add nationwide networking to its menu of products. Denser networks can serve more secondary cities and they can also offer a higher level of reliability. Thus, the competition for basic connectivity between major U.S. cities is essentially symmetric between all networks above a certain size, but the competition for basic connectivity in smaller cities and for high-redundancy networks is less symmetric. Larger networks have an advantage in these latter two markets.

[5] The FCC's Worldcom data appear to include regional networks. The database uses only national route miles reported by Worldcom (and its predecessor LDDS) in SEC filings.

[6] In Table 3, EPIK appears never to have reached this threshold, but it briefly rose above it during 2001 before giving up its IRUs and reassuming its regional network role in Florida.

Table 4
Real route miles, 1990–2001.

Network	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
360networks (Worldwide Fiber)									1181	3709	5309	6764
AT&T	32,398	32,500	33,500	35,000	36,022	37,419	38,704	38,704	39,576	39,576	41,064	44,009
Broadwing (IXC)	914	914	914	1257	1357	1365	2025	4647	6028	11,186	12,666	12,666
DTI								927	1500	1900	4650	4900
Dynegy												0
ENRON									1740	1740	1740	1740
EPIK (Florida East Coast RR)										790	894	1244
Genuity (GTE)								0	0	0	0	0
Global Crossing (Frontier)								0	0	0	0	0
Level 3									410	9022	15,174	15,577
MCI	16,000	16,700	17,040	16,793	18,207	17,858	19,595	25,234				
McLeodUSA (+CapRock)	332	332	332	332	519	519	621	866	5052	8036	9475	9740
Metromedia									0	255	255	255
Pathnet										239	980	
Qwest (Southern Pacific RR, +LCI)	1210	1406	1406	1406	1408	1408	3977	7101	14,467	16,322	16,322	14,522
Sprint (limited data)	22,093	22,725	22,799	22,996	22,996	22,996	23,432	23,574	23,574	23,574	23,574	23,574
Touch America (Montana Power)								137	3263	3308	7820	8147
Velocita (PF.net)												1462
WilTel	9700	9700	9700	9700	9700							
Williams									1830	10,101	14,812	17,800
Worldcom/MCIWorldcom (LDDS)					1300	11,000	12,589	13,878	41,788	42,065	42,065	42,065
XO (NEXTLINK)											0	0
Total	82,647	84,277	85,691	87,484	91,509	92,565	100,943	115,068	140,409	171,822	196,798	204,463
% Change		2.0%	1.7%	2.1%	4.6%	1.2%	9.1%	14.0%	22.0%	22.4%	14.5%	3.9%
Total owned as % of total	100%	100%	100%	97%	97%	97%	97%	86%	74%	61%	55%	52%

Table 5
Real as a percentage of total route miles, 1990–2001.

Network	1990 (%)	1991 (%)	1992 (%)	1993 (%)	1994 (%)	1995 (%)	1996 (%)	1997 (%)	1998 (%)	1999 (%)	2000 (%)	2001 (%)
360networks (Worldwide Fiber)									100	47	44	48
AT&T	100	100	100	100	100	100	100	100	100	100	97	95
Broadwing (IXC)	100	100	100	100	100	100	100	84	65	71	68	68
DTI								100	100	26	32	27
Dynegy												0
ENRON									51	11	11	11
EPIK (Florida East Coast RR)										21	8	100
Genuity (GTE)								0	0	0	0	0
Global Crossing (Frontier)								0	0	0	0	0
Level 3									100	99	100	100
MCI	100	100	100	85	85	85	85	100				
McLeodUSA (+CapRock)	100	100	100	100	100	100	100	100	100	100	57	37
Metromedia									0	1	1	1
Pathnet										50	65	
Qwest (Southern Pacific RR, +LCI)	100	100	100	100	100	100	100	100	96	64	64	61
Sprint (limited data)	100	100	100	100	100	100	100	100	100	100	100	100
Touch America (Montana Power)								5	33	32	45	38
Velocita (PF.net)												37
WilTel	100	100	100	100	100							
Williams									20	59	71	62
Worldcom/MCIWorldcom (LDDS)					100	100	100	71	88	88	88	88
XO (NEXTLINK)											0	0
Total	100	100	100	97	97	97	97	86	74	62	56	53

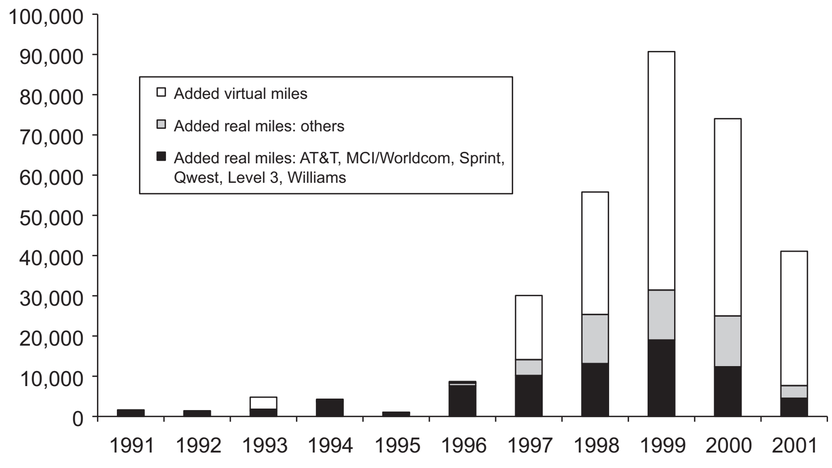

Fig. 1. Yearly additions to total route miles, 1990–2001.

One way to evaluate competition in an industry is to calculate a Herfindahl–Hirschman Index (HHI), which is found by taking the sum of the squares of the market shares of each firm in the industry. A monopoly industry thus has an HHI of 100% squared, or 10,000, while a perfectly competitive industry has an HHI approaching zero since the squared market shares are all tiny. The Department of Justice's *1992 Horizontal Merger Guidelines* define an HHI of 1000–1800 as a loose oligopoly and HHI above 1800 as a tight oligopoly.

Table 7 presents the HHI and the equivalent number of equal-sized firms (calculated from the inverse of the HHI) for each year based on total miles and real miles. Note that these measures are slightly different from conventional HHIs, which are based on quantity sold. Not all of the networks use their capacity equally, so if the data described actual usage, the HHIs might be different. But these measures based on route miles do provide a guide to the potential long-run industry structure.

Table 6
Number of national networks, 1990–2001.

Year	> 0 Miles		> 9700 miles	
	Total	Real	Total	Real
1990	7	7	4	4
1991	7	7	4	4
1992	7	7	4	4
1993	7	7	4	4
1994	8	8	4	4
1995	7	7	4	4
1996	7	7	4	4
1997	11	9	4	4
1998	15	12	6	4
1999	17	15	11	6
2000	18	15	17	7
2001	19	15	17	8

Table 7
HHIs and equivalent number of firms, 1990–2001.

Year	HHI total miles	HHI real miles	Equal-sized firms total miles	Equal-sized real firms miles
1990	2767	2767	3.6	3.6
1991	2743	2743	3.6	3.6
1992	2764	2764	3.6	3.6
1993	2740	2788	3.6	3.6
1994	2658	2696	3.8	3.7
1995	2723	2770	3.7	3.6
1996	2529	2561	4.0	3.9
1997	1778	2233	5.6	4.5
1998	1401	2110	7.1	4.7
1999	892	1546	11.2	6.5
2000	708	1315	14.1	7.6
2001	674	1299	14.8	7.7

The difference between competition in terms of total miles and real miles is striking. Using total miles, the industry moved from an oligopolistic HHI to a very competitive one. But using real miles, the industry remained above 1000. Still, there were eight equivalent equal-sized firms using real miles (representing the core group of six plus the fringe firms) which is a large number of competitors by the standards of previous infrastructure developments such as railroads and early telephone. In early telephone, most cities had two firms, a Bell company and an independent company. Many early railroad routes had parallel lines, but cases of a whole region served by three or more systems were rare. Down to the present day, the US has no railroad systems with national reach. Canada does have two national systems, and the national HHI calculated from their route-kilometers was 5133 in 2009 (Transport Canada, 2009).

4.2. *Were investments in route miles needed?*

The output of these communications networks is not observed in the data; output is difficult to measure even for the owners of the networks themselves and is not publicly available. But two measures can be used as proxies for industry output: industry revenue and Internet traffic. For the revenue measure, the revenues of the networks themselves are the seemingly logical focus of interest, but many firms, such as AT&T, derive most of their revenue from lines of business not directly related to their long-haul networks. The firms do not report sufficiently disaggregated revenue to correct for this problem. As an alternative, total revenue of the U.S. telecoms industry can be used as an index for opportunities to build additional route miles. (This is a conservative measure since a good part of revenue growth came from mobile telephony which uses less long-haul fiber than other types of traffic.) The source for these data is the International Telecommunications Union *Yearbook of Statistics*, 2003 and 2000 editions. Revenue is measured in 1995 dollars using the consumer price index.

Industry revenue is reported in Table 8. The last two columns of the table attempt to create some notion of capacity utilization by calculating industry revenue per mile. This measure is reported for both total miles (reflecting what actually happened) and real miles (reflecting a counter-factual situation without IRUs).

In 1990 there appear to have been modest opportunities to expand route miles since there was a gradual increase in miles in the succeeding years. An interesting feature of these data is that in 1995–1997, there were arguably opportunities to add route mileage (based on revenue), particularly when looking at real miles only. By the end of the sample period,

Table 8
Revenue and revenue per mile, 1990–2001 (1995 dollars).

Year	Industry revenue $ Billions	Revenue per mile $ millions	
		Total	Real
1990	156	1.89	1.89
1991	155	1.84	1.84
1992	160	1.86	1.86
1993	163	1.80	1.87
1994	170	1.80	1.86
1995	175	1.83	1.89
1996	206	1.97	2.04
1997	220	1.64	1.91
1998	230	1.21	1.64
1999	247	0.88	1.44
2000	259	0.73	1.32
2001	261	0.66	1.28

revenue per mile had fallen sharply. Real miles show much less of this trend than total miles since so much of the increase in total miles is virtual, not real.

5. Conclusion

This paper reviewed the conventional wisdom that there was "excessive" investment in national fiber–optic networks that ended with a crash in 2001. It showed a conceptual caveat and a factual caveat to this conventional wisdom. The conceptual caveat is that sunk investment in rights of way is not directly tied to non-sunk investment in traffic capacity that allows these networks to be used. This limits the analogy with other infrastructure investments such as railroads, because for other infrastructures the right of way and traffic capacity are inextricably linked.

The factual caveat to the conventional wisdom is to distinguish between real route miles representing right of way and virtual route miles representing leased capacity within others' rights of way. The data presented here were obtained from each firm's SEC reports and press releases, and show which routes are based on sunk investments in right of way and conduit and which are based on relatively non-sunk investment in IRUs. More than half of total route miles added during the period 1990–2001 were based on non-sunk forms of investment. This leads to the conclusion that the loss-producing level of competition that prevailed circa 2001 was due more to the willingness of firms to sell IRUs than to actual over-investment like that which occurred in the nineteenth century railroad boom.

This paper reports industry-wide changes in revenue per route mile. This measure suggests that there were opportunities for increased investment in route miles in the mid-1990s, but that investment after that proceeded faster than revenue growth.

The paper's general conclusion is that the "excessive" element of national fiber–optic network investment was the very extensive creation of virtual route miles using IRUs. IRUs led to remarkably low concentration for an industry with such high fixed, sunk costs. Not including virtual miles, the underlying investment in real route miles was more moderate, and led to more reasonable (if still low) industry concentration.

IRUs continue to be used widely in the telecom industry, and they are especially important as a means for sharing the high costs of submarine cable systems. Some of the firms mentioned in this paper, for example XO Communications, have survived and continue to manage networks that are based on virtual route miles. This paper does not argue that IRUs are necessarily bad for the telecom industry; indeed as a cost-sharing device they can be very beneficial. But they can obscure the total amount of underlying physical investment, and like any asset they can be subject to booms and busts. In the case of the late 1990s fiber boom, this paper has shown that a large part of the boom and bust cycle was attributable to IRUs and not physical investment.

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