The Relative Costs of Local Telephony Across Five Countries

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1. Introduction

Many countries have been liberalizing their telecommunications regulations in recent years. Government-owned telecommunications companies have been privatized, competition has been given greater scope, and remaining regulation relies more heavily on private incentives. Among those countries leading this liberalization and moving towards a more competitive foundation, while peripheral services were typically allowed somewhat earlier, the United States allowed entry in long distance in 1982, the UK in 1983, New Zealand in 1989, Australia in 1991, and Sweden in 1993. Each is now attempting to move towards a more competitive outcome for local service, but so far with mixed success.

The rationale for the network industries' complicated governance structures has been challenged by an improved understanding of regulation, governance, and other political economy issues that has developed over the last few decades: an understanding that often calls for a greater scope for competition.[1] The liberalization of these industries has usually been led by the belief that certain services could be offered competitively, and that these services should not be directly regulated. With railroads, trucks can competitively serve time-sensitive or relatively high-value freight. With natural gas pipelines, the production and sale of natural gas, separate from the pipeline transportation of this gas, can be offered competitively. In electric power, the generation and sale of electric power is increasingly offered competitively. In telecommunications, international and long-distance services have often been offered competitively. Importantly, these deregulatory changes have generally led to clear benefits for consumers.[2]

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[1] See, for examples, Evans and Quigley (1998), Winston (1998), and the studies to which they refer.

[2] See, for example, Winston (1998).

This process of deregulation has had different, historically determined, starting points and has proceeded in various forms and at different paces in the countries we consider: UK, USA, Australia, Sweden and New Zealand. Because regulatory regimes have been different at any point in time, benchmarking comparisons across countries can be informative about the efficacy of different regimes. In this "comparative institutional" approach to analysis, attainable outcomes are compared and this may indicate what level of performance is feasible and actual effects of regulatory regimes. In contrast, studies that compare outcomes with an estimate of an idealised market counterfactual may not suggest feasible possibilities for change. Comparisons across countries should control for country-specific characteristics that affect costs whatever the characteristics of the regulatory regime.

In this paper, we take three steps towards evaluating the relative performance of the telecommunications markets in these five countries. First, we identify and then limit our examination to only those components of the telecommunications network that may generate market power concerns. We determine that market power concerns, where they exist at all, are limited to those facilities connecting a customer with its neighboring central office, collectively called the local loop. Second, we identify regional factors that may significantly affect relative costs for the local loop. Using data and a cost model from the US to examine these regional factors, we find that customer density is the most significant. Third, using this same cost model along with regional data, we estimate local loop costs relative to the US for New Zealand, Australia, the UK, and Sweden.

Network industries generate market power concerns because they have some natural monopoly properties. These industries include telecommunications, the electric power grid, oil and natural gas pipelines, railroads, the postal network, and highways, all share some natural monopoly properties as transport cost between certain nodes may be minimized with a single transport facility. Network industries have generally faced a history of heavy regulation. The resulting governance structure for each of these network industries has become quite complicated, and the effectiveness of each is now questioned.

In most network industries, and in telecommunications especially, the rationale for these complicated governance structures is vigorously challenged by recent technological change. For telecommunications, along with the advancements in the computer industry, the costs of digital technologies have dropped significantly. Fiber optic lines continue to be laid at a strong pace and telecom networks have shifted to digital technology because the biggest cost savings have been in dealing with digitally encoded information. Wireless systems, too, are becoming more prevalent. Each of these technological changes seems to provide for a broader scope for competition.[3]

In Section 2 below, we offer an introduction to the technology and economics of a telecommunications network. We will see that with this recent technological change, many components of a telecommunications network could now be efficiently held independently by multiple competitors. These components, many of which still operate under heavy regulation, do not now naturally generate any significant market power concerns, and any regulatory intervention designed to limit abuses of market power here is not appropriate. Significant market power concerns appear likely only for the local loop of the network, and then not for customers of local loop substitutes offered by cable, optical fiber, or mobile telephony.

In Section 3, we examine the determinants of costs by means of a cost model developed by HAI Consulting Inc. The HAI model contains data that allows estimates of forward-looking long-run costs within each of the 50 US states. It calculates today’s cost of constructing and operating a wire-only network based upon current costs, expectations such as those about the economic life of various telecommunications network assets, and regional-specific factors such as customer density and geological conditions.

In this section, we first examine costs by density zone as well as for an entire state. Estimates of the average cost of the local loop component of a telecommunications network for the 50 states ranges from \$8.50 to \$38.13 per line per month and for the US is \$13.96 per line per month (all prices expressed in \$US). We conclude from these estimates that telephony costs vary tremendously as a result of differences in basic factors that affect cost. Additional analysis of this and much finer data shows that the density of customers explains most of this variation. We demonstrate that the unit cost of local wireline service falls very steeply as density increases, but at a decreasing rate. Costs differ hugely between rural areas and urban areas. We also consider the variations in cost that result from variations in other factors such as wage rates, the economic life of various network assets, different depreciation rules, and the competitive rate of return.

In Section 4, we construct relative cost estimates between our five countries. Using regional data to estimate customer density, and assuming a constant number of lines per capita within each region, we estimate that average unit costs for Australia, New Zealand, and Sweden, respectively, are about 10-14%, 15-20%, and 23-27% greater, and the UK 19-22% lower, than the US average. Section 5 provides concluding comments. We also provide an appendix on wireless alternatives that could be incorporated within the telecommunications network, and a second appendix that presents detailed tables and figures describing data that support our analysis.

2. An Introduction to the Technology and Economics of a Telecommunications Network

Much of the movement towards more competition in telecommunications has been stimulated by dramatic technological change. This technological change has not only both significantly reduced costs and allowed the provision of new

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[3] Furthermore, the very fact of uncertainty about facets of technological change has changed the competitive possibilities of network industries (see Evans and Quigley (1998)).

and higher quality services, but also has increased the ability of new suppliers to effectively compete with the incumbent supplier. Along with the advancements in the computer industry, the costs of digital technologies have dropped dramatically. For heavily used transmission corridors, the capabilities of optical fiber for digital transmission have dramatically lowered transmission costs. The cost of switching has also fallen substantially, and computer-enhanced services have added valuable new services at low cost. These lower costs, to the extent that they lead to lower prices, also have lead to a significant increase in the quantity of transmission services demanded. Further, technological change has created new telecommunications industries for data transmission, cable TV, and wireless communications. As a result of this technological change, multiple suppliers can now efficiently provide transport in these heavily used transmission corridors, provide switching services, or provide non-voice telecommunications services that provide some substitutes for the traditional voice-oriented telecommunications network. Firms that have wanted to profit by exploiting these new technological advancements, along with consumers that would benefit, have led efforts to liberalize telecommunications regulation.

2.1 The driving force of technological change

The technologies necessary to use optical fiber became mature in the 1980s. Optical fiber has clearly become the medium of choice for heavily used transmission corridors. Fiber deployment started for long-distance transmission, including international, but now is used for transmission throughout much of the network. Fiber is the medium of choice between central offices on the local level, for some feeder transmission in the local loop between the consumer and the neighboring central office, and for large telecom customers or other high-bandwidth users, for transmission all the way to the customer’s premises. As time passes, fiber’s advantages have become even stronger. The cost of manufacturing fiber, of lasers, and of the necessary digital electronics have all been dropping continuously and even the fiber itself improves, as new methods for increasing the purity of the glass allow new wavelengths to be used, further increasing capacity. As a result, fiber optic lines have been laid at a strong pace that continues today. As an illustration, in the US, interexchange carriers increased the mileage of their fiber lines by approximately five times from 1985 to 1995 and local exchange carriers (LECs) increased theirs nearly fifteen times in the same period.[4]

Switches have experienced lower costs primarily because of rapid, continuous advancements in the computer industry. Costs have fallen most in those technologies employed in telecommunications that are most like those of the computer industry. Unfortunately for the telecommunications industry, it seems those technologies most like the computer industry's are not those that have been traditionally adopted by the industry. Two technology alternatives seem most important in this regard.

First, telecommunications may transmit signals in an analog or a digital form. In its analog form a broadcast-like wave is sent down the wire, while in a digital form, the message is encoded as a sequence of on/off pulses. The traditional wired telecommunications network was constructed for analog transmissions, but the biggest cost savings have been in dealing with digitally encoded information. As telecom networks have been upgraded over the last two decades, they have shifted to the digital technology, so that now most networks are mixed between analog and digital signals.

Second, when transmitting a message, telecommunications operators may switch circuits, that is, open dedicated connections from one point to another, or send small digitally encoded packets, many of which would be necessary to compose a message, on non-dedicated lines. Traditional voice telecom networks have been circuit switched. Decades have passed with the industry considering the implementation of the packet-switched digital technology known as ATM. Although ATM is used for telephony at present voice telecom networks still are based overwhelmingly upon circuit switching. The primary exceptions are

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[4] See FCC, Industry Analysis Division, Fiber Deployment Update.

packet-switched data networks based upon Internet technologies, which are now growing at a tremendous rate.[5]

Another important technological change affecting the cost of switching actually comes from the use of optical fiber. Optical fiber can transmit signals over longer distances than copper cable, so that a switch can efficiently be much further from customers than previously.

The last few decades has also seen extremely rapid growth in telecommunications services other than voice, and these new services significantly alter the economics of the traditional network. These services may use the same traditional network constructed for voice or they may offer a substitute for it. Advancements in data transmission for facsimile transmission and the Internet, cable TV, and wireless technologies have each led to entirely new industries, which have had two important effects on the traditional network. First, the new services that these new industries offer each increase the demand for telecommunications transmission significantly. These increases will be even larger in the future. The prime example is a 50% annual growth rate expected for the Internet. Second, to the extent new physical facilities are constructed, these industries offer substitutes for some traditional wireline telecom services.

Data transmission has become a major telecommunications service. Businesses have used private lines for decades sending data between themselves. Facsimile transmission has been prominent since the late 1970s. The Internet (the net), which started as a private network to connect research institutions, seems to be overtaking all. Each of these data services is best offered over a digital network. Internet messages, in particular, usually pass over a data network largely separate today from the voice network, though

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[5] Private packet-switched networks that use the Internet Protocol (IP), including the Internet, are now starting to be used for voice communications as well as data. Over the next few years, IP networks will grow tremendously, becoming the predominant digital packet-switched technology, and will likely carry a quickly growing share of voice traffic over time.

translations between digital and analog signals and between transmission protocols are made when necessary.

The net has several advantages. Its digital, packet-switched architecture efficiently uses the resources of the telecommunications network, much more so than the traditional circuit-switched network. The packet-switched network is roughly an order of magnitude more efficient at transporting information. Further, it faces quickly declining costs over time as the technologies most heavily used by the net are just those experiencing the greatest cost reductions from technological change. And demand growth for services provided over the net has been tremendous over a sustained period.

Inevitably, the net will soon offer a high-quality substitute for voice, as well as for data transmission, but for general use it is not yet a perfect substitute. At present, sending voice over the net sometimes faces quality problems during peak periods because of the net's "best efforts" transmission. Not all packets may arrive in real time, as is needed for voice transmission. This is not a technical problem, since users can establish priorities for all packets that put those providing real-time services at the head of the queue. This is an economic problem, as charges necessary for at least the highest-priority packets to implement such a system require significant transactions costs and adjustments to existing economic relationships between the multiple operators of the interconnected facilities making up our total network. As the economic advantages of using the net widen over the traditional network, one should expect this problem to be overcome.[6] The net also is just in its infancy in developing the capability for offering enhanced services such as call forwarding or 911.

Cable television, another relatively new telecommunications service, this one offered over coaxial cable, was implemented initially in the 1960s to provide

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[6] Proprietary data networks may offer high-quality voice services first, since the packets can remain on the facilities of a single owner. Nevertheless, this should be only temporary, because it does not capture some efficiencies of interconnecting networks.

better TV reception in rural areas that broadcast did not serve well. With technology advances that significantly increased the capacity of the coaxial cables used to feed the signals into each household, cable TV penetration grew tremendously from the 1980s in the U.S., and somewhat later in other countries. Penetration varies a great deal in different countries, but it can be widespread. In the US, for example, 98% of households are now passed by cable.

An important side-benefit of cable networks for telephony is that they offer a second wire to the home, a potential substitute for the local loop. The technologies naturally used for cable and telephony are not the same, though, as cable sends the same information to everyone and telephony sends individual messages both to and from individual customers. To provide a second local loop, additional investments are necessary to provide two-way, addressable capabilities to the cable network. While a number of trials have been held,[7] few have yet gone to regular service.[8] Even so, the technology for economically sharing the coaxial cable between broadcast TV signals and switched telephony is expected to have a significant impact soon.[9] Another option for relative latecomers to cable TV is to lay traditional twisted-pairs along with the cable to share installation costs.[10]

Wireless cellular telephone services started in the 1980s, and they have had a strong growth rate ever since. As demand has grown, new radio spectrum has been allocated for its use, accommodating its strong growth. Wireless

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[7] In the US, Time Warner has offered local telephone service within Kansas City, Indianapolis, Rochester, and Orlando; Jones Intercable and MCI outside Chicago and in Virginia; Cablevision on Long Island; MediaOne in Phoenix and Michigan; Cox Communications in California; and TCI in several areas. Similar trials have also been held in the UK. In the same time frame, cable modems are being tested and rolled out for broadband Internet access. The largest supplier of this service in the US is @Home, an affiliate of TCI.

[8] In Australia, Optus offers switched telephone service on coaxial cable in Sydney and Melbourne.

[9] AT&T recently announced a merger with TCI, the largest cable operator in the U.S., expressly to upgrade cable facilities to offer, among other services, local telephony.

[10] In New Zealand, Saturn Communications has done this in Wellington and its environs.

services started with analog signals, and has shifted, though not entirely at this time, to digital signals. The primary attraction of this technology for most customers is that it provides telecommunications for the mobile user, whatever their mode of transport. A potentially important side-benefit is that wireless connections provide economic competition for the wireline local loop under certain circumstances.[11] At present these circumstances are limited primarily to rural applications or to mobile telephony customers, but they are expected to become much more common in the future. Wireless services have also increased demand for wireline communications, both for transmissions between wireless facilities and to connect with customers of the traditional fixed network.

With all of these technological advancements, firms that want to offer long-distance or international services, broadband data services, switched services on cable TV lines, or wireless services, have all promoted liberalizing telecommunications regulation so that they may enter these businesses. Consumers that could benefit from these new entrants' offerings have joined in these efforts led by these potential entrants.

2.2 Technological advancements occur unevenly in the network

The sum effect of these technological advancements on various components of the telecommunications network is quite uneven. One way to view a telecommunications service is as a bundle of services that could be provided by each of the vertically-related elements of the telecommunications network. While these network elements might fruitfully be defined in a number of different ways, in considering the effectiveness of economic regulation they certainly would include at least the following: the local loop connecting the consumer to the neighboring central office, switching at the central office including the use of

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[11] A number of trials or plans around the world use wireless technology in fixed telephone networks. One of the largest was conducted by AT&T, which eventually rejected a mid-bandwidth wireless technology for bypassing wireline local loops universally. See Appendix I on wireless technologies for further discussion. It describes particular patterns of usage in a range of locations where cellular telephony is a cost-efficient alternative to fixed-wire connections.

the signalling system, local transmission between central offices, long-distance transmission between central offices, and retail support services, such as retail billing and marketing. The technological changes that we have experienced in the last decade or two have affected these network elements substantially but unevenly.

We start by considering the components of a telecommunications network that may be used in placing a telephone call.[12] Once a message has left the customer's premises an intermediate destination is the neighboring wire center or central office, which is that location of the first switch that the call passes through. This route from the customer's premises to the wire center is known as the local loop.

The local loop itself is made up of several different components. For the typical customer, the local loop starts with the Network Interface Device (NID) that connects wiring in the customer's premises with the provider's facilities. A twisted-pair of copper distribution cable, along with its supporting infrastructure, then connects the NID to a block terminal in a segment called the drop. The drop is either buried directly in the ground or carried in the air, supported by telephone poles. At the block terminal, which services several housing units either at a ground pedestal or attached to a pole, each drop is spliced into a distribution copper cable composed of multiple twisted pairs.

This distribution cable then moves toward and eventually connects with the Serving Area Interface (SAI), while lines are spliced into it from other distribution cables en route. Distribution cable is either buried (buried lines are placed in trenches or plowed directly into the ground), placed underground (underground lines are strung through conduit such as plastic pipe, which is buried in the ground), or carried in the air (aerial lines are connected to utility poles). In more urban areas, drops and distribution cable may lie within a high-rise building. Between the NID and SAI each customer has one or more pairs of lines dedicated to its own use, whether they are in use or not. The drop and distribution cable may carry either an analog or a digital signal, though the preponderance is still analog.

At the SAI, signals are aggregated and transferred to feeder cable, which are used by any signals as needed. Signals in feeder cable may be either analog or digital. If analog, open circuits are cross-connected to copper feeder cables, a bundle of many twisted pairs, sized to anticipate the largest number of open circuits necessary to handle this area. If digital, the distribution carrier connects with a digital loop carrier (DLC) remote terminal, which converts the signal to digital form, if necessary, and multiplexes it with other digital signals, and then sends it to an optical fiber feeder cable. Feeder cable, whether copper or optical fiber, transmits the signals from the SAI to the switch at the wire center. Feeder cable is buried, underground, or aerial, and the structures supporting it (*i.e.*, trenches, conduits, or poles) may be shared with other telecom providers, cable television providers, or electric utilities. Due to capacity limitations of an SAI or the design of the distribution cable, multiple SAIs usually feed the same wire center.

For a wireline network providing only basic local voice services, drop and distribution lines are copper, and feeder lines may be either copper or optical fiber depending upon engineering constraints (optical fiber can transport signal farther than copper) and the economics of using each medium. Higher bandwidth services, say to businesses, might use optical fiber for distribution as well as for feeder lines. SAI facilities differ for copper feeder lines, where the distribution signals are simply connected to available feeder lines, or optical fiber feeder lines, where a remote terminal must convert the analog distribution signal to a digital one and then multiplex several digital signals for the feeder.

A wire center normally contains at least one end-office switch. The end office provides dial tone and connections to other switches. The wire center may

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[12] Much of this description of the telecommunications network is taken from HAI Version

also contain a tandem switch (an intermediate switch connecting a number of end offices, operating something like an airline's hub), an operator tandem, or facilities for the signalling system needed to establish and route a call plus provide access to central databases and central services, such as operator services and emergency lines. Physical facilities include a building and power and air conditioning systems plus the switches and the necessary entrances for feeder and interoffice cable. Interoffice transmission is predominantly provided over optical fiber, and it increasingly uses a fiber optic ring architecture.

The greatest effects of the technological advancements described earlier have appeared in switching and heavily-used transmission corridors, especially long-distance lines, transmission between central offices, direct lines to high-bandwidth customers, and wireless services, and the least effect is seen in the local loop, especially between the customer's premises and the SAI.

Due to advancements in the use of optical fiber, multiple, independent transmission cables between central offices can now be used efficiently . Existing cable is not sufficient for expected demand, so that new cable must be laid. Incumbents laying fiber to replace copper-wire plant in their own right of way or new entrants laying fiber in rights of way also used by pipelines, railroads, electric utilities all face virtually the same costs. Further, providing the desired reliability from the network itself requires multiple routes, possibly through other central offices, so that service can remain after a failure in one line. Transport between central offices is not now a natural monopoly.

Due to advancements in switching and in optical fiber, an entrant with even a small market share could now deploy a switch at an efficient scale for most markets. Similarly, packet-switched signalling systems allow databases for managing calls and for providing intelligent services to be located in regional or national depositories, so that again even an entrant with a small market share could operate at an efficient scale. Switches do not now provide a natural monop-

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5.0a Model Description (1998).

oly. Further, with nearby switches from multiple suppliers, even optical fiber feeder transport from a remote terminal at an SAI to a nearby switch could be efficiently supplied by multiple firms.

Many telecommunications networks are upgrading as fast as they can to digital switching, digital transmission past the central office on optical fiber, digital feeder lines in the local loop, and, for high-bandwidth business customers, digital transmission all the way to the customer. The incremental cost of such investments is virtually the same for entrants, incumbents, small firms, or large ones, as long as they can share existing transmission towers, poles, underground conduits, and rights of way. For these new investments, the entrant is at no significant disadvantage, and new competitors have constructed such facilities in many countries. For most markets, the network can incorporate multiple efficient facilities from such investments.

2.3 Interconnection to the local loop

Certain classes of customers cannot yet be economically served by multiple providers for that "last mile" of transmission in local loop. The factors that determine these classes are: the location, customer density, and the nature of the service required. Two technologies created by recent technological advancements can provide an efficient second provider of a local loop for a range of customers today, and will do so for many more in the future, but not for all customers now or in the immediate future.

One new technology that may provide a second local loop is high-bandwidth optical fiber or coaxial cable, which has lower but still relatively high bandwidth. Some consumers demand high-bandwidth video-laden digital services, including cable TV, video on the Internet, or high-bandwidth data services. For these customers, a high-bandwidth local loop must be constructed to provide these services. With this second local loop, voice services can then be provided as a by-product. These consumers, typically business customers and cable TV customers today, face little market power, if any, from the LEC's control of its local loop.

The second new technology that may provide a second local loop is wireless.[13] Wireless technologies can efficiently provide a substitute for the wireline local loop for three types of customers.

First, since wireless technologies have costs that vary much less with distance than a wireline network, they provide a local loop at the least cost for a customer in a low density area and some distance from major telecommunications facilities. Scattered rural customers, especially those in difficult terrain, are most cheaply supplied with a wireless connection.[14]

Second, the incremental cost of adding a wireless connection for the fixed location of a customer who values mobility sufficiently to pay for mobile service may be less than a wireline local loop. Where cellular transmission facilities are close enough to provide strong reception indoors, as may often happen in a relatively high-density urban or suburban area, the incremental cost is virtually zero. At some further distance, the customer may require some additional equipment that boosts the signal for this use indoors, but still the incremental cost may be lower than a wireline alternative.

Third, customers that demand voice services only, or at most few data services, can be supplied by a cellular technology that provides sufficient bandwidth for voice calls but no, or a very slow, data service. This lower quality wireless technology has even lower fixed costs and can provide services over greater distances than the higher quality wireless service whose quality matches

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[13] See Appendix I for more discussion of wireless technologies.

[14] Microwave connections have been cheaper than wireline connections for very low-density customers for decades. Newer wireless technologies are now cheaper than wireline connections for somewhat higher densities. For more discussion, see Appendix I and Gable and Kennet (1997), who calculate that it would have been economic to replace wire with wireless (cell phone) service in certain areas of rural New Zealand. The fact that wireless can also offer broadband services increases the range of economically viable local service locations that it may serve.

wireline service. This may be an especially important alternative when considering universal service requirements.[15]

Together, scattered rural customers some distance from major telecommunications facilities, existing mobile customers, and customers that demand only voice services may find a wireless local loop is less expensive than a wireline local loop.

If an incumbent were to raise its prices significantly above those necessary to earn competitive profits for its switches, transmission between central offices (assuming sharing of transmission infrastructure), or local loops to scattered rural customers, existing wireless customers, or some customers that demand only voice, customers would shift to a competitor's facilities. Actual and threatened competition constrain the incumbents to competitive pricing for these network elements. Nevertheless, this competition does not constrain the pricing of the local loop for other customers to the competitive level. For some customers, the local loop is still most economically provided by the standard twisted pair of copper wires, and no substitute can yet be efficiently provided for it.

3. Sources of Cost Differentials

Cross-country comparisons of price must control for differences in cost if they are to be useful measures of telecommunications market performance. We use the HAI model and the detailed US data it contains, holding constant input prices and model assumptions, to isolate important cost determinants that are country specific and minimally affected by differences in regulatory regimes.

3.1 The HAI cost model

The HAI model has been developed by HAI Consulting Inc. of Boulder, Colorado, and is sponsored by AT&T and MCI in the United States. The model contains data that allows it to construct cost estimates for each of the local exchange carriers (LECs) for each of the 50 states. It was developed for use in regulatory proceedings in each of the 50 states and at the federal level in response to the US Telecommunications Act of 1996.

3.1.1 telecommunication regulation in the US and the HAI model

In the United States, the intrastate telecommunications market in each state is regulated by its own public utilities commission, while interstate markets are regulated by the Federal Communications Commission (FCC). Federal regulation, and much of its implementation at the state level, is currently undergoing great change due to the passage of the Telecommunications Act of 1996. A primary purpose of the Act is to increase competition for local telecommunications services.[16]

Under the 1996 Act, new entrants and incumbent local telephone carriers can negotiate the terms and conditions for interconnection and access to the existing LEC network elements. However, most of the pricing of interconnection, unbundled network elements, and transport and termination of interconnected traffic has not been resolved by private negotiations and the state public utility commissions have intervened. The FCC has established a pricing methodology based on forward-looking economic costs for states to use in setting rates for interconnection and the purchase of unbundled elements and with a view to settling pricing disputes. The pricing methodology is to add to the "total element long-run incremental cost" (TELRIC) a share of forward-looking joint and common costs.[17]

The forward-looking long-run costs of the HAI model, are based upon today's costs for constructing and operating the network. They are expressed as

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[15] There exist tariff plans now that provide cellular services in New Zealand that for limited use patterns are considerably less expensive than fixed wire interconnections.

[16] For a review of the influence of this Act see Harris and Kraft (1997).

[17] Before the use of TELRIC, the FCC used "total service long-run incremental cost." The difference between the two is that TELRIC applies to network elements rather than to services

the cost level per month in order to be comparable to pricing on a monthly basis. Because capital is a large component of telecommunications costs the monthly costs depend upon a variety of assumptions about the future such as interest rates and the economic life of the assets. The HAI costs we report exclude billing and marketing expenses. They may be interpreted as the wholesale local wireline service cost on a monthly basis.

Forward looking costs, are those that would lead to efficient investment decisions. Efficient prices for both new and existing facilities should be based upon the forward-looking costs of these new facilities. Clearly, if new facilities are necessary, efficient prices for services from both the new facilities and existing facilities should be equal and based upon these new costs. Further, if new facilities are not necessary as services are efficiently supplied from existing facilities, the prices for services from these existing facilities should not exceed those that could be offered with new facilities. These prices are necessary to avoid inefficiently constructing new capacity. [18]

Given this environment, the HAI model was constructed to be used by each of the individual states and the FCC in setting rates for interconnection and for unbundled network elements (UNEs) for basic local telephone service. Modifications have been made progressively to improve the model's data, logic, and documentation. It has also been extended for universal service funding requirements.

3.1.2 the network for basic local voice services constructed in the HAI model

The network that the model designs is only for the wholesale provision of basic local voice services. This basic local telephone service is assumed to include the following functional elements:

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which usually share the use of one or more network elements and therefore are subject to more common costs. The underlying concepts are the same.

[18] This conclusion may be modified if uncertainty, particularly uncertainty about technological change, is properly accounted for. If costs are expected to fall in the future by an uncertain

- single-line, single-party access to the first point of switching in a local exchange network;
- usage within a local exchange area, including access to interexchange service;
- touch tone capability;
- access to emergency services, operator services, directory assistance, and telecommunications relay service for the hearing-impaired.

The network that the model designs does not include any extra facilities or capacity necessary for other telecommunications services other than the basic local voice services implicit within them. Any of these extra facilities for services such as long distance, international, facsimile, or broadband data services are not included, even if they might be incorporated into actual local networks. This restriction of the model is adopted because it simplifies network design and cost estimates, eliminating common costs with these other services. If this restriction affects the resulting cost estimates at all, because of economies of scope between these services and local service, it would lead to over-estimated basic local service costs.

While the design of the model does not require it, in its current implementation wireless alternatives for wireline connections are not considered.[19] The model estimates costs for an all wireline network.

Even though the model estimates costs for all of the network elements necessary for basic local service costs, in this paper we focus on the cost of constructing and operating the local loop in the network since potential market power problems are greatest here. Costs for wireline local loop facilities depend upon the distances between facilities, the architecture of the network used to reach customers from the wire center, the type of medium and infrastructure

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amount, prices for existing services may efficiently exceed those of new services because of optimal-time-to-invest principles (see Dixit and Pindyck (1994)).

[19] The model has a wireless investment cap that can be imposed for distribution plant investment calculations. As a default, this cap is disabled.

selected, the type of geological conditions (soil type, rock depth, and water depth), the costs of materials and installation, and both the quantity and quality of services to be provided. To estimate the investment costs of a local exchange network, the model uses data on the costs of materials and installation, geological conditions, and most importantly, data on customer locations, line demand, and traffic volumes. Given these data, the model designs an efficient network to satisfy both the quantity and quality demanded from the customers with the one exceptional restriction that wire centers are to be located where LEC wire centers are currently located.[20] Once investment costs are calculated, capital cost parameters and depreciation schedules are used to report these investment costs as monthly charges, and these are added to estimates of operating expenses, calculated from FCC data for existing operating expenses.

3.1.3 the operation of the HAI model

Our study used the HAI model release 5.0a (HM 5.0a)[21]. HM 5.0a is a spreadsheet-based model supported by Microsoft Excel 97. The programming languages used are Visual Basic and Visual Basic for Applications. Once the desired US state and LEC are selected, the model automatically runs four modules: the Distribution, Feeder, Switching & Interoffice, and Expense Modules. The Expense Module summarizes results by, at the choice of the user, the density zone, wire center, Census Block Group (CBG), or cluster.

Running the model is straightforward. To suit various needs, the model allows easy changes to the default values of over 1400 user adjustable inputs, including the costs of network materials and their installation, engineering parameters, capital cost and depreciation parameters, and percentages of the

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[20] The original Hatfield/HAI model (called the Greenfield model) assumes all network facilities would be built in cost efficient numbers and locations, regardless of the locations of existing wire centers. Later Hatfield/HAI models, at the prodding of the FCC, assume that wire centers are fixed at the current locations to allow the use of more detailed data that is reported by wire center. The estimated cost of constructing a network is smaller if we allow efficient numbers and locations of wire centers.

[21] This HM 5.0a version was released in January 1998.

joint use of end offices, tandem offices, or infrastructure. For this study, these input parameters are set at their default values.

In designing local loops, the most basic aggregation of customers within this model is in a cluster. To define each cluster, the model uses an algorithm common within the industry to group nearby customers together to share feeder, SAI, and distribution facilities. Costs for the local loop depend almost exclusively on conditions faced within the cluster, and not on any conditions outside it. Each cluster is also associated with the dominant Census Block Group to which it belongs, because some demographic data that the model uses is broken down by CBGs. More than one cluster may be associated with the same CBG, and we may aggregate the model's results for these clusters by CBG. Results for all clusters also can be aggregated by wire center, combining results for clusters that feed into the same wire center. Results for all wire centers in the same state and owned by the same LEC can be aggregated for that state and LEC. Also, as line density is an important factor for determining costs, HAI has constructed nine density "zones" that group CBGs with similar line densities, and results can be aggregated by density zone.

3.1.4 potential limitations of the HAI model

Given the use of the HAI model to influence the setting of regulated rates, its estimates might potentially be biased. AT&T and MCI, sponsors of the model, as potential new entrants into local services, would prefer lower estimates. They are constrained primarily by the credibility that they must maintain with regulators, both state and federal. If regulators were to reject the model, it would be of no use to its sponsors.

Although absolute cost estimates from the HAI model are subject to wide variation with different values of the input parameters, relative costs vary much less. That is, we can expect that, given common assumptions, the model will reasonably reliably indicate relative cost differentials resulting from different regional characteristics. Even if there were any biases in the model's estimates of absolute costs, any biases in its estimates of relative costs between various components of a network or between networks constructed in different regions is expected to be small if they exist at all.

Other models have also been constructed to estimate the costs of construction or operation of a telecommunications network.[22] The HAI model was selected among these because it uses an appropriate methodology for estimating these costs, which some of the others do not, and because of a more sophisticated and complete design process for determining a least-cost investment.

3.2 The importance of line density

We use the HAI model's estimates of the costs for all LECs in the United States to construct a measure of relative costs for other regions. Using the multi-company selection option, the model was run twice for all the LECs within each of the 50 states given the default values for their input parameters. The first run reported its results aggregated by density zones and the second run by wire centers. According to the model, there are 1,391 carrier-state combinations (carriers) in the 50 states and there are 20,351 wire centers operating under these 1,391 carriers.

3.2.1 cost study by density zones

We first aggregated results by density zones. For each state, we aggregated the total loop cost for all carriers across all density zones and divided it by the aggregated total number of lines in each state to work out the state mean unit cost. As seen in each of the tables in Appendix A3 (the HAI estimates column), the average cost calculated for the 50 states ranges from $8.50 to $38.13 per line per month.[23] If we aggregate across all 50 states, the average cost of a

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[22] LECOM, an alternative forward-looking telecommunications cost model, estimates the level of local loop costs in New Zealand in Gabel (1997). Another alternative is the BCM model, constructed by some US LECs. Since this study started, the FCC has developed its own model, which uses many elements of the HAI model.

[23] All financial data are expressed in US dollars, unless otherwise indicated.

local loop network for the US that the HAI model estimates is $13.96 per line per month. These results reveal a substantial variation in the average cost of a local loop across regions.

An obvious effect that we observe about line density is the substantial decline in the local loop's cost as density increases. Results aggregated over all 50 states and each HAI density zone are tabulated in the second column of Table 1. We treat the 50 states as a random sample of size 50, and report the sample mean and the percentage changes for each of the 9 density zones in the third and fourth columns of the table.

Table 1: Density and Cost

Density zone (lines per square mile)	Mean unit cost (Nation wide) (US$/line&month)	Statistics on mean unit costs for the 50 states	
		Sample mean (US$/line&month)	% change of mean unit cost as density increases
0-5	128.18	116.99	---
5-100	37.72	36.59	68.72 %
100-200	20.06	19.79	45.91 %
200-650	14.90	14.92	24.61 %
650-850	11.98	12.04	19.30 %
850-2550	10.04	9.98	17.11 %
2550-5000	8.29	8.10	18.84 %
5000-10000	7.38	6.94	14.32 %
10000+	4.89	4.39	36.74 %

We, of course, expect a fairly strong effect from line density. The cost of laying a cable between any two points changes very little as the number of lines in the cable change, and both distribution and feeder cables are for many different sizes of multiple lines. The incremental cost of additional lines to be included within each cable is quite low. If only the number of lines served to be changed, and nothing else, the cost of the local loop would change very little. The cost of materials in the cable is relatively small compared to the cost of the transport infrastructure and the installation of the cable on this infrastructure. Double the lines served at each address, and the cost per line served would drop nearly by half. The percentage change in the lines served at each address would be inversely and directly proportional to the percentage change of the cost per line served, or equivalently, the elasticity of the unit cost with respect to line density would be -1.

Unfortunately, if the number of lines served in a specific geographic region were to change, other factors do, in fact, change: in particular, the distance and location of local loop cables change. The number of premises for customers would increase, the number of streets to serve would increase, the number of clusters of customers would increase; and the routes taken to cover the new customers would change. If these other factors were to change significantly, the drop in cost associated with an increase in line density may be significantly less than a -1 elasticity would imply.

How much do local loop costs vary in practice when only line density is known over fairly large geographic regions? Consider first the variation of the HAI estimates of local loop costs over the 50 states within each density zone. In Appendix A1, we present for each density zone a scatter plot of the estimated state mean unit cost against the number of lines served in that density zone for each of the 50 states, overlaid by the mean cost in the US for that density zone.

One can observe that the variation from the mean tends to fall as a state has more lines to serve in that density zone. This should be expected if we interpret the data for each state as the mean of a sample size n, where n is the number of draws from the underlying random variable. Given that local loop costs are largely determined by factors relevant within each individual cluster, we can consider the cost estimated for local loops for each cluster as the underlying random variable. If we do so, and consider each state a random draw among these cost estimates for clusters, then traditional confidence intervals for a normal distribution based upon the standard deviation for sample means serving the number of lines indicated are those shown with dotted lines in the graphs.[24] As can be seen, this effect captures some of the dispersion that we see with the state data, but not all of it. Two factors might account for this. One is that this random variable (the cost to serve a cluster) may not be independent; other characteristics that affect local loop costs may be present and have a similar effect across large regions of the state. Another is that clusters are not all the same size, as assumed, and size and cost are correlated, with especially small ones tending to have especially high costs.

3.2.2 cost study by wire centers

Now consider estimates aggregated by wire center. From several sets of HAI work files, we can obtain data for the number of lines served and the area for each of these wire centers, which yields a measure of line density for the wire center. Given the data that we see in Figure 1 below and the elasticity we expect from them for reasons given above, we then fit a regression with a logarithmic specification to these data. The scatter plot of the double natural logarithm (ln) of unit cost against density depicts a non-linear relationship between the two.[25] We have considered two non-linear specifications, and the results for each are presented in Table 2.1 of Appendix A2. The first has a double log quadratic.

The ordinary least squares (OLS) regression output implies that a double log quadratic form fits the data well as the adjusted R^2 and F-statistics are both high,[26] and all the coefficient estimates are significantly different from zero. However, as can be seen from the plot of the actual and fitted values of ln unit cost against ln density, the fitted values tend to consistently overestimate the actual values for all the ln density values that are greater than 10 and the fit deteriorates.[27] The situation gets worse as density increases.

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[24] See Figures 1.1 to 1.9 of Appendix A1.

[25] Hereinafter double natural logarithm will be referred to as “double log”. See Figure 2.1 or 2.2 of Appendix A2 for a scatter plot of the data.

[26] See Table 2.1 of Appendix A2.

[27] See Figure 2.1 of Appendix A2.

The second specification, a cubic form, generates an improvement in fit and the cubic term has a significant coefficient. In it, the elasticity of unit cost for the local loop with respect to line density is assumed to vary linearly not only with **(ln density)** and **(ln density)^2**, but also with **(ln density)^3**. The OLS results of this model show a good fit to the data with high values of adjusted R^2 and F-statistics and low standard error.[28] All coefficients are significantly different from zero. However, the model seems to have heteroscedastic residuals[29] and this is confirmed by application of White's heteroscedasticity test.[30] We then follow the White's procedure to correct for this non-constant variance.[31] The following is the cubic estimated model:

$$\mathbf{ln\ unit\ cost} = \underset{(20390.6)}{6.253} - \underset{(-4894.1)}{1.121}\ \mathbf{ln\ density} + \underset{(2063.8)}{0.112}\ \mathbf{(ln\ density)^2} - \underset{(-1141.3)}{0.005}\ \mathbf{(ln\ density)^3}$$

$R^2 = 0.89$ Adjusted $R^2 = 0.88$ F-statistics = 148.18 Standard error: 0.3

This regression fits the data very well. Its unadjusted R^2 tells us that the model can explain about 89% of the variation in ln unit cost. Line density alone does indeed have substantial explanatory power. It indicates an elasticity that varies with density, approximately –1 for 1.75 lines per square mile, increasing to –0.21 for 3,450 lines per square mile, and decreasing thereafter. It is represented in Diagram 1.

Diagram 1

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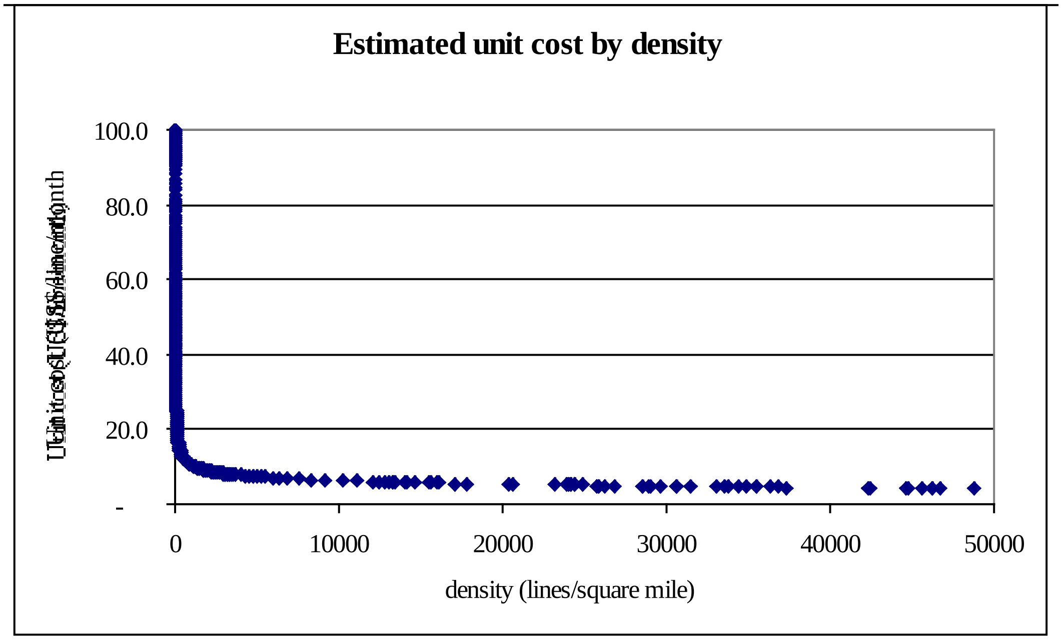
[28] See Table 2.1 (the OLS column under Model 2) of Appendix A2.

[29] As can be seen from Figure 2.2 of Appendix A2, points are closer to the regression line for high ln density values but are widely scattered for low ln density values. This exhibits a non-constant variance of the residuals around their mean zero.

[30] White's test is a large sample LM test that does not depend on prior knowledge of heteroscedasticity or assumption of normality.

[31] Note that OLS t-statistics based on the standard OLS covariance matrix for a heteroscedastic model are inconsistent and hence non-reliable.



The concentration of dots in the diagram represent the fact that the bulk of the observations fall below the density of 10000 lines per square mile, and thus are at, or close to densities at which cost declines sharply.[32]

3.3 Other factors affecting cost

Differences in several other factors, in addition to line density, may also have significant effects on international cost comparisons for constructing and operating a basic local telecommunications network. We discuss several below.

3.3.1 extent of clustering or homogeneity of density

One clearly important factor affecting the cost of constructing a network is the degree of clustering or dispersion within an area where line density is measured. Constructing a network is significantly cheaper if customer locations are clustered together rather than being uniformly dispersed over a particular region. On some scale, this issue is similar to the one that we will discuss about constructing cost estimates for other countries. Large regions or areas often have a large percentage of territory not covered by any wire telephone network. If we

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[32] Observations that are not on the line are not represented.

follow the same procedure on a smaller scale, and the area where no customers are located within a much smaller region is separated out, we have eliminated much of the differences in clustering, with the remaining region of clustered customers then measured with a higher, more homogeneous density, and hence, lower unit cost.

Similarly, regions that have areas within them that have quite different line densities, say a low density area and a high density area, have an average cost higher than a region of the same area but with a homogeneous density throughout. We could eliminate these differences in density by selecting regions that have a homogeneous line density throughout each region, typically small regions. When estimating relative costs for a country other than the US, consideration of this issue argues for measuring line densities on as small a scale as is feasible, while attempting to define regions with relatively homogeneous density.

3.3.2 geology

Another set of factors affecting the cost of constructing a network are the geological conditions over which lines are to be placed. The type of soil, rock depth, and water depth all affect the cost of placing buried or underground cable or in placing poles. The worst geological conditions could lead to cost estimates three times higher than the best. For cost comparisons to non-U.S. regions, unfortunately, no comparable data is typically available, so that we will not be able to control for this variable, except loosely. One mitigating factor is that poorer geological conditions tend to be correlated with lower densities, so that the density regression captures some of the affect of different geological conditions as well as density alone.

3.3.3 labor costs

Another factor that might be thought to significantly affect international comparisons of costs of both constructing and operating a telecommunications network are labor rate differences not captured by exchange rates. Wage rates for relatively low-skilled labor is a key factor in installation costs and for network operation, and labor mobility is much slower than capital mobility, so that these labor rates may adjust much more slowly than do exchange rates. In fact, real labor costs do vary over countries.

Nevertheless, labor rate differences do not have a large impact in our estimates of telecommunications costs. We could use international data for labor rates to adjust for this factor, but the effect cannot be large. When the HAI model is re-run for 57 carriers within 4 randomly selected states with an internal labor cost factor reduced by 25% and 50%, the estimated unit cost decreases by 1.1% and 2.2% respectively. The results are summarized in Table 2 below.

From Table 2, as the line density increases, the percentage change in unit costs due to the change in wage rates also increases. Even so, the differences between density zones are not material as they range only from 1.5% to 3%.

Table 2: Change in the Cost of Labor

Density zones (lines per square mile)	Mean of % change in unit cost when labor cost factor reduced by 25%	Mean of % change in unit cost when labor cost factor reduced by 50%
0-5	-0.96%	-1.91%
5-100	-1.20%	-2.41%
100-200	-1.25%	-2.49%
200-650	-1.20%	-2.40%
650-850	-1.20%	-2.41%
850-2550	-1.43%	-2.86%
2550-5000	-1.90%	-3.81%
5000-10000	-1.95%	-3.91%
10000+	-2.42%	-4.80%
Total	**-1.11%**	**-2.21%**
Note: Total is the mean percentage change across all of the 57 carriers.		

3.3.5 capital costs

Another set of factors that significantly affects the estimated monthly costs reported to summarize telecommunications costs are the cost of capital and related components: rates of return, the economic life of various assets, accounting depreciation rates, and taxes. We are most interested in those factors that are both likely to differ between countries and have differences likely to affect relative costs.

Risk-adjusted after-tax rates of return required for a telecommunications investment are likely to be quite similar in different countries. Capital can cross international boundaries fairly easily so that the returns for marginal investments that determine this competitive rate of return should be nearly equal. One qualification would come from differences in regulatory regimes that create different levels of risks for earning profits from the same network investments. We have not considered cost differences due to the regulatory regime itself.

Pretax rates of return required for telecommunications investments that are in different countries will reflect differences in country risk premia, and business taxes differences. If, as examples, a profits tax, an excise tax, or a value added tax were to siphon off funds that would otherwise be profits, the marginal investment must generate more pretax profits to earn the after-tax competitive rate of return. We have not incorporated country risk or the effect of the different taxes; if this study were extended, examining the effect of differences in taxes would be an early set of factors to come under review.

Another variable that significantly affects the total cost of capital is the economic life of various assets. The cost of an investment must include the present value of earning the pretax competitive rate of return (one determined for the risks undertaken) for all of the economic life of the assets that the marginal investor expects. A longer economic life increases total capital costs, and their present value, but by less than the proportion of the increase in the economic life. If the fixed investment cost of the network and its operating cost are summarized as a single monthly charge, this means a longer economic life decreases the monthly “cost” reported.

This effect can be seen in the HAI model if we were to reduce the assumed economic life of copper cable, either when we reduce the assumed life of all copper cables in the local loop or when we reduce the assumed life of only the underground and buried copper cables.[33] When the HAI model is re-run for the same 57 carriers with the assumed economic lives of all copper cables reduced from their default values by 25%, 50% and 75%, the reported unit cost increases by 2.93%, 9.83% and 32.78% respectively. If its re-run in the same way, but reducing only underground and buried copper cables’ economic lives, the reported unit cost increases by 2.19%, 7.39%% and 24.87% respectively. As can be seen, the effect on the reported absolute level of cost can be significant, especially at higher densities. Furthermore there is some differential effect as between the lowest and other densities. This would have some effect on relative cost comparisons.

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[33] Underground and buried cables are more likely to be in feeder cables, and are, thus, more susceptible to obsolescence due to cost reductions for optical fiber.

Table 3: Change in Economic Depreciation

Density zones (lines per square mile)	Mean of % change in unit cost when the economic lives for 4 copper cables are reduced by			Mean of % change in unit cost when the economic lives for 2 copper cables are reduced by		
	25%	**50%**	**75%**	**25%**	**50%**	**75%**
0-5	1.87%	6.30%	21.16%	1.47%	4.97%	16.79%
5-100	3.39%	11.37%	37.91%	2.52%	8.51%	28.60%
100-200	4.32%	14.44%	48.02%	3.11%	10.48%	35.18%
200-650	3.91%	13.08%	43.42%	2.66%	8.97%	30.11%
650-850	4.19%	13.99%	46.41%	2.85%	9.59%	32.18%
850-2550	4.62%	15.47%	51.35%	3.26%	10.97%	36.82%
2550-5000	4.04%	13.57%	45.20%	2.95%	9.91%	33.32%
5000-10000	4.29%	14.34%	48.04%	2.68%	9.02%	30.37%
10000+	4.83%	16.23%	54.42%	2.91%	9.81%	33.08%
Total	**2.93%**	**9.83%**	**32.78%**	**2.19%**	**7.39%**	**24.87%**

Note:

(1) The 4 copper cables are aerial , underground, buried and intra-building cables and their default economic lives are 20.61, 25, 21.57 and 18.18 years respectively.

(2) The 2 copper cables are underground and buried cable and their default economic lives are 25 and 21.57 years respectively.

(3) Total is the mean percentage change across all of the 57 carriers.

For our purposes, however, even though expected economic lives can play a significant role in determining absolute level of reported monthly unit costs, adjustments in these factors will affect all regions near equally, and will have relatively little effect on relative costs. If economic lives were over-estimated, for example, reducing the estimate would increase the reported monthly cost of a higher density region by more than a lower density region, but the effect would be quite small.

4. Relative Costs Across Five Nations

Ultimately, we wish to make cost comparisons between the US, where detailed data for estimating costs are available, and other nations, where such detailed data may not be available. Data on line density, or data closely related to line density, are available for other nations, while data for other factors that affect telecommunications costs are not generally available. How accurate should we expect such estimates to be that are based upon this line density data alone?

One way to assess this accuracy is to use each estimating procedure that may be used on other nations on each of the 50 US states. Apply each procedure that uses only line density data to estimate the per unit cost of a local loop for each of the 50 states, and then compare these estimates with the full HAI estimates that are based upon a myriad of factors in addition to line density. We consider each of the procedures below, whose use would depend primarily upon the line density data available. Line density data might come in several forms: the average line density for the entire state, the population density of the entire state, the numbers of lines served in each density zone for the entire state, or possibly line densities for each wire center for a state. A table presenting the estimates obtained from each type of data, the full HAI estimates, and the percentage differences between them is given in Appendix A3.

4.1 Using only average line density data for the entire region

If we have data only on the total number of lines served and the total area in the region, we may estimate local loop costs assuming a distribution over density zones similar to the US with the closest line density.

This approach reveals a complication. For many states the total area covered by the telephone network is quite different from the total area of the state. This coverage also varies tremendously by state. At extremes, telephone networks for several western states cover less than 10% of their total area, while those for some eastern states cover almost the entire state. Wire telephone networks were not designed to cover uninhabited mountains, deserts, swamps, forests, lakes, or rivers.

The total area that a telephone network covers and the total area for each state yield quite different measures of line density. Unfortunately, the relationship between line density and cost depend upon the area a telephone network covers, but for international comparisons, it is the total area of a political region that is measured. Data available usually does not provide the area covered by a telephone network.

If we do have the area that a telephone network covers, in addition to the total lines served, several procedures might be used to estimate regional relative cost.[34] First, after ranking states by line density, one could estimate a target state's per unit cost as that given by the model for the state with the closest line density. With this procedure, the estimate is within 10% of the HAI value for 22 states, within 20% for 43 states, and within 30% for 46 states.[35]

Second, using a similar approach, but modified to reduce the effect of an unusual cost calculated for that one state with a similar line density, an average from two states with a similar density could be used. This procedure is somewhat

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[34] The area that the telephone networks cover for each state is obtained by aggregating the areas served by all wire centers in the same state. See Table 3.1 or 3.2 (the column under total area with phone in square mile) of Appendix A2.

more accurate as it yields more accurate estimates for 31 states and less accurate ones for only 18.[36] The distribution doesn't change radically, though. The estimate is within 10% of the HAI value for 22 states, within 20% for 39 states, and within 30% for 47 states.

Third, one could estimate the targeted state unit cost using the best-fit regression results. This procedure does not perform that well (8 states within 10%, 23 within 20% and 40 within 30%) and it appears biased toward overestimates (47 overestimates, 3 underestimates).[37] As the objective of any regression model is to minimize the in-sample squared errors, any out of the sample prediction will be less reliable outside the sample than within. In this particular regression, cost estimates were made at the wire center level, and line density tends to be much more homogeneous within wire centers than within much larger regions covered by entire states. Given the convexity of the logarithmic structure between line density and unit cost, an average of the unit costs for two small areas with different densities is higher than the unit cost estimated for the combined region with its average line density. This means that an average of the unit costs for all clusters within a wire center, which is what makes up the unit cost estimates for each state, is higher than an estimated unit cost based upon the wire center's average density, which the regression provides. This effect will become smaller as the regions whose costs are to be estimated have more homogeneous line densities.

4.1.1 using only average population density data for the entire region

While statistical data available normally does not provide line density data, another possibility for estimating local loop costs is to use population density data instead. With population and the corresponding area for each state and the assumption of constant line per capita throughout the US, we obtain another set of estimates. Table 3.2 of Appendix A3 considers parallel estimates

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[35] See Table 3.1 (the first set of estimates next to HAI estimates) of Appendix A3.

[36] See Table 3.1 (the second set of estimates) of Appendix A3.

to those in Table 3.1. As can be seen from the results, as expected, the estimations are not as good as those using the line density data.

4.1.2 based on the number of lines served in all density zones

If we have data on the number of lines to be served in each density zone in the region of interest, we may estimate the local loop costs by multiplying the national mean cost of any density zone by the sum across density zones the number of lines.

When we consider cost estimates based upon lines served in each of the density zones, 40 states are within ±10% of the HAI value, 48 are within 20%, and all 50 are within ±30%.[38] Reasons for the differences are not always apparent, but the states with the largest underestimates tend to be mountainous. As expected, the statewide data that provides the most detail on density yields the most accurate estimates.

4.1.3 using the average line density for all wire centers in a region

If we have data on line density for each wire center, we can provide another set of estimates by using the regression model. First we get the fitted values for each wire center. Then, we take[39] a weighted average (by number of lines) of the fitted unit costs across each state. 34 states are within ±10% of the HAI value, 49 are within ±20%, and 50 are within 30%. The results may be slightly biased upward (28 overestimate, 22 states underestimate).

4.2 International cost comparisons

To make our international cost comparisons, we need line density data for Australia, New Zealand, Sweden, the United Kingdom, and the United States. As data on actual line density (or data on the area covered by the telephone network and the actual number of lines served in relatively small regions) are

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[37] See Table 3.1 (the last set of estimates) of Appendix A3.

[38] See Table 3.3 of Appendix A3.

[39] See Table 3.4 of Appendix A3.

usually not available, we will create proxies for it. This approach uses population data for various regions within each country and assumes the number of lines per capita in a country is constant. The population density and number of lines per capita for the five countries are as follow:

Table 4: Population and Number of Lines

Country	Population density (person/square mile)	Number of phone lines per capita *
Australia	6	0.504
New Zealand	36	0.495
Sweden	56	0.679
United States	75	0.701
United Kingdom	627	0.522
* These figures are based on ITU data.		

According to these figures, population densities are quite different across countries but their number of telephone lines per capita are somewhat similar with value ranges from 0.5 to 0.7 lines per capita. Intuitively, cost estimations based on the above constant lines per capita and country-wide population density data would yield the highest cost for Australia, followed by New Zealand, Sweden, the US, and finally the UK.

We are susceptible to significant errors due to misestimating the area that telecommunications networks do not serve. To address this concern, we estimate the number of lines and line density for each city for each of the five countries, as the entire area of a city is likely to be served by the telephone network. We are then left with a relatively small number of rural customers located in a broad area where a substantial portion may be unserved by the telephone network. We take as a proxy for this unused portion, the unused portion in a similarly dense area within the US. The following table shows the effect of the difference between using national data or this city/rural approach:

Table 5: Estimates of Relative Cost

	estimated state mean unit cost for state with nearest line density using HAI estimates		Weighted ave. of state mean unit cost for two states that bracket line density		Estimated mean unit cost with population density data using regression model	
	using nation wide data	using regional/ city data	using nation wide data	using regional/ city data	using nation wide data	using regional/ city data
Australia	$ 35.92	$ 16.76	$ 35.01	$ 16.38	$ 165.20	$ 652.63
New Zealand	$ 35.92	$ 17.58	$ 35.03	$ 17.17	$ 50.41	$ 17.58
Sweden	$ 25.61	$ 18.71	$ 25.79	$ 18.42	$ 31.18	$ 25.32
UK	$ 13.62	$ 11.96	$ 13.55	$ 11.60	$ 13.62	$ 11.49
US *	$ 14.70		$ 14.92		$ 18.19	

* The estimates for the US are based on the total phone lines and total area served by all wire centers in the US.

As expected, the use of data for broader regions tends to produce higher estimates due to a tendency to under-estimate line density. The main difference in relative costs is is the position of Sweden. On nationwide data it has lower costs than Australia and New Zealand, but on a regional basis it has higher costs. This may be explained by lower regional densities and less population concentration in few cities in Sweden. According to the first two sets of estimates using smaller regional data, average unit costs for Australia, New Zealand and Sweden and the UK are relative to each other as summarized in Table 6.

Table 6: Estimates of Cost Rankings

Average Unit Cost Relative to the US		
	greater than US average	less than US average
Australia	10-14%	
New Zealand	15-20%	
Sweden	23-27%	
United Kingdom		19-22%

As before, the estimates using regression model appear to be higher, though less so with regional/city data.

Finally, we obtained another set of estimates for New Zealand using ESA data from New Zealand Telecom. The results are summarized below:

Table 7: New Zealand Costs

	Estimated state mean unit cost for state nearest line density using HAI estimates	Weighted ave of state mean unit cost for two states that bracket line density	Estimated mean unit cost with ESA data using regression model (double ln cubic for all wire centers)
New Zealand	$ 16.79	$ 16.28	$ 50.77

One difference for these estimates is that we do not have constant line per capita, as the number of phone lines in each ESA is given. Another is that the total area served by all ESAs seems to have included the area not served by the telephone network. This caused an under-estimate of the line density compared to our previous measurements, and hence, an over-estimate of the unit cost using the regression model. When we look at the first two estimates, average unit costs for New Zealand are about 9-14% greater than the US average.

5. Synopsis and Concluding Remarks

In order to conduct informative comparative institutional studies across countries, relative cost estimates are required that are largely independent of the regulatory regime. These are necessary because what is of most interest in evaluating consumer and producer benefits is price relative to cost.

Telecommunications technology is the same worldwide. Differences in costs between countries for their networks will primarily be due to country-specific characteristics such as population density and topography. After examining the economics and technology of telecommunications networks and determining that any market power concerns, if any, would be limited to the network's local loops, we examined the determinants of relative costs for constructing and operating the local loop using data and a cost model from the US. We found that unit costs for the local loop can vary tremendously in different regions, and the primary factor for the difference is the line density from the network's customers. We found that unit costs of local loops fall steeply as density increases, but at a decreasing rate. We also examined other regional factors, including the extent of the clustering of customers, geological conditions, labor costs, and elements of capital costs. While certain of these factors materially affected absolute cost levels, they were much less important in relative-cost comparisons. We then estimated average unit costs of the local loop for Australia, New Zealand and Sweden, respectively, are about 10-14%, 15-20% and 23-27% greater, and the UK 19-22% less, than the US average.

While we do not examine in this study the many additional factors important for determining the absolute level of costs, as opposed to relative costs, New Zealand readers will find it interesting to note that the absolute level of costs suggested from our relative cost estimates for New Zealand are substantially higher than those of Todd (New Zealand Telecommunications: the state of competition, 1998). Because not all the relevant assumptions of the Todd HAI model are public information, an exact explanation of the difference is not possible. However, those modeling differences that appear responsible for the largest differences in the absolute level of costs have a much smaller impact on estimates of relative costs. These different results indicate that, comparing actual practice in various countries, and adjusting for differences in relative costs due to the most important regional factors such as customer density, is less prone to error and to differences in expectations about critical inputs than evaluating the many important variables that determine absolute costs, and what might be achieved using a hypothetical model of cost levels.

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6. Appendix I Wireless Local Loop Alternatives[40]

Substantial technological progress has occurred over the last couple decades in wireless transmission. This appendix will discuss wireless technologies, conditions when a wireless local loop is likely to be preferred over a traditional wireline local loop, and approximate costs of a wireless local loop relative to a traditional wireline local loop.

Two network architectures are now used to provide wireless telecommunications services. The choice of which wireless technology to use depends on the distance to be covered, where in the network they need to be used, and the types of services to be delivered.

The first architecture has been used for many years and occurs where radio is used as a distribution technology, where a central network node is directly connected with remote nodes by radio, and access is provided to individual customers from the remote node via either copper loops or radio. The choice of copper versus radio access is usually dictated by the combination of distance from customer to remote node, density of customers, and the services to be supplied. In this architecture, the radio link from the central network node is a substitute for the wireline feeder, and the links from the remote node substitute for the wireline distribution and drops.

Costs for these traditional microwave-based wireless connections are relatively insensitive to distance compared to a wireline network, so that the cost per line is essentially the same anywhere within the transceiver’s line of sight. While a wireline network may have smaller fixed costs at short loop distances, as distance goes up, costs increase faster than it does microwave radio. As a result, for longer distances and lower line densities, radio technologies offer the lowest cost alternative for a local loop.

The second architecture is more recent. It allows the central network node to be directly connected to individual customers, thus providing a substitute for feeder, distribution, and drop in one radio path over quite a range of distances. While the cost characteristics are similar to the traditional microwave-based technology, with higher fixed and lower variable costs compared to wireline, this

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[40] This material is taken from Pulido and Svanberg (1998) and an interview with Jan Jager, Solutions Manager, Ericsson.

technology does provide wireline quality over longer distances and therefore involves a different mix of factors in the trade-off decision.

This architecture uses three wireless technologies to provide telecommunications services. They differ primarily by the frequency range that they use, which then dictates their range and power requirements, and the relative cost of transmission facilities. They can usually be classified as short-range cordless services, longer-range cellular services, and even-longer-range microwave services.

Short-range cordless services have a 2-3 kilometer range. They are usually deployed in relatively dense urban environments, possibly operating with a low 5-10% share of the access lines in the area, but require 400-500 lines for each cell (central node) to be economic. In these circumstances the line density of the area could be as low as about 140 lines per square mile which is in the bottom third of the nine density zones that the HAI model defines. If the wireless service quality matches that of a traditional wireline service then investment per line of about $500 is required at these densities.

Cellular technologies typically have a longer range than the “cordless” technology when used to provide local loop access but, because they tend to use a high degree of voice compression, generally offer a lower quality service than a wireline network. This technology is now used to provide local loop capability in developing countries such as Indonesia, Poland, several South America and Middle East countries as well as South Africa.

Microwave technology, developed initially in the 1970’s is now relatively mature and its range is restricted only by line of sight. Under the right conditions microwave can provide service quality that matches that of wireline and, in a rural environment or one with difficult terrain, a microwave-based wireless local loop may be the least cost alternative over a wireline. Used in these conditions (which are generally also combined with a low density of lines) investment per microwave line can be 10 to 15 times the short range/medium density costs.

Other technologies will offer more options in the future. While cellular technology does not, at present, provide the same service quality as a wireline network, and would therefore not be considered a substitute for all customers in all countries, it may provide a real alternative for those customers needing only basic voice service. Further, a cellular technology based upon CDMA transmission is soon to be offered in the US and in many developed countries within three years. It will offer wireline quality service, may well have costs closer to the cordless than microwave technologies and therefore provide a local loop alternative for many customers.

Beyond these applications, any mobile wireless technology that allows equivalent service quality may provide a least cost alternative for fixed access to its mobile customers. The incremental cost of providing fixed local access can easily be lower than a wireline local loop for these customers because the fixed costs are largely covered by the mobile services and the value they provide.

7. Appendix II

(The appendices demand a lot of storage and are not included with the electronic form of the paper. They may be obtained by facsimile at request: email. iscr.org.nz, or fax. +64 4 462 5566).

A1: scatter plots of all states for each density zone

A2: regression results and plot of ln unit * ln density for each of two specifications

A3: estimates of average unit costs for 50 states given only line density data

3.1: given average line density for state
- HAI estimates
- state mean for state with nearest line density
- weighted average of state means for two states that bracket line density
- regression mean for state line density

3.2: given average population density for state
- HAI estimates
- state mean for state with nearest line density
- weighted average of state means for two states that bracket line density
- regression mean for state line density

3.3: given number of lines served for density zones within state
- HAI estimates
- national means weighted by number of lines in each density zone

3.4: given average line density for wire centers within state
- HAI estimates
- regression mean for each wire center line density