Article

The Urban-Rural Telecommunications Divide Endures: A Historical Perspective from Landline Telephony

Jean-Michel Guldmann (ID)

Department of City and Regional Planning, The Ohio State University, Columbus, OH 43210, USA; guldmann.1@osu.edu; Tel.: +1-614-202-9989

check for updates

Abstract: The popular press and academic literature show that the urban-rural divide persists with regard to recent telecommunications technologies, such as broadband and wireless service. As was the case for landline telephony, this lack of deployment in rural areas is rooted in cost differentials and lack of agglomeration economies. This paper provides historical insights on this divide, using 1990 data on voice communications in a region located in the northeastern United States, and investigates (1) whether there are differences in telecommunications usage between urban and rural firms, (2) whether advanced telecommunications technologies provide an economic advantage to rural firms, and (3) what are the factors encouraging and inhibiting the provision of these technologies in rural areas. Exchange-level data on telephone usage by eleven economic sectors are first linked, through regression analysis, to data characterizing the exchange employment, rural character, availability of advanced technology, and geography. Rural activities turn out to use telecommunications less than urban ones in the absence of advanced technologies, but the latter tend to significantly increase usage. Next, a logit model is estimated to link the deployment of one advanced technology—digital switching—to market and geographical variables. The results tend to support the idea that an advanced telecommunications infrastructure in rural areas may be important to attract activities that make heavy use of telecommunications, but also that its provision is inhibited by the traditional rural barriers of distance and low population density.

1. Introduction

A recent article in the New York Times (14 November 2020), titled "In Rural 'Dead Zones', School Comes on a Flash Drive", describes the wrenching problems that many schoolchildren in North Carolina rural communities face in trying to connect from their homes to their schools to attend online classes in the time of Covid-19. Broadband service is often unavailable and wireless cell service is often spotty. In the specific case of Robeson County, N.C., about 20,000 of residences (43% of all households) have no Internet connection, and, for N.C. as a whole, 100,000 of the state's 1.5 million K-12 students cannot connect to online services. This is the case of 15 million K-12 students in the U.S. This situation has prodded temporary innovations by school districts, such as setting Wi-Fi hot spots in school buses parked in connectivity-deprived neighborhoods. The article further indicates that N.C. politics has stopped municipal broadband providers from serving residents where commercial networks are unwilling to go.

The issue of the urban-rural telecommunications or digital divide is an old one, which endures and does not seem close to a resolution. It continues to hamper the economic development of rural areas

while large cities and metropolitan areas enjoy the availability of advanced technologies, that spur innovations and further increase the economic divide, with large-scale political implications [1].

Recent academic research on mobile telecommunications and Internet broadband access confirms the continuing worldwide urban-rural divide, primarily because, as was the case for landline telephony in the past, the required investments to wire rural areas are not profitable for private service providers, and subsequently rural areas are slow to adopt the new technologies. For instance, Sundquist and Markendahl explain mobile coverage limitations in the rural areas of the European Union (EU) because of long inter-site station distances [2]. Michailidis et al. analyze the factors affecting adoption of mobile technology in rural areas of Macedonia, Greece, using survey data on 490 residents, and show that different factors influence farms, rural enterprises, and rural households [3]. Schneir and Xiong show that the deployment of high-capacity broadband access networks in European rural areas lags behind urban and suburban areas because of an 80% cost difference [4]. Freeman et al. point to the inferior availability and quality of Internet connections in rural areas of Australia, including slow and unreliable fixed wireless and satellite connections [5]. Lehtonen, using detailed data on population and broadband availability in Finland, shows that the availability of broadband reduces depopulation in remote rural areas [6]. Finally, Reddick et al., using survey data on San Antonio, Texas, show that the digital divide is not exclusively urban-rural, but also takes place within the city in low-income areas [7].

Telecommunications are often viewed as the tool capable of neutralizing the major barriers to economic growth in rural areas: Distance and lack of economies of scale and agglomeration. In particular, an advanced telecommunication infrastructure is believed to help attract information-intensive firms, allowing them to trade their services beyond local markets. However, research on this subject suggests that telecommunication advances may also be a two-way street for rural areas, because they also make it easier for urban firms to capture and serve rural markets. The purpose of this paper is to provide a historical perspective on the relationship between rural economic activities and telecommunications, focusing on voice communications and landline telephony, and making use of data for the year 1990. The research questions are as follows: (1) are there differences between urban and rural activities in terms of their usage of telecommunication services? (2) do advanced telecommunication technologies in rural areas provide an economic advantage to rural firms? (3) what are the factors that influence the provision of advanced technologies, and are rural areas disadvantaged in this provision?

In contrast to the conceptual, small-local-survey, and case-study orientation of much of the literature, this study makes use of detailed, exchange-level (wire center) telecommunication usage and infrastructure data and Census socio-economic data for a region in the northeastern United States. Based on a micro-economic production function framework for both the firms that purchase/consume telecommunication services and the local exchange company (LEC) that provides these services, (1) standard regression equations are developed and estimated for 11 economic sectors, relating telecommunication usage to employment, telecommunication infrastructure, and various geographical variables, and (2) a logit model is estimated, that explains the provision of digital switching by the LEC. The insights provided by these results may provide guidance for developing policies for improving access to broadband and wireless service in rural areas.

The remainder of the paper is organized as follows. Section 2 consists of a literature review. The conceptual framework is presented in Section 3. Data sources and processing are described in Section 4. Functional specifications and regression empirical results are presented in Section 5. Results implications are discussed in Section 6. Conclusions are outlined in Section 7.

2. Literature Review

Most studies dealing with the impacts of information and communication technologies (ICTs) on rural economic development are based on the premise that high-quality ICTs can help attract footloose industries, particularly information-intensive producer services (PS) firms, to peripheral and rural areas, and thus contribute to their economic development. ICTs allow these firms to trade their services beyond their local markets, in contrast to consumer services bound to residential activities. PS activities

(e.g., consulting, computing, engineering, finances, advertising, insurance, public relations, and legal analysis), whose output is primarily information and knowledge that serve as inputs to producers of goods and services, are considered export (or basic) activities, responsive to external demand, and thus with strong multiplier effects on the regional economy. Kirn, Conway, and Beyers analyze the growth of PS in the Seattle SMSA (Standard Metropolitan Statistical Area) and surrounding rural areas, and the role played by telecommunications [8]. They find that PS opportunities are largest in large rural communities, with high-quality ICTs, and, in particular, quality data transmissions. In smaller communities, however, PS firms serve predominantly local markets, with very limited exports, due to smaller pools of skilled workers and lack of agglomeration economies. They conclude that ICT advances may be a two-way street for rural America: (1) ICTs increase a rural community's access to information and help rural businesses serve non-local markets, but (2) ICTs make it easier for urban firms to capture and serve rural markets, thus inhibiting local rural development. Coffey and Polese, studying the growth of PS in Canada from 1971 to 1981, concluded that PS employment growth beyond metro areas occurs primarily through extended urbanization, rather than in rural regions and smaller towns, and that the potential for higher-order PS firms to locate outside major metro areas is highly limited [9]. Their view is that ICTs free office functions from locating close to the operations they direct or support, thus contributing to the growing centralization of such functions in a small number of large metro areas. OhUallachain and Reid observe two types of changes in the location patterns of PS firms: (1) a decentralization down the urban hierarchy, where back-office functions seem to be attracted to lower-wage non-metro areas, and (2) a rapid growth and concentration in several large metro areas [10]. They hypothesize that this selective decentralization/centralization is associated with inter-firm flows of information, and that minimizing the costs of acquiring information drives firm localization. Hudson and Parker, noting that farming employs only 9% of all rural workers, find that ICTs are key to improved efficiency in managing rural enterprises and savings in travel costs and times, particularly in very low-density areas [11]. Egan discusses the importance of deploying microwave and fiber optics facilities in rural areas, because large service and manufacturing businesses often require broadband communication capability for high-quality data and video transmission to keep up with their urban and suburban counterparts [12]. Richardson analyzes the decentralization from London to peripheral regions of firms involved in teleservices, such as travel booking/sales/reservation and computer direct sales/technical support [13]. Finally, Richardson and Gillespie analyzed the impact of a British government initiative to upgrade ICTs in a rural region of Scotland to attract data-intensive businesses [14]. New jobs, predominantly professional (consultancy, programming) in home-based and small businesses, have been created, but most of the employment growth has been driven by returnees with ICT skills. These skills turn out to be difficult to develop within these peripheral regions, and the initiative had little impact on existing small/medium firms. This study underscores the need to upgrade educational levels and professional skills in rural areas, as prerequisites to the efficient use of telecommunications. Infrastructure availability is not sufficient, and rural firms must have competencies, skills, networks, and contacts to compete.

The above review underscores that there are few systematic empirical studies to identify and systematically quantify the relationships between telecommunication infrastructure and use, and rural economic activities and development. Such studies become feasible only with the assembly of appropriate data on the socio-economic structure of rural areas, and their telecommunications infrastructure and usage, as proposed in this paper.

3. Conceptual Framework

The purpose of this section is to outline a micro-economic behavioral framework explaining firms' decisions regarding telecommunications services and other input purchases, as well as the decisions to supply/deploy advanced technologies by telecommunication service providers. The resulting generalized equations are then to serve as a basis for specifying empirically estimable relationships.

3.1. Telecommunications Usage

Standard micro-economic theory can be used to provide a general explanatory model for a competitive firm's consumption of telecommunications. The various telecommunication flows generated/purchased by a firm make up its information input, and are constrained by the telecommunication infrastructure available at the firm's location (i.e., exchange), such as number and type of access lines and switching technology. The telecommunications variables make up the following vectors:

$$\mathbf{F} = (F_{1\ldots\ldots} \; F_n \ldots \ldots \; F_N): \text{Telecommunication flows}$$

$$\mathbf{T} = (T_{1\ldots\ldots} \; T_k \ldots \ldots \; T_K): \text{Telecommunication infrastructure components}$$

By extending the concept of information function first introduced by Larson et al. [15], the firm's information input, I, can be represented by:

$$I = f_I \, (\mathbf{F}, \mathbf{T}) \tag{1}$$

The firm's standard production function relates its output Q to the information input I, the labor input L, and all the other inputs represented by vector **X**, with:

$$Q = f_Q \, (I, L, \mathbf{X}) \tag{2}$$

Combining Equations (1) and (2) leads to:

$$Q = g_Q \, (\mathbf{F}, \mathbf{T}, L, \mathbf{X}) \tag{3}$$

Let P_Q, $\mathbf{P_F}$, P_L, and $\mathbf{P_X}$ be the prices associated with Q, **F**, L, and **X**, respectively. The standard problem of the firm is to select the values of the output, Q, and inputs, **F**, L, and **X**, that maximize its profit

$$\Pi = P_Q Q - \mathbf{P_F} \, \mathbf{F} - P_L L - \mathbf{P_X X} \tag{4}$$

The following telecommunications and labor inputs functions are derived from this maximization:

$$\mathbf{F} = \mathbf{f_F} \, (\mathbf{T}, \mathbf{P_F}, P_L, \mathbf{P_X}, P_Q) \tag{5}$$

$$L = f_L \, (\mathbf{T}, \mathbf{P_F}, P_L, \mathbf{P_X}, P_Q) \tag{6}$$

Combining Equations (5) and (6) by eliminating the labor price P_L leads to:

$$\mathbf{F} = \mathbf{g_F} \, (L, \mathbf{T}, \mathbf{P_F}, \mathbf{P_X}, P_Q) \tag{7}$$

Equation (7) will be adapted and empirically estimated to analyze sectoral telecommunication usage decisions at the exchange level, as discussed in Section 5.1.

3.2. Telecommunications Infrastructure Provision

Micro-economic theory can again be used to develop a general model of infrastructure provision decisions by the telephone company (LEC) that serves all the firms and households located within its service territory. Let $\mathbf{F_{LEC}}$ be the vector of all the telecommunications flows generated by these firms and households. This vector represents the total output of the LEC. Assume that the LEC's inputs are (1) labor, L_{LEC} (the LEC's employees), and (2) capital, represented by the LEC's infrastructure (access lines, trunk lines, central offices, switching equipment, etc.), subsumed in the vector $\mathbf{T_{LEC}}$. The LEC's production function is formalized as:

$$\mathbf{F_{LEC}} = \mathbf{h_F} \, (\mathbf{T_{LEC}}, L_{LEC}) \tag{8}$$

Let $\mathbf{P_T}$ and P_L be the prices of capital (infrastructure) and labor. The LEC is a regulated carrier that minimizes costs under price regulation, and, therefore, its input demand functions have, as arguments, the output vector and input prices. The infrastructure provision (capital demand) function is of particular interest here, with:

$$\mathbf{T_{LEC}} = \mathbf{k_T}\,(\mathbf{F_{LEC}},\,\mathbf{P_T},\,\mathbf{P_L}) \tag{9}$$

Equation (9) will be adapted and empirically estimated to analyze switching equipment decisions at the exchange level, as discussed in Section 5.2.

4. Data Sources and Processing

4.1. Telecommunication Data

The telecommunication usage data pertain to a 5 percent random sample of all the toll calls that were made within a certain local access and transport area (LATA) in the northeastern United States during the month of February 1990. All calls originate and terminate within the LATA. Because of the proprietary nature of the information and a data protective agreement signed by the author, the name of the LEC that provided the data may not be revealed, and any parameter that might be used to identify it is given on an interval basis only.

The LATA is subdivided into 100–200 local exchanges, also called wire centers, each with a central office building housing one or more switches, to which all local loops converge. The sample includes 500,000–700,000 calls. Each message is characterized by several variables, such as the message date, starting time, duration, and charge; the coordinates of the two wire centers where the message originates and terminates; and the standard industrial classification (SIC) code of the party (caller, callee, or third party) that pays for the message. A complex data matching process was undertaken to assign SIC codes to as many calling and called numbers as possible and is described in more details in Guldmann [16]. This SIC-code assignment, which was initially completed for 73.2% of all the calls in the sample, was expanded by using SIC identifications available in CD-ROM telephone directories. The following major toll services were retained: (1) message toll service (MTS), originating at private residential and business stations, and (2) wide-area toll service (WATS), originating at WATS business numbers. Only MTS calls have their charge included in the database. The pricing of WATS service involves (1) a fixed monthly access line charge, and (2) a monthly usage charge related to the monthly hourly usage through a declining block rate structure, irrespective of the timing of a call or the location of its destination. Given the rate structure in effect in February 1990, the total monthly usage and the resulting total monthly charge have been estimated for each WATS number in the sample. The resulting average charge (¢/second) has then been used to estimate an equivalent charge for each individual call, based on its duration.

At the completion of the SIC-code assignment process, each telephone number is classified into one of four categories: (1) SIC-identified business (BUSID), (2) SIC-non-identified business (BUSNID), (3) residential (RES), and (4) unknown (MIX). Telephone flows (conversation seconds) have been aggregated by origin exchange along the above categories, and the BUSID flows have been further grouped into 11 economic sectors, in order to match the available employment data categories:

(1)   construction (CON), SIC 15-19,
(2)   manufacturing (MAN), SIC 20-39,
(3)   transportation, communications, and other public utilities (TCPU), SIC 40-49,
(4)   wholesale trade (WT), SIC 50-51,
(5)   retail trade (RT), SIC 52-59,
(6)   finance, insurance, and real estate (FIRE), SIC 60-69,
(7)   business and repair services (BRS), SIC 73-76,
(8)   personal services (PERS), SIC 70-72,
(9)   professional and related services (PROS), SIC 80-89,

(10) public administration (PA), SIC 90-98,

(11) all other industries (primarily, agriculture and mining) (OTH).

The BUSNID flows were assumed to be distributed across sectors to reflect the proportions of the BUSID flows, and were allocated to the BUSID flows accordingly. The MIX flows were assumed to reflect the relative sharing of residential and business flows, and were allocated accordingly. The basic flow variable finally retained is: MST_{ki} = number of conversation seconds (MTS + WATS) from sector k located in exchange i to regular (not toll-free 800 numbers) business and residential destinations. Total flow shares across the 11 economic sectors are presented in Table 1. Services (Sectors 6–9) make up 40% of the traffic, followed by trade (Sectors 4 and 5), 30%, and manufacturing, 10%. Call charges have been aggregated/allocated in the same way as the flows. The total charge is defined as: MCT_{ki} = total charge ($) for all the calls/conversation seconds (MTS + WATS) from sector k located in exchange i to regular destinations. The average price is then derived by dividing total charge by total flow duration:

$$PMST_{ki} = MCT_{ki}/MST_{ki} \tag{10}$$

Table 1. Telephone flow distribution and price statistics.

Sector	Total Flow Shares (%)	Average Price (¢/sec.)		
		Mean	Minimum	Maximum
1-CON [1]	5.6	0.48	0.15	2.22
2-MAN	10.4	0.48	0.17	1.28
3-TCPU	7.1	0.61	0.25	5.95
4-WT	4.6	0.52	0.12	1.71
5-RT	14.3	0.49	0.20	1.16
6-FIRE	15.9	0.56	0.24	10.73
7-BRS	3.2	0.46	0.14	1.16
8-PERS	7.9	0.48	0.21	1.16
9-PROS	22.9	0.50	0.19	1.29
10-PA	5.4	0.78	0.16	35.0
11-OTH	2.3	0.48	0.11	2.31

[1] CON = construction; MAN = manufacturing; TCPU = transportation, communications, and public utilities; WT = wholesale trade; RT = retail trade; FIRE = finance, insurance, and real estate; BRS = business and repair services; PERS = personal services; PROS = professional services; PA = public administration; and OTH = other industries (agriculture and mining).

Descriptive statistics for the average prices are presented in Table 1 and suggest that there are no major differences across sectors. As this average price is to be used in the econometric estimations, several clarifications are here necessary. A major criticism of the approach of dividing revenues (i.e., charges), R, by the quantity to be explained, Q, is that it necessarily establishes a negative relationship between Q and the computed price P (=R/Q). This is true for local calling with only a fixed monthly charge. However, this study focuses on toll calling exclusively. Taylor has argued for using elements of the rate schedule: The price of the initial period as a determinant of the demand for calls, and the price of an overtime period as a determinant of the duration of a call [17]. While this is theoretically correct when analyzing the demand of individual customers facing the same rate schedule, in this study the demands for conversation seconds are aggregations of individual demands under different rate schedules. First, toll users face schedules depending upon the time of day and day of week, and eight distance ranges. Each range is characterized by a fixed price for the first minute, and a variable price for each additional minute. Both prices increase with distance. Daytime prices are the highest, and evening and nighttime/weekend prices represent 65% and 35% of the daytime prices, respectively. The normal charge of a toll call, based on length of haul, duration, and timing, may be further adjusted to account for special calling features such as operator assistance and credit card or calling card messages. Second, WATS users face a completely different rate schedule, invariant with time and length of haul. As a result of this calling heterogeneity, there is no specific rate element

that can be chosen as a representative price for all calls, and the average price, as computed here, is considered the best overall representation of these different prices [18,19].

The telecommunications infrastructure data include exchange-level information on switching technology (digital, analog, electromechanical, or step-by-step) and types of access lines (one or multiple party, PBX, or WATS). These data are available for the exchange as a whole and cannot be assigned to specific groups of users defined by their SIC codes. Using the basic telephone calls database, all numbers classified as WATS were first extracted, then associated to the proper SIC code, and finally summarized by exchange and sector, providing estimates of WATS access lines by exchange and sector. Statistics on WATS access lines are presented in Table 2. The sectors with the highest concentrations of such lines are professional services (Sector 9) and finance, insurance, and real estate (Sector 6).

Table 2. Exchange wide-area toll service (WATS) lines–1990.

Sector	Number of WATS Access Lines		
	Average	Minimum	Maximum
1-CON	1.80	0	50
2-MAN	4.98	0	139
3-TCPU	1.40	0	31
4-WT	3.40	0	143
5-RT	4.78	0	133
6-FIRE	8.57	0	333
7-BRS	0.65	0	15
8-PERS	3.04	0	147
9-PROS	9.59	0	280
10-PA	1.93	0	53
11-OTH	0.75	0	17

4.2. Socio-Economic Data

The LATA has a total area of 25,000–35,000 square kilometers, a 1990 population of 0.8–1.2 million, and 250–350 county subdivisions (city, town, village) spread over 10–15 counties. The urban/rural structure of the population is as follows: 49% rural (hamlets, isolated farms, and places with less than 2500); 20% urban in places with more than 2500, but outside urbanized areas; and 31% urban in urbanized areas. In 1990, 400,000–600,000 workers (16 years and over) were employed in the LATA, representing an aggregate growth of 43% over the 1980 total employment. Employment data by industry are drawn from the 1980 and 1990 Census of Population and Housing, where they are available at the county subdivision level (Minor Civil Division (MCD)). The 1980 employment data, drawn from the Census publication Characteristics of Workers by Place of Work, are disaggregated among the 11 sectors described in the previous section. The 1990 employment data, drawn from the Census Transportation Planning Package-State Level, Part B, are slightly more detailed, but have been aggregated to match the 1980 classification. The distributions of employment across the 11 sectors, in the whole LATA in 1980 and 1990, are presented in the first two columns of Table 3. Particularly striking are the strong decline in manufacturing and the solid increases in trade and services.

While some telephone exchanges and MCDs have common boundaries, this is not the general case, and it was necessary to estimate exchange employment and population by electronically overlaying three geographical information systems (GIS) coverages: (1) the exchange boundary map, (2) the MCD boundary map, and (3) a land-use map for the LATA for the early 1980s. The amount of commercial–industrial land was used to allocate MCD employment to exchanges, while block-level population was used to allocate socio-demographic data to exchanges. The sectoral employment shares have been computed at the exchange level, and their descriptive statistics are presented in Table 3. While average shares are close to the shares for the LATA as a whole, there are significant variations, with some exchanges characterized by a high concentration in specific sectors (e.g., 60.8% in PROS, 57.4% in MAN, and 48.8% in RT). Any sector can be found absent in one or more exchanges. Using 1990

employment data, location quotients have been computed for each sector and exchange, with the whole LATA serving as "national" reference. These location quotients measure the degree of relative concentration of a sector in a given exchange and may indicate the presence of an export-oriented (basic) activity when the quotient is greater than one. Table 4 presents descriptive statistics on these location quotients, showing that some sectors (1-construction, 8-personal services, and 11-agriculture and mining) display a higher degree of concentrations than the other sectors.

Table 3. Sectoral employment shares in 1980 and 1990 (%).

Sector	LATA		Exchanges (1990)			Exchanges (1980)		
	1980	1990	Average	Minimum	Maximum	Average	Minimum	Maximum
1-CON	6.2	6.9	11.3	0	30.0	9.8	0	42.0
2-MAN	30.4	20.6	18.3	0	57.4	24.9	0	74.2
3-TCPU	4.9	5.2	5.3	0	37.9	5.0	0	100.0
4-WT	2.9	3.8	3.1	0	19.7	2.7	0	14.6
5-RT	16.7	19.0	16.7	0	48.8	15.0	0	50.7
6-FIRE	5.5	7.1	4.4	0	19.2	3.5	0	12.3
7-BRS	3.1	4.2	4.3	0	18.4	3.2	0	16.1
8-PERS	2.8	3.0	4.5	0	57.1	4.4	0	35.1
9-PROS	20.9	23.5	21.5	0	60.8	20.0	0	66.8
10-PA	4.0	3.5	3.2	0	13.4	3.3	0	18.9
11-OTH	2.5	2.9	5.9	0	33.3	6.8	0	62.8

Table 4. Exchange location quotients–1990.

Sector	Location Quotients		
	Average	Minimum	Maximum
1-CON	1.66	0.42	4.31
2-MAN	0.94	0.14	2.79
3-TCPU	1.05	0.14	7.26
4-WT	0.91	0.00	5.16
5-RT	0.90	0.08	2.56
6-FIRE	0.69	0.06	2.71
7-BRS	1.05	0.21	4.35
8-PERS	1.70	0.18	18.70
9-PROS	0.94	0.19	2.59
10-PA	0.93	0.14	3.79
11-OTH	2.16	0.41	11.29

5. Empirical Analyses

5.1. Telecommunication Usage

Equation (7) is adapted to the data described in the previous section. The dependent flow variable is, for each of the 11 economic sectors, the total conversation seconds to regular destinations (MTS + WATS). Thus, 11 equations are estimated. The labor input is the total sectoral employment in each exchange, and the telecommunication price is the average price (Equation (10)). There are no data on the prices of the sectoral outputs and the other inputs (materials, energy, capital, land, etc.) across the exchanges of the LATA. While some prices (e.g., capital) are unlikely to vary within the LATA, other prices may vary, and these variations may be captured by proxy variables, such as the distance between the exchange and the economic core of the LATA, or the urban/rural character of the exchange. Let **LOC** be a vector representing these locational variables. The general form of the telephone flow function is then:

$$MST = f(L, \mathbf{T}, \mathbf{LOC}, PMST) \tag{11}$$

Two infrastructure variables (vector **T**) turned out to have significant effects on the flows:

- ISW = 1 if the exchange is equipped with digital switching equipment, = 0 if not;
- WAL = number of WATS lines serving the sector in the exchange (Table 2).

Digital switching is illustrative of advanced telephone technologies, as it makes available touch-tone (a prerequisite for various business services, such as telephone banking, reservations, and voice messaging) and custom-calling services (e.g., three-way calling, call forwarding, call waiting, and caller identification), and reduces the amount of dedicated loop plant by allowing wireless connections to remote nodes. Close to 60% of the exchanges had digital switching in 1990. Several locational variables (vector **LOC**) were considered, and the following ones turned out to be significant in some or all the estimated equations:

- RUR = ratio of rural to total population, measuring the rural character of the exchange;
- DIST = distance (in miles) between the central office and the population-weighted center of gravity of the LATA, measuring the peripheral character of the exchange; it may have either a positive impact (need to increase communications to compensate for isolation) or a negative one (isolation decreases the need to communicate);
- LOQ = employment-based location quotient (1990), reflecting the relationship between export activities and telecommunications.

RUR varies between 0 and 1, with an average value of 0.84; 75% of the exchanges have RUR > 0.8, and 72% are completely rural. There is only one exchange that is completely urban (RUR = 0), and 16% have RUR < 0.25. DIST varies between 2.4 and 132 miles, with an average of 42.5 miles. Equation (11) can then be rewritten as:

$$\text{MST} = f \text{ (L, ISW, WAL, RUR, LOQ, DIST, PMST)} \tag{12}$$

Various functional specifications of Equation (12) have been considered. The first specification, where the elasticities of L and PMST are assumed constant and independent of the other variables, turned out to be inferior in explanatory power to the second specification, where the employment elasticity is a function of the infrastructure (ISW and WAL) and locational (RUR, LOQ, and DIST) variables. The price elasticity turned out to be unrelated to these variables. The final functional form is then

$$\ln\text{MST} = a + b \text{ (ISW, WAL, RUR, LOQ, DIST)} \bullet \ln\text{L} + c\bullet\ln\text{PMST} \tag{13}$$

In order to test for interactions between the rural character of the exchange (RUR) and its telecommunications infrastructure (ISW and WAL), the products of these variables were included in the elasticity function b, in addition to all the variables taken separately. After deleting the insignificant variables, the final specification of b is:

$$b = d + e\bullet\text{RUR} + f\bullet\text{RUR}\bullet\text{ISW} + g\bullet\text{RUR}\bullet\text{*WAL} + h\bullet\text{LOQ} +k\bullet\text{DIST} \tag{14}$$

All regression models are estimated using ordinary least squares. The regression results and the employment elasticities under different locational and technological scenarios, are presented in Tables 5 and 6. The price elasticities are all highly significant (1% level), negative, and consistent with earlier estimates [20]. The analysis of the employment elasticities is more complicated. First, consider the coefficient of lnL, which is positive and highly significant in all cases, and varying within the range [0.7–1.0]. This coefficient would be the actual employment elasticity if the exchange were completely urban (RUR = 0), located exactly at the regional core (DIST = 0), and with a location quotient equal to zero. This is unfeasible, as LOC = 0 implies no employment in the sector. Alternatively, and as a benchmark, consider a fully urban exchange located 10 miles away from the regional core, and with a location quotient of 1. The corresponding elasticities, reported as Case 1 in Table 6, vary between 0.553 and 0.951. The positive sign points to the complementarity between telecommunications and

labor inputs, i.e., the more employees the more conversation seconds. This result casts doubts on the hypothesis that the efficiencies derived from increased use of ICTs allow for a reduction in the labor input. This complementarity is particularly strong in Sectors 9 (0.951: Professional services), 6 (0.893: FIRE), and 11 (0.933: Agriculture and mining). The lower elasticity for Sector 7 (0.553: Business and repair services) is puzzling but may be due to a predominance of repair services, which may require less telecommunication interactions per employee. Next, consider how the previous results are modified in a rural environment (RUR = 1), in the absence of advanced telecommunications infrastructure (ISW = 0 and WAL = 0). The coefficients of RUR*lnL are all negative, and, except for Sectors 10 (public administration) and 11 (agriculture and mining), significant at least at the 5% level, pointing to an important "rural penalty", i.e., there is less complementarity between labor and telecommunications in rural areas, and thus less calling per employee. The corresponding elasticities are presented as Case 2 in Table 6. In the case of Sectors 3, 4, 7, and 8, the elasticities are in the range [0.23–0.33], thus much closer to the pure substitution case (negative elasticity).

Table 5. Regression models of telecommunications usage (conversation seconds).

Variable	Sector										
	1-CON	**2-MAN**	**3-TCPU**	**4-WT**	**5-RT**	**6-FIRE**	**7-BRS**	**8-PERS**	**9-PROS**	**10-PA**	**11-OTH**
Intercept	6.824 (13.73) ***	6.632 (11.76) ***	7.539 (16.92) ***	8.022 (25.43) ***	6.212 (12.83) ***	6.847 (17.75) ***	8.427 (16.19) ***	7.360 (18.54) ***	5.381 (13.07) ***	7.375 (24.26) ***	6.254 (12.09) ***
lnE	0.779 (8.49) ***	0.811 (7.82) ***	0.698 (6.08) ***	0.706 (6.41) ***	0.703 (7.70) ***	0.934 (7.99) ***	0.696 (6.28) ***	0.725 (7.77) ***	0.956 (12.31) ***	0.885 (10.16) ***	0.985 (9.19) ***
RUR*lnE	−0.243 (2.78) ***	−0.235 (3.31) ***	−0.345 (2.99) ***	−0.447 (4.20) ***	−0.172 (2.59) **	−0.375 (3.76) ***	−0.323 (2.59) **	−0.372 (3.94) ***	−0.172 (2.93) ***	−0.153 (1.58)	−0.134 (1.35)
RUR*ISW*lnE	0.083 (1.65) *	0.100 (2.07) **	0.169 (2.14) **	0.241 (2.91) ***	0.070 (1.60)	0.256 (3.61) ***	0.135 (1.58)	0.243 (3.64) ***	0.078 (2.04) **	0.080 (1.16)	0.048 (0.79)
RUR*WAL*lnE	0.026 (2.30) **	0.017 (2.98) ***	0.053 (2.44) **	0.037 (3.06) ***	0.012 (2.56) **	0.008 (1.91) *	0.105 (4.08) ***	0.049 (4.06) ***	0.003 (2.10) **	0.042 (3.89) ***	0.050 (1.70) *
DIST*lnE	−0.00049 (0.55)	0.00042 (0.52)	0.00283 (2.32) **	−0.00049 (0.34)	0.00188 (2.62) ***	0.00223 (2.06) **	0.00323 (2.18) **	0.00079 (0.67)	0.00148 (2.23) ***	0.00102 (0.94)	−0.00071 (0.66)
LOQ*lnE	−0.019 (0.72)	−0.084 (2.73) ***	−0.046 (1.51)	−0.025 (0.67)	0.006 (0.14)	−0.063 (1.13)	−0.175 (3.17) ***	−0.072 (4.72) ***	−0.020 (0.62)	−0.122 (3.51) ***	−0.045 (3.21) ***
lnPMSR	−2.506 (8.49) ***	−2.339 (6.93) ***	−1.936 (6.80) ***	−1.526 (5.29) ***	−3.029 (9.00) ***	−2.045 (7.78) ***	−0.857 (2.48) **	−2.893 (9.20) ***	−2.543 (8.87) ***	−1.675 (8.69) ***	−1.831 (7.06) ***
R^2	0.673	0.744	0.674	0.672	0.767	0.801	0.503	0.741	0.836	0.765	0.674

Significant: At the 1% level ***; at the 5% level **; and at the 10% level *.

However, the "rural penalty" is reduced by the availability of advanced telecommunication infrastructure, as indicated by the positive signs of the variables RUR*ISW*lnE and RUR*WAL*lnE. The impact of having digital switching is significant (10% at least) in seven sectors (1–4, 6, 8, and 9), while the impact of having WATS access lines is significant in all sectors. Employment elasticities have been computed for two "rural" scenarios, reported as Cases 3 and 4 in Table 6: (1) digital switching, but no WATS lines, and (2) digital switching with 10 WATS lines. Consider the case of Sector 3 (TCPU). Without advanced features, the employment elasticity is 0.335. With a digital switch, this elasticity increases to 0.504, and, with 10 WATS lines, to 1.034. Similar results apply to the other sectors, more or less dramatically. Clearly, an advanced telecommunications infrastructure leads to a more intensive use of telecommunications (i.e., telephone flows) in rural areas. Interestingly, when the variables ISW and WAL were introduced into the model separately from the RUR variable, they turned out to be much less significant, which suggests a distinct interaction between a rural environment and advanced

telecommunications infrastructure (TI) in generating telecommunications flows. This increased usage may be due to specific subgroups of firms that locate in rural areas to take advantage of the TI.

Table 6. Employment elasticities.

CASE	Sector										
	1-CON	2-MAN	3-TCPU	4-WT	5-RT	6-FIRE	7-BRS	8-PERS	9-PROS	10-PA	11-OTH
1. RUR = 0 DIST = 10 LOQ = 1	0.755	0.731	0.680	0.676	0.728	0.893	0.553	0.661	0.951	0.773	0.933
2. RUR = 1 ISW = 0 WAL = 0 DIST = 10 LOQ = 1	0.512	0.496	0.335	0.229	0.556	0.518	0.230	0.289	0.779	0.620	0.799
3. RUR = 1 ISW = 1 WAL = 0 DIST = 10 LOQ = 1	0.595	0.596	0.504	0.470	0.626	0.774	0.365	0.532	0.857	0.700	0.847
4. RUR = 1 ISW = 1 WAL = 10 DIST = 10 LOQ = 1	0.855	0.766	1.034	0.840	0.746	0.854	1.415	1.022	0.887	1.120	1.347
5. RUR = 1 ISW = 1 WAL = 10 DIST = 100 LOQ = 1	0.811	0.804	1.289	0.796	0.915	1.055	1.706	1.093	1.020	1.212	1.283
6. RUR = 1 ISW = 1 WAL = 10 DIST = 100 LOQ = 2	0.792	0.720	1.243	0.771	0.921	0.992	1.531	1.021	1.000	1.090	1.238

RUR = rural population/total population; ISW = 1 if switching is digital, = 0 if not; WAL = number of WATS access lines; DIST = distance (miles) between the exchange central office and the regional core; and LOQ = employment–based location on quotient.

The impact of the core-periphery location of an exchange, as measured by the coefficient of the variable DIST*lnE, is positive and significant (5%) for five sectors (3, 5–7, and 9). This result suggests that the farther away the exchange is located from the regional economic core, the more isolated this exchange is, and therefore the higher the level of telecommunications interactions needed, as they replace face-to-face interactions that are more common in urban, higher-density areas. Elasticities have been computed for a rural exchange with advanced features located 100 miles away from the regional core, and are reported as Case 5 in Table 6. Consider again Sector 3 (TCPU): Increasing the distance from 10 to 100 miles increases the employment elasticity from 1.034 to 1.289. Finally, the impact of the exchange location quotient, as measured by the coefficient of the variable LOQ*lnE, is negative and highly significant (1%) for only five sectors (2, 7, 8, 10, and 11), and insignificant (though mostly negative) in all the other cases. These results are counterintuitive, as the expectation is that the higher LOQ, the larger the exports out of the exchange, and therefore the higher the level of telecommunications interactions between the exchange and other export-destination exchanges. However, it may be that some activities with a high LOQ do export much of their goods beyond the LATA's boundaries, and these exports require inter-LATA telecommunications interactions not reflected in the available database. This is quite likely the case for primary and secondary activities, such as manufacturing (Sector 2) and agriculture and mining (Sector 11). The three other sectors with significant coefficients are all consumer-oriented: Repair services (Sector 7), personal services (Sector 8),

and public administration (Sector 10). It may be that high concentrations of such activities constitute attracting poles, where consumers come to purchase or receive the services. They possibly initiate prior interactions, thus reducing the telecommunications needs of these activities. Elasticities have been computed under Case 6 in Table 6, modifying Case 5 by increasing the location quotient from one to two. Except for Sector 5, all elasticities slightly decline, remaining within the range [0.72–1.53].

5.2. Telecommunications Infrastructure Provision

It is assumed that the LEC's optimization process presented in Section 3.2 applies to each exchange within the LEC's service territory. The same wage rate applies to all employees of the LEC, whatever the exchange they are working in. Hence, P_L does not vary across exchanges, and its effect is unobservable. Equation (9) is thus reduced to:

$$\mathbf{T_{LEC}} = \mathbf{k_T}\ (\mathbf{F_{LEC}}, \mathbf{P_T}) \tag{15}$$

The focus is on digital switching provision, and the dependent variable is taken as the binary variable ISW, equal to 1 if digital switching is installed in the exchange in 1990, and to 0 if not. Such switches have been installed throughout the 1980–1990 decade, with very few available in 1980. The installation decision may be a function of past observed flows, of future predicted flows, or of both types of flows. Because flow data are only available in 1990, the employments in the 11 sectors in 1980 and 1990 are used as proxies for these flows and are defined as the "Market Variables". The infrastructure cost variables are proxied by a set of "Locational Variables". Equation (15) is transformed into a logit model, with:

$$\text{Probability (ISW} = 1) = h\ (\text{Market Variables, Locational Variables}) \tag{16}$$

Neither the 1990 employment nor the 1980–1990 employment increment variables turned out to be significant. Location quotients and occupation-related employment variables were also considered for both years, but with insignificant results. However, several of the 1980 employment variables (construction, TCPU, retail, business and repair services, and professional services) turned out to be highly significant. Among the locational variables, only DIST, the distance of the exchange to the regional core, and POPCITY, the population of all the cities within the exchange boundaries, turned out to be significant. POPCITY varies between 0 and 99,288, with a mean of 2607. While city population represents 35% of the LATA's population, there are only 16 exchanges with a city, in part or in whole. The results of the logit estimation are presented in Table 7.

Table 7. Logit model of digital switching provision.

Variable	Coefficient Estimate	Standard Error	Chi-Square	Pr. > Chi-Sq.
Intercept	1.7580	0.4741	13.75	0.0002
CON-80	0.0106	0.0046	5.25	0.0220
TCPU-80	−0.0182	0.0062	8.67	0.0032
RT-80	0.0035	0.0016	4.85	0.0277
BRS-80	−0.0263	0.0093	7.96	0.0048
PROS-80	0.0013	0.0006	5.59	0.0181
POPCITY	0.00015	0.00008	3.50	0.0615
DIST	−0.0350	0.0089	15.64	0.0000
Loglikelihood Ratio	43.94			0.0002
Wald	24.83			0.0008

The significance of the 1980 employment variables suggests that digital switching installation decisions are based on past observed market demands. Construction, retail, and professional services activities increase the probability of digital switching, and must be viewed by the LEC as likely users of the services made possible by such switches, potentially increasing the profitability of these services. In contrast, TCPU and business/repair services activities have a negative effect, possibly because they

are viewed as less likely users of these services. The larger the population of a city located within the exchange, the higher the probability of digital switching, probably because the LEC views such population as more likely to use digital services and making these services profitable. Finally, the farther away from the regional core, the lower the probability of digital switching. This probably reflects a strategy of installing digital switches first close to the core and within metropolitan areas, and then moving outwards, towards less populated, more rural exchanges. As for the provision of other rural services, distance and low population density appear to be barriers to the deployment of advanced telecommunications technologies. Finally, one should recognize the possible endogeneity between infrastructure provision and market demands, namely that market demands may also be a function of past infrastructure provision, and not only the other way around. Unfortunately, the available data preclude the testing of this hypothesis, as detailed data on switching technology prior to 1990 cannot be obtained.

6. Discussion

In summary, the results presented in Section 5 indicate that:

(1) There is a strong and complementary relationship between the telecommunications and labor inputs for all economic sectors in urban areas, with elasticities in the ranges of [0.55–0.95]. However, this relationship is uniformly weakened (i.e., less calling per employee) in rural areas, in the absence of advanced telecommunications infrastructure.

(2) The above weakening is reversed when advanced features, such as digital switching and WATS lines, are available in rural areas, pointing to a much more intensive use of telecommunications. This result suggests, but does not prove, that the availability of advanced telecommunications infrastructure in rural areas may serve as an attractor of economic activities that need intensive use of telecommunications.

(3) The effect of the distance between the exchange and the economic/population core of the region is positive, suggesting that peripheral exchanges make more intensive use of telecommunications, probably to compensate for the isolation of their location. However, location quotients, taken as proxies for exporting activities, have a negative effect on telecommunication flows, suggesting that exports may take place beyond the LATA's boundaries.

(4) The telecommunications price elasticities turn out to be highly significant in all cases, and mostly in the elastic range, a result consistent with earlier research [20].

(5) The probability of having digital switching increases with the size of the city located within an exchange but declines the larger the distance from the population and economic core. This reflects the cost-minimization strategy of the LEC, which avoids provision of advanced services in low population density areas.

While the literature reviewed in Section 1 indicates that the urban-rural divide persists nowadays with new technologies, such as wireless telephony and Internet broadband access, it is legitimate to question the use of 1990 data for this analysis. It is first important to note that the focus is on voice communications and not on data transmission. In 1990, voice communications primarily took place over fixed land lines (traditional telephony), while wireless telephony was only emerging and occupied a very small share of the market, and voice over the internet (VOIP) was not yet available. Therefore, the data used represents a comprehensive coverage of the voice interactions within the analyzed economic sectors and over the considered geographical area. Could more recent data have been used? The answer is most likely "No". An extensive balkanization of the telephone market has taken place over the last 20 years, with multiple providers (e.g., AT&T, Verizon, and Sprint) offering competitive plans and sharing the available market. In order to create a geographically acceptable database, data would need to be gathered from all these service providers. Because of competition, these providers consider their data as critical for their economic survival and are no longer willing to share them. As a result, the earlier 1990 data obtained from the unique service provider

represent all the voice interactions that take place in all the economic sectors of the region considered. Therefore, they can be considered reliable for the analyses presented in this paper. Theresults and insights are consistent with the contemporaneous socio-economic system. For instance, distance from economic centers and population density continue to hinder the deployment of new technologies. When these technologies are deployed, they are likely to support rural economic development. This calls for a strong public-policy intervention in rural areas, such a subsidization of private providers and support for municipal providers of new telecommunication technologies.

7. Conclusions

Using an extensive, exchange-level database on voice telephone usage and infrastructure, employment, and population for 1990 and a region located in the northeastern U.S., this paper set out to clarify the relationships between rural economic activities and telecommunications. First, relationships were estimated through regression analysis, linking telephone usage, measured in aggregate conversation seconds, by each of eleven economic sectors, to sectoral employment, the rural character of the exchange, the availability of advanced telecommunication technology features, the regional core-periphery location of the exchange, and sectoral employment concentration, as measured by the location quotient. The results show that telecommunications and labor are complementary inputs in each sectoral production function, that rural activities use telecommunications less in the absence of advanced technology, and that the latter, such as digital switching and WATS access lines, tend to significantly increase telecommunications usage in rural activities. This result tends to support the idea that an advanced telecommunication infrastructure in rural areas may be important to attract specific activities, particularly professional services, and thus to promote economic development. However, a logit analysis of digital switching installation decisions support the widespread notion that rural, remote locations are at a disadvantage with regard to such installations, although the existence of specific economic activities may encourage the LEC to install such equipment. These results are consistent with current deployment problems of broadband and wireless service in rural areas, as demonstrated in the popular press and academic literature.

References

1. Graham, S.; Marvin, S. *Telecommunications and the City*; Routledge: London, UK, 1996.
2. Sundquist, M.; Markendahl, J. A case study cost modelling of regulatory alternatives to mitigate the mobile network coverage and capacity problems in rural areas. In Proceedings of the 26th European Regional Conference of the International Telecommunications Society (ITS): "What Next for European Telecommunications?", Madrid, Spain, 24–27 June 2015.
3. Michailidis, A.; Nastis, S.A.; Loizou, E. Mobile communications technology in rural societies of developing countries. *J. Rural Dev.* **2012**, *31*, 319–334.
4. Schneir, J.R.; Xiong, Y. A cost study of fixed broadband access networks for rural areas. *Telecommun. Policy* **2016**, *40*, 755–773. [CrossRef]
5. Freeman, J.; Park, S.; Middleton, C.; Allen, M. The importance of broadband for socio-economic development: A perspective from rural Australia. *Australas. J. Inf. Syst.* **2016**, *20*, 1–18. [CrossRef]
6. Lehtonen, O. Population grid-based assessment of the impact of broadband expansion on population development in rural areas. *Telecommun. Policy* **2020**, *44*, 1–12. [CrossRef] [PubMed]
7. Reddick, C.G.; Enriquez, R.; Harris, R.J.; Sharma, B. Determinants of broadband access and affordability: An analysis of a community survey on the digital divide. *Cities* **2020**, *106*, 1–12. [CrossRef] [PubMed]

8. Kirn, T.J.; Conway, R.S., Jr.; Beyers, W.B. Producer services development and the role of telecommunications: A case study of rural Washington. *Growth Chang.* **1990**, *21*, 3–50. [CrossRef]

9. Coffey, W.J.; Polese, M. Producer services and regional development: A policy-oriented perspective. *Pap. Reg. Sci. Assoc.* **1989**, *67*, 13–27. [CrossRef]

10. OhUallachain, B.; Reid, N. The location and growth of business and professional services in american metropolitan areas. *Ann. Assoc. Am. Geogr.* **1991**, *81*, 254–270. [CrossRef]

11. Hudson, H.E.; Parker, E.B. Information gaps in rural America—Telecommunication for rural development. *Telecommun. Policy* **1990**, *14*, 193–205. [CrossRef]

12. Egan, B.L. Bringing Advanced technology to rural America—The cost of technology adoption. *Telecommun. Policy* **1992**, *16*, 27–45. [CrossRef]

13. Richardson, R. Teleservice and Europe's Peripheral Cities and Regions: Threat or Opportunity? In Proceedings of the 34th European Congress of the Regional Science Association, Groningen, The Netherlands, 23–26 August 1994.

14. Richardson, R.; Gillespie, A. Advanced communications and employment creation in rural and peripheral regions: A case study of the highlands and islands of Scotland. *Ann. Reg. Sci.* **1996**, *30*, 91–110. [CrossRef]

15. Larson, A.C.; Lehman, D.E.; Weisman, D.L. A General Theory of Point-to-Point Long Distance Demand. In *Telecommunications Demand Modeling-An Integrated View*; De Fontenay, A., Shugard, M.H., Sibley, D.S., Eds.; Elsevier Science: Amsterdam, The Netherlands, 1990.

16. Guldmann, J.-M. Input-Output analysis of regional telecommunication flows. *Inf. Econ. Policy* **1993**, *5*, 311–329. [CrossRef]

17. Taylor, L.D. Problems and Issues in Modeling Telecommunications Demand. In *Economic Analysis of Telecommunications: Theory and Applications*; Courville, L., de Fontenay, A., Dobell, A.R., Eds.; Elsevier Science: Amsterdam, The Netherlands, 1983.

18. De Fontenay, A.; Marshall Lee, J.T. B.C./Alberta Long Distance Calling. In *Economic Analysis of Telecommunications: Theory and Applications*; Courville, L., de Fontenay, A., Dobell, A.R., Eds.; Elsevier Science: Amsterdam, The Netherlands, 1983.

19. Acton, J.P.; Vogelsang, I. Telephone demand over the Atlantic: Evidence from country-pair data. *J. Ind. Econ.* **1992**, *40*, 305–323. [CrossRef]

20. Guldmann, J.-M. Intersectoral Point-to-Point telecommunication flows: Theoretical framework and empirical results. *Reg. Sci. Urban Econ.* **1998**, *28*, 585–609. [CrossRef]