Digital Telecommunications Technologies in the Rural South: An Analysis of Tennessee

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Executive Summary

This research examines variations in telecommunications levels-of-service in one state: Tennessee. Specifically, our research analyzes the capabilities of central office (CO) switches in the state of Tennessee, providing detail on local variation in telecommunications technologies that has been generally unavailable. We used as a data set the Local Exchange Routing Guide (LERG), which includes the location, system manufacturer and product, features, and functionality of each switch.

In Tennessee, 53 local operating companies have 493 switches, including 49 different switching systems. We propose a six-level hierarchy of digital capability in the switches, ranging from the absence of international direct long distance dialing (IDDD) through multi-rate ISDN capability. Although the hierarchy does not account for all switches in the state, 85% of switches in Tennessee conform to it, with all lower levels of capability being present at any given level. We hypothesize that rural areas will be underserved by advanced telecommunications services, and that urban areas are more likely to have higher levels of service.

The rural-urban distinction does not account fully for the pattern found in Tennessee. For example, 21 of the state's switches are incapable of international direct long-distance dialing (IDDD); ten of these are in metropolitan areas. However, the general pattern is that the number of switches in metro areas with Level 1 capability drops off much less as we move up the hierarchy to Level 3 capability than is the case in rural areas. We illustrate this for the Chattanooga area.

The case of switches that do not conform to the proposed hierarchy is accounted for by some of the switch characteristics. Remote switches are more likely to be among the 74 nonconforming switches, as are those in the BellSouth service area. Nonconformance is explained in large part by co-location of two or more switches at a single location. While we do not have data on "tandem" switching, co-location accounts for 13 of the 21 switches without IDDD. More importantly, co-location explains the large number of low-level switches in metro areas, effectively upgrading them from lower levels of digital capability to the two highest levels of the hierarchy, in 19 of 23 locations.

Each of the 95 counties in Tennessee has at least one CO switch. The central counties of the state's four metro areas (Nashville, Memphis, Knoxville, and Chattanooga) together contain 144 switches, or 29.3% of all switches in Tennessee. The remaining 91 counties have between one and 13 each. The number of switches in a county is, statistically, primarily a function of a county's population and its population density. Using the Economic Research Service Rural-Urban Continuum Code (Beale code) for each county, the mean number of CO switches per county is highest in the metro counties and lowest in the most rural counties. In an analysis of all 95 counties, the number of switches increases with Beale code when both population and population density are taken into account. It is increasing population density that accounts for most of the explained variance.

Six counties—all rural—have no switch higher than Level 1. Standing out sharply is the contrast between metro and nonmetro counties where Level 1 or 2 is the highest level in a county, versus those with Level 3 or higher. When aggregated in this way, the difference between metro counties and nonmetro counties and the highest level of CO switch is highly statistically significant. This research documents the inequality in telecommunications level-of-service for one state. Using the proposed hierarchy of level-of-service, the highest capability switches are concentrated disproportionately in metropolitan areas, largely in response to higher population density. Rural counties are more likely to have both fewer switches and switches with lower levels of digital capability.

1. Introduction

This research examines variations in telecommunications levels-of-service in one state in the southeastern United States: Tennessee. Specifically, our research analyzes the capabilities of location-specific central office (CO) switches in the state of Tennessee. Our research provides a degree of detail on local variation in digital technologies that has been generally unavailable.

This report is organized as follows. The next section reviews briefly technological change in telecommunications, particularly its impact on the public switched telephone network (PSTN) in the United States. This is followed in Section 3 by a discussion of CO switches and their digitalization. Section 4 describes the data set used in this research, and Section 5 presents a proposed hierarchy of digital level-of-service or capability of CO switches. The next section discusses in detail the characteristics of the 493 CO switches in Tennessee, including their conformance or nonconformance to the proposed hierarchy of switch capability, and contrasts between metropolitan (metro) and nonmetropolitan (nonmetro) areas. Section 7 addresses the situation of two or more switches located together. Section 8 presents an analysis by county for the 95 counties in Tennessee. This includes the number of switches in a county and their highest level of switch capability. Section 9 discusses, based on this study of one state, implications for residents of rural areas. Finally, Section 10 presents some conclusions and plans for further research.

2. Technological Change in Telecommunications

The proliferation of fiber-optic cabling has permitted high-quality transmission along coast-to-coast and medium-distance trunk lines, and has prompted a general decrease in the cost of service. The coast-to-coast nature of U.S. telecommunications has been a priority of all—and especially new—communications providers, in order to tap into the large business markets in and between the East Coast and California. The large city business routes, connecting markets in New York, the Boston-Washington corridor, and then Chicago and (via Texas) Los Angeles, are the consistent priority of telecommunications providers, both in conventional telephone networks (Langdale, 1983) and in Internet backbones (Moss and Townsend, 1998).

However, despite the information superhighway, the quality of *local* service—and of an individual customer's service—depends more on the capabilities of the local CO switch, and the distance to it, than on the availability of fiber-optic trunk lines. Fiber to the home (at $3,000) is not yet a realistic option (Egan, 1996a: 69-70). The "first" or "last 100 feet" to the customer remains unresolved (Akimaru et al., 1997; Hurley and Keller, *forthcoming*). Although there are exceptions, generally speaking, rural areas are at a disadvantage when it comes to telecommunications technologies. Being unable to muster the demand needed to justify or amortize large infrastructure investments, rural areas are less likely to see the complete set of telecommunications innovations. In turn, the quality-of-service in local areas will suffer, as new technologies are increasingly needed for access to the latest broadband (multimedia) transmissions (Akimaru et al., 1997; Lu et al., 1998).

Since the 1960s, the technologies of computers and electronics have converged with those of broadcasting and wire-based telecommunications. Most applications have been driven by a growing set of information technologies for business applications, such as computer-aided design, remote sensing devices, management information systems, and data bases. For individuals the ability to send and receive data and images, in addition to voice, effectively merged computer and telecommunications technologies in the form of the Internet and the World Wide Web. The Internet and personal computers require digital capability, and preferably interactive video (broadband), which is not universally available, especially in rural areas, where the cost of upgrading voice or dialtone lines to broadband service would be prohibitive. Urban and suburban (metropolitan) areas have been the principal markets for new telecommunications services, because their customer base includes larger numbers of customers who are willing to adopt new services. The much smaller number of rural customers in any service area, as well as nationwide, means that rural areas are certain to be late in the service provision sequence (Malecki, 1998).

Quality-of-service meant, not many years ago, the availability of a dialtone and service reliability. The few variables monitored by the Federal Communications Commission (FCC) included number of seconds delay for a dial tone, number of service complaints, and time without telephone service (outage line-minutes, switches with downtime) (Kraushaar, 1995). Recent decades have brought dramatic improvements in the computational power and networkability of computers. This, in turn, has created new demands for data transmission, with the result that data transfer has surpassed voice in the quantity of traffic on the public network. Thus, quality today relates to *data* as well as to *voice* transmission, and many new technologies focus primarily on data rather than voice. It also can be argued that data services, in contrast to voice, are generally unregulated (Leo and Huber, 1997). The proliferation of pagers and high-speed modems for access to the World Wide Web and its graphical interface has meant that high-speed and/or broadband capability, low error rates, and ready connectivity are the hallmarks of high-quality communications from the point of view of today's consumer. In order to minimize delays in transmission, greater-than-needed capacity is installed in order to keep utilization below overload conditions (Akimaru et al., 1997; Lu et al., 1998). Thus, redundancy in the Internet backbone on some city-pairs, such as San Francisco-Los Angeles, New York-Washington, and Washington-Atlanta, is considerable—on each of these links, 20 or more providers operate direct fiber-optic service (Moss and Townsend, 1998).

3. Digital Switch Technology

Several aspects of quality-of-service are dependent on the capabilities of the CO switch. Digital technology as yet has not changed the overall architecture of the telephone system. As a type of "modular technical change," digital switches can be added individually within a firm's network. Digital signaling permits the clear transmission of data and enables higher data rates, characteristics not possible in an analog system. Digital switches, combined with fiber-optic lines, also give rise to system-scale economies and network effects, because these systems reduce the cost of training, maintenance, and spare parts (Majumdar, 1997). Perhaps more significant than the cost savings is the capability to add value-added services such as custom-calling, which can bring a carrier additional revenue (Heldman, 1992; Majumdar, 1995).

A useful indicator of digital capability is the capability for integrated services digital network (ISDN), a technology that is the benchmark against which newer technologies are commonly compared (Akimaru et al., 1997; Lu et al., 1998). To be upgraded to ISDN (the current generation of digital technology for residential customers) requires that digital CO switches be upgraded with electronic signaling equipment and ISDN software. These upgrades, especially installation of signaling system 7 (SS7) software, had been made in only 54% of switches in the regional Bell operating companies (RBOCs) as of 1994 (Egan, 1996a, p. 63). Newer modem technologies that permit transfer rates of 56 Kbps now compete with ISDN's 144 Kbps at far lower cost to the customer. However, these systems also require digital capability in the CO switch.

Despite these advantages, as well as declining equipment prices, digitalization of CO switches has not been rapid in the United States—surprisingly much slower than advances in the computer industry (Flamm, 1989). In 1990, less than 10% of the U.S. network was digital;

somewhat higher levels were common within the Bell system. The slow adoption is attributed to investment in analog systems during the 1980s (Majumdar, 1997; Zanfei, 1992). Much of the digitalization was an "overlay" of digital remote switch units next to existing analog systems and connecting SS7 signaling to them. (Remote switches are dependent on a "host" switch or office). "In this manner, the switching system initially designed for the rural environment was being used for the more complex urban community, extending its product life cycle" (Heldman, 1992: 155).

Investments in digital switches followed the patterns of radio, television, and basic telephone development—being installed first in larger markets where the costs of their investments could be more easily realized, and later moving to secondary and tertiary markets as the technology matured and costs declined (Egan, 1996b). In general, digital switches were implemented first by larger firms in urban areas, where their greater capacity is most efficient and where business customers are most plentiful. The high cost per customer of rural remote switch units resulted in delay in full digitalization in rural areas, reinforced by regulatory pressure for digital voice, not data services (Heldman, 1992). In the nine states it serves, BellSouth reports 100% of its lines as equipped for SS7, 93.6% of its COs as digital, 89.8% of its lines having access to ISDN, and 40.6% of lines served by digital carrier. Regionwide, BellSouth reports 150 broadband switches in service (BellSouth, 1998).

Business communication demand is the driving force behind telecommunication investment, and is the telephone industry's cash cow. One of the correlates of digitalization is the proportion of business lines in a telco's total line mileage. In the years since deregulation, many entrenched telephone companies, primarily the "Baby Bells," have experienced significant decreases in business revenue due to new entrants in the telecommunications marketplace seeking to draw away lucrative business contracts. Such marketing tactics, called "cherry-picking," have left many local telcos scrambling for business. In the monopolistic past, such business revenues were used as cross-subsidies to redress price imbalances that were involved in providing service to more rural service areas. With deregulation, many local service providers have found that it is not worth the expense to upgrade rural infrastructure. Rural areas have low customer densities and few high-volume business customers to justify their investment. Farrell and Katz (1998) believe that current regulation works against incumbent firms, which are required to invest in rural portions of their service areas, while new firms can "cherry-pick" without this requirement.

Unrelated to digitalization—even slightly negatively correlated—is the percentage of metropolitan or urban territory in a firm's operating territory (Majumdar, 1995). The lack of correlation may well be a result of the concentration of business services in the largest—rather than in all—urban areas (Salomon, 1996; Sassen, 1995; Warf, 1995).

There are incentives for a firm to adopt and implement digital technology. Majumdar (1997) has found that the degree of switch digitalization—as well as the combination of fiber optic lines and digital switches—significantly affects a telephone carrier's productivity. There are also efficiency gains from digitalization because the technology permits greater flexibility in the use of the resources of a telephone network (Banker et al., 1998). Such efficiency gains and revenue-generation potential typically are highest with business customers, especially large businesses, and their locations suggest a strong correlation with metropolitan locations. The newly-announced Sprint ION network will be typical—it will hook up only 36 urban markets by the end of 1998; connections to homes will take much longer (Crockett, 1998).

4. Central Offices Switches and Level-of-Service

Studying the digitalization of American telecommunications is no easy task. Since 1988, there is no requirement that firms disclose the technological composition (e.g. electronic or analog) of their installed base of switches. Majumdar (1995) has studied the national data available through 1987, when the average penetration of digital switches was 56.16%. As with most FCC data, even these data refer only to individual firms—in this case the over 1,500 U.S. telephone companies. There has generally not been at the federal level a requirement that firms disclose implementation of digital technology at individual locations within their systems.

The state regulatory agencies have occasionally required that firms file documentation of their plans for inter-connection between telephone firms. For an earlier study (Boush and Malecki, 1998), we were able to obtain from the Florida Public Service Commission such a data set, listing CO switches and the exchanges they served, but not their location or capabilities. We assumed digital capability in each switch, estimated switch locations based on the local exchanges served, and estimated digital availability by means of 15-kilofoot circles around each switch in two service areas in Florida. The results indicate that switches are heavily concentrated in urban areas and that rural areas get at most remote switches, leaving large areas of rural Florida unserved by digital technology.

Data at the state level typically are not obtained by state regulatory commissions for the purpose of monitoring digitalization, so even the identity of such data can be difficult at best. However, Bellcore (Bell Communications Research, Inc.) compiles and updates regularly a Local Exchange Routing Guide (LERG) for the entire United States. We used this data set, dated February 1, 1998, which includes not only the specific CO switch by location, system manufacturer and product, but also the features and functionality of each switch. In this report, we present some analyses of this data set for Tennessee and attempt to draw conclusions about rural-urban differences in quality-of-service.

For Tennessee, the LERG data show 493 switches used by the 53 local operating companies in Tennessee, including 49 different switching systems (of approximately 350 systems or models of switches catalogued in the LERG). Table 1 shows the most common switches installed in Tennessee, the top three of which are switches made by Northern Telecom and labeled as digital switches. (All tables and figures are found at the end of this report.) The three Nortel switch models account for nearly 32% of all the switches in the state, and the top four switch models alone account for 41% of all switches. Overall, there is some indication that the switches serve predominantly urban areas in Tennessee. The switches are clustered in census tracts other than those with lowest population density. We address metro-nonmetro differences in a later section.

Several of the functions and service indicators represent digital technology and lend themselves to analysis. We recognize that digital capability can be provided to customers distant from a switch in either of two ways: they could be connected by cabling (reinforced by signal repeaters and amplifiers) to a switch elsewhere, or a digital “remote” switch could be installed nearer to those customers. This is a typical broadband topology (Heldman, 1992: 188). However, both of these options are expensive, especially on a per-customer basis in rural areas, and will not be implemented everywhere. The latter case (remote switches) is included in our data set (205, or 41.58%, of the switches are labeled as remotes), whereas the former is not.

5. A Proposed Hierarchy of Level-of-Service of Central Office Switches

Preliminary analysis in Tennessee indicates that the 493 switches in the state generate what can be seen as a hierarchy of digital capability, comprising six distinct levels (Table 2). The lowest level (Level 0 in Table 2), representing minimal telephone service, is the presence of a switch that does not have international direct long-distance dialing (IDDD). Level 1, the lowest level of digital capability, is IDDD capability, which is available in 96% of Tennessee's switches. Level 2 service is the implementation of signaling system 7, the software that enables all advanced digital services. This is available in approximately 65% of Tennessee's switches. Level 3 service—switches capable of switched 56 Kbps service—is present in only about 26% of the switches in Tennessee. At the next level (Level 4) is primary-rate interface ISDN, which provides a constant connection to the customer (usually a T1). This level, along with basic-rate ISDN capability (generally found in leased lines), is found in approximately 25% of the switches in the state. At the highest level, Level 5, found in only 10 (2%) of the switches in Tennessee, is multi-rate ISDN capability, permitting the customer to control the amount of bandwidth as needed (and to pay only for what is used).

6. Central Office Switches in Tennessee: Levels of Service

This hierarchy is imperfect, but 419, or approximately 85%, of the switches in Tennessee "fit" or conform to it. By "fit" we mean that a switch that has a given level of capability also has all lower levels as well. This section of the report discusses the geographical dimensions of this hierarchy, as well as metro/nonmetro contrasts. This is followed by a discussion of the switches that do not conform to the hierarchy in Table 2.

6.1 Switches That Conform to the Hierarchy

Although the proposed hierarchy of service in Table 2 is imperfect, 85% of switches in Tennessee conform to it. We have hypothesized that rural areas will be underserved by advanced telecommunications services. This should be indicated by the hierarchy of service in Table 2 (or by a similar revised hierarchy), with urban areas more likely to have higher levels of service. The rural-urban distinction alone does not account for the pattern found in Tennessee. For example, the locations of the 21 (4.26%) of the state's switches that are incapable of international direct long-distance dialing is puzzling. Eleven of them (52%) are in rural locations, but ten of them are in urban centers (four in Knoxville, three in Nashville, two in Chattanooga, and one in Memphis). This is somewhat puzzling. Direct international dialing may be possible through a neighboring or tandem switch but, even so, this would represent a minimal level of digital capability, and one that is possible in the rest (95.74%) of the state.

Telecommunications availability corresponds to a shrinking space as the service level increases. The lowest level of digital capability, international direct long-distance dialing (Level 1) is fairly widespread, missing from only a handful of counties in eastern and extreme northwestern Tennessee. Some degree of concentration is visible in the state's metro areas (Figure 1). Level 2 service, SS7 implementation (also found in all higher-level switches) is less available; several more counties, mainly in north central Tennessee, are without SS7-capable switches. When we turn to Level 3, switched 56 Kbps service, the state(except for the metro areas and other, mainly nearby locations(empties out (Figure 2). This trend continues for Level 4 and Level 5; the latter (multi-rate ISDN) is a purely metropolitan level-of-service.

6.2 Metro/Nonmetro Contrasts

A close-up view of the shrinkage of service areas between Level 2 and Level 3 is seen in Figure 3, which shows the Chattanooga metropolitan statistical area (MSA) and the nonmetro counties that surround it. Each switch is shown surrounded by an 18,000-foot circle of service, which is the outer radius of ISDN service; newer ADSL technologies are limited to an even smaller 12,000-foot radius (Egan 1996a: 62-65). While the number of switches in the Chattanooga metro area itself declines by 55% from 20 with Level 1 capability to nine with Level 3 capability, the number in the nonmetro counties declines even more dramatically, by 73%, from 26 to 7. The same shrinkage of digital capability is evident statewide, as one compares Figures 1 and 2.

Table 3 provides a comparison between metro and nonmetro areas in Tennessee. Nonmetro areas cover over two times the land areas as metro areas, but contain about one-half the population. The two areas contain nearly the same number of CO switches. This means that the land area served by the average metro CO switch (at 51.55 sq. mi.) is less than half that of the average nonmetro switch (118.32 sq. mi.). This greater land area translates into greater loop length—and therefore greater cost—to reach each customer (Egan, 1996a). The number of customers (and, therefore, revenue) per switch is over twice as great in metro areas. These geographic "facts," in turn, lead to differences in the levels of investment in new infrastructure, such as digital capability.

The urban bias of digital capability also is evident in Table 4. Although Level 0 (no IDDD) is mainly a metropolitan phenomenon, Levels 1 and 2 are predominantly rural. This means that rural switches have minimal digital capability. In fact, 76% of rural switches have no higher than Level 2 service; 53% of urban switches are at the same level-of-service. It is the higher levels-of-service (3, 4, and 5) that are overwhelmingly urban—far more than the 49.9% of Tennessee's switches found in metro areas. Level 5 is only found in the state's metro areas. Most importantly, only 32 (13%) of all rural switches are Level 3 or higher, whereas 69 (28%) of metro switches are at this level or higher (Table 4).

6.3 Switches That Do Not Conform to the Hierarchy

A total of 74 (15%) of Tennessee's CO switches have some higher level of digital capability without having all lower levels (Table 5). Failure to conform to or "fit" our proposed hierarchy is not necessarily a bad thing. Indeed, in most cases, nonconformance means that a switch has higher-level capability, but without one or more lower levels of capability. Two such switches, both located in Memphis and belonging to Time Warner Communications, have multi-rate ISDN (Level 5) service and international direct long-distance dialing but, in one switch, none of the intermediate-level capabilities and, in the other switch, only basic-rate ISDN. This "cherry-picking" by new LECs is aimed at large urban markets. Indeed, nonconformance with the proposed hierarchy is generally a metropolitan phenomenon: of the 74 switches that do not "fit" our hierarchy, 28 are in nonmetro areas, but 46 are in metro areas (Table 6).

The number of local exchange companies (LECs) in the state suggests that some of the complexity lies in their heterogeneity. In Tennessee, South Central Bell (part of BellSouth) is the dominant provider, and its 240 switches represent 48.68 % of the state's total. The rest of the state is divided among the other 52 LECs, 15 of which have a single CO switch. The largest non-Bell LEC, United Inter-Mountain Telephone, has 31 switches, or 6.29% of the state's total, in its service area of Upper East Tennessee in and around the Johnson City-Kingsport-Bristol MSA. Of the 74 switches that fail to conform to our hierarchy, 45 of these are BellSouth switches, a higher percentage (60.81%) than BellSouth switches represent of Tennessee's total (48.68%). Furthermore, 14 are United Inter-Mountain's (18.92% of the total, three times higher than its percentage of the state's switches).

The largest single category of nonhierarchical capability is that Signaling System 7, typically a prerequisite for digital service, is not coded as a capability in 35 switches that have a higher level of capability (including five that have Level 5 capability) (Table 5). All 14 of United Inter-Mountain's nonconforming 31 switches are in this category, having switched 56 kb service without SS7; eight BellSouth switches are among the 35, as are both of Nextlink Tennessee, Inc.'s switches, located in Memphis and Nashville, the single switch of Brooks Fiber Communications, in Knoxville, and 360 Degree Communications, located just outside Johnson City. The next largest category is the 34 switches that have IDDD and SS7, as well as PRI and BR ISDN, but not switched 56kb service. That is, they have Levels 2, 4, and 5 capability, but not Level 3. All 34 of these switches are BellSouth's, and nine different models of switch are represented. Finally, 47 switches do not have switched 56kb service capability but have one or more of the higher-level capabilities.

Some switch characteristics are associated with their conformance or lack of conformance with the hierarchy in Table 2. We are unable to account for this nonconformance completely, but there are several partial explanations of hierarchy nonconformity (Table 6). Switches coded as an "end office" are more likely not to conform to the hierarchy; 69 of the 74 nonconforming switches (93.24%) are end offices [of 421 statewide]. End offices are the lowest tier in the hierarchical call-routing network (Heldman, 1992: 152-154). On the other hand, 45 nonconforming switches are coded as "remote" switches (60.81% of the 74) [of 206 statewide], and 12 (16.22%) are identified as "host" switches [of 99 statewide] (Table 6). There are 45 BellSouth remote switches that provide higher capability without all lower levels, representing 60% of Tennessee's nonconforming switches. "Host" switches and non-BellSouth switches are somewhat more likely to fit the hierarchy we have proposed (Table 6).

Finally, the heterogeneity of CO switches stands out. Of the 74 nonconforming switches, 18 different models of switch are represented. The most common is the Northern Telecom Remote Switching Center (RSC), with 19, the same switch that is the most common switch statewide; the other 41 RSC switches in Tennessee fit our hierarchy. This particular switch, like the 17 other models (with one exception), probably cannot be implicated in the failure to fit this hierarchy.

7. Co-Location of Switches

Although the analysis in Section 6 treats all switches as separate entities, as does the LERG data set, a substantial number of switches are installed at the same location as other switches. These can be identified both by location coordinates and by street addresses. In some cases, the coordinates are off by one digit in either or both directions. Of the 493 switches in Tennessee, 116 switches are located at the same address or coordinates at 37 locations, and four other locations have two or more switches that are very near (perhaps in the same block). Co-location is most common in the state's seven metropolitan areas: 23 locations contain 85 switches, including one site with nine switches, two with eight, and one with seven. Three additional sites are likely to have two switches: addresses are almost identical, coordinates off by perhaps two digits. In nonmetro counties, 14 locations (and an additional three probable sites) have multiple switches. Co-location is a common practice among telcos, enabling "tandem" switches, which effectively enable two (or more) switches with the capability of the higher switch and the capacity (in number of lines) of both combined. However, we have no knowledge of whether any two switches are, as we assume, actually linked in this way.

Co-location helps to explain—and eliminate—most of the 21 Level 0 switches in Tennessee, (i.e., those without international direct long-distance dialing (IDDD)). Co-location is the case mainly in metro areas, where nine sites involve either clear co-location of a Level 0 switch and a higher-level switch (n=6) or probable co-location (n=3). In nonmetro counties, four sites include co-location of a Level 0 and a higher-level switch (and another probably does). Therefore, the apparent abundance of 21 Level 0 switches in Tennessee is reduced to eight and, including probable co-location, to four. Of the remaining Level 0 switches, only one is in a central city of a metro area (Knoxville), another is in suburban Knoxville, two are in suburban counties of Nashville, and the remaining three are in nonmetro counties.

Co-location of switches affects other levels in the digital hierarchy as well. But the greatest impact of co-location is to explain the large number of low-level switches in metro areas. In addition to the Level 0 switches discussed above, co-location upgrades switches in metro areas from lower levels of digital capability to Level 4 or 5 in 19 of 23 locations. In only four metro locations is the highest level of co-located switches as low as Level 2; three of these are in

Memphis, the other in Knoxville. In nonmetro counties, co-location raises the highest switch capability to Level 3 or higher in only five of 14 cases. As a result, the number of metro switches with capability below Level 3 is very small. This is best shown by aggregating switch locations to the scale of the county.

8. County Analysis

The switches in Tennessee were aggregated to the county level, using the ZIPFIP program of the USDA's Economic Research Service (ERS) to translate the zip code of a switch to its appropriate county. In several cases, there was no county output because zip codes had changed or new ones assigned; these were identified using a road atlas and the U.S. Postal Service Web site. A few zip codes were coded in the LERG data incorrectly (e.g., off by one digit) and these were corrected using the street address and city of neighboring switches to identify the error. One switch in the LERG data for Tennessee was unable to be located within the state, its location being in Virginia. The remaining 492 switches were assigned to the 95 counties in Tennessee.

8.1 Number of Switches in a County

Each of the 95 counties in Tennessee has at least one CO switch. Two counties (Davidson and Shelby, the central counties of the Nashville and Memphis MSAs, respectively) have over 40 switches each. Two other counties, the central counties of the Chattanooga and Knoxville MSAs, have over 25 switches. In all, these four counties contain 144 switches, or 29.3% of all switches in Tennessee. The remaining 91 counties have between one and 13 each (Figure 4). The number of switches in a county is not simply a function of population, although that variable captures much of the urban dimension. Ordinary least-squares analysis shows that the best statistical explanation for the number of CO switches in a county is the county's population *and* its population density (Table 7). The statistical performance is best in the analysis of metro counties and all counties, and is weakest for nonmetro counties. In effect, there is much greater variation—and variance—among the 69 nonmetro counties. However, for all three groups of counties (all, nonmetro, and metro) population and population density explain the greatest proportion of the variance. However, they do so in different ways. For all counties, larger numbers of switches are found in counties that have both larger populations and higher population densities. In nonmetro counties, more populous counties have more switches, but, once population is taken into account, levels are lower in counties with higher densities. In metro counties, the opposite combination sequence prevails: the number of switches is larger in counties with higher population density and, holding density constant, declines in those counties with larger populations.

The county level of analysis also allows us to examine differences by the ERS Rural-Urban Continuum code (Beale code).[2] Figure 5 shows that counties with larger numbers of switches are in the metro categories 0 through 3, as well as 4 and 5, those with larger cities. Table 8 shows this information for all ten classifications. The mean number of CO switches per county is highest in the metro counties (Beale codes 0 through 3) and lowest in the most rural counties (Beale code 9).

However, Beale code alone explains only a small amount (less than 20%) of the variance in the number of switches (Table 7). As expected, in all three analyses, the largest numbers of switches are in the most urban counties along the urban-rural continuum. As the Beale code increases—or as a county is less urban (or more rural)—the number of CO switches declines. When combined with population and population density, Beale code is consistently significant statistically, and with the appropriate negative sign in both the metro and nonmetro analyses. In the analysis of all 95 counties, the number of switches increases with Beale code, when both population and population density are taken into account. In all three analyses, it is increasing population density that accounts for most of the explained variance, Beale code actually causing instability in the estimate and a decline in R^2 compared to the equation containing only population and density.

8.2 Highest Level of Switch in a County

Despite the presence of 21 Level 0 switches in several locations, no county is below Level 1 in digital capability (Table 9). Six counties—all rural—have no switch higher than Level 1. What stands out most sharply in Table 9, however, is the contrast between metro and nonmetro counties in Level 1 or 2 versus Level 3 or higher. When the data are aggregated in this way (Table 10), the difference between metro counties and nonmetro counties and the highest level of CO switch is statistically significant at the 0.001 level, using a chi-square test.

Population density partially accounts for the variation across counties in highest level of switch (Table 11). Although at least one county at each Beale code from 0 through 7 has at least one Level 4 switch, the most rural counties (Beale codes 8 and 9) have more Level 2 switches than any other. For all metro and nonmetro counties, once again population, population density, and Beale code account for most of the variance in the highest level of switch in a county (Table 12). Population is the most consistent individual variable. However, less than one-third of the variance is accounted for by these three variables in all analyses. Several other variables were tried, such as the presence of a university or college, but none performed better than those in Table 12.

The highest level of switch in each county exhibits the same downward trend with Beale code seen for number of switches (Figure 6). Only one metro county has a switch as low as Level 2, whereas this is the most common capability in counties of category 8 and 9, and is common as well in categories 6 and 7. In counties of category 4, 5 and 6, on the other hand, Level 4 switches are the most commonly found.

9. Implications for Rural Residents

Increasingly, residential customers are also business customers. Entrepreneurship has become a typical rural lifestyle among rural non-farm residents. These firms also are increasingly involved in services, for which communications is a key aspect of doing business (Beyers and Lindahl, 1996). Large firms also seek to place communications-intensive back-office and telemarketing functions in rural areas to take advantage of wage disparities between rural and metropolitan areas (Howland 1993). Therefore, for these and many other rural businesses, digital communications is a “must” for doing business, and the availability of high-speed and broadband technologies can determine the services they can offer to their customers (Egan, 1996a, p. 284). This is as true of manufacturers as it is of service firms (Kasarda and Rondinelli, 1998). The quality of rural jobs depends to a great extent on rural America having access to the same communications technology as the rest of the nation.

One of the best explanations for the location of high-level switches in Tennessee is the presence of business-service employment (SIC 73). With very few exceptions, switches at Levels 3 and higher are found only where employment in SIC 73 is above some minimal level; no high-level switches are found in sites remote from business-service clusters, and these are found in both metro and nonmetro locations (Figure 7).

The lower density and greater distances—the rural penalty—work against nonmetro areas (Parker et al., 1989). New remote switch technologies can serve areas up to 650 miles from a host switch, and they can provide between 4,480 and 6,400 lines (or up to 480 trunks, or a mix of lines and trunks) (Northern Telecom, 1998). It is unlikely that such a switch will be installed where the numbers of customers (data customers, not voice customers) is not nearly equal to these capacity figures.

10. Conclusions and Plans for Further Research

This research has documented the inequality in telecommunications level-of-service for one state. Proposing a hierarchy for level-of-service, the highest-capability switches are concentrated disproportionately in metropolitan areas, largely in response to higher population density. Rural counties are more likely to have both fewer switches and switches with lower levels of digital capability.

We plan to replicate the analyses of CO switches in Tennessee described in this report for three additional states in the TVA region of the southeastern United States: Kentucky, Mississippi, and North Carolina. The analysis of more than one state should provide insights into some of the difficult-to-explain patterns found in Tennessee. Analysis of the correspondence between the location of business or producer services (SIC 73) and CO switch capability will be part of this further research. It may be that we also need to delve more deeply into the arcane technical differences among CO switch systems.

We have attempted to provide an understanding of differences in level-of-service, especially in new digital technologies. While our hierarchy is not ideal, it sheds considerable light on the nature of technological change in the telecommunications industry under deregulation, and on the geographical disparities that are evolving.

Endnotes

1. A preliminary version of this research was presented at the Workshop on Rural Telecommunications, sponsored by the U.S. Department of Agriculture's Economic Research Service, TVA Rural Studies, and the Western Rural Development Center, in Washington, DC, September 1998.

2. The rural-urban continuum codes are: Metro counties: 0 - Central counties of metro areas of 1 million population or more, 1- Fringe counties of metro areas of 1 million population or more, 2 - Counties in metro areas of 250,000 to 1 million population, 3 - Counties in metro areas of fewer than 250,000 population; Nonmetro counties: 4 - Urban population of 20,000 or more, adjacent to a metro area, 5 - Urban population of 20,000 or more, not adjacent to a metro area, 6 Urban population of 2,500 to 19,999, adjacent to a metro area, 7 - Urban population of 2,500 to 19,999, not adjacent to a metro area, 8 - Completely rural or less than 2,500 urban population, adjacent to a metro area, 9 - Completely rural or less than 2,500 urban population, not adjacent to a metro area. These are available on the ERS Web site: http://www.ers.usda.gov/epubs/other /typolog

References

Akimaru, H., M.R. Finley, and Z. Niu (1997) "Elements of the emerging broadband information highway." *IEEE Communications Magazine* 35 (6): 84-92.

Banker, R.D., H.-H. Chang, and S.K. Majumdar (1998) "Economies of scope in the U.S. telecommunications industry." *Information Economics and Policy* 10: 253-272.

Beyers, W.B. and D.P. Lindahl (1996) "Lone eagles and high fliers in rural producer services." *Rural Development Perspectives* 11 (3) June: 2-10.

Boush, C. and E.J. Malecki (1998) "Telecommunications innovations: regional and local variations in new technologies and challenges for regional research." *Submitted for publication*.

Crockett, R. (1998) "'Only Sprint has it all' - or does it?" *Business Week* June 15: 51.

Egan, B.L. (1996a) *Information Superhighways Revisited: The Economics of Multimedia*. Boston: Artech House.

Egan, B.L. (1996b) "Improving rural telecommunications infrastructure." Paper prepared for the Center for Rural Studies. New York: Columbia University Institute for Tele-Information.

Farrell, J. and M.L. Katz (1998) "Public policy and private investment in advanced telecommunications infrastructure." *IEEE Communications Magazine* 36 (7): 87-92.

Flamm, K. (1989) Technological advance and costs: computers versus communications, in R.W. Crandall and K. Flamm (eds.) *Changing the Rules: Technological Change, International Competition and Regulation in Communications*. Washington: Brookings Institution, pp. 13-61.

Heldman, R.K. (1992) *Global Telecommunications: Layered Networks' Layered Services*. New York: McGraw-Hill.

Howland, M. (1993) "Technological change and the spatial restructuring of data entry and processing services." *Technological Forecasting and Social Change* 43: 185-196.

Hurley, D. and J.H. Keller (eds.) (*forthcoming*) *The First 100 Feet: Options for Internet and Broadband Access*. Cambridge, MA: MIT Press.

Kasarda, J.D. and D.A Rondinelli (1998) "Innovative infrastructures for agile manufacturers." *Sloan Management Review* 39 (2): 73-82.

Kraushaar, J.M. (1995) Quality-of-service measurement and the Federal Communications Commission, in W. Lehr (ed.) *Quality and Reliability of Telecommunications Infrastructure*. Mahwah, NJ: Lawrence Erlbaum, pp. 187-211.

Langdale, J.V. (1983) "Competition in the United States long distance telecommunications industry." *Reg. Studies* 17: 393-409.

Leo, E. and P. Huber (1997) "The incidental, accidental deregulation of data ... and everything else." *Industrial and Corporate Change* 6: 807-828.

Lu, H.-L., I. Faynberg, A. Toubassi, F. Lucas, and F. Renon (1998) "Network evolution in the context of the global information infrastructure." *IEEE Communications Magazine* 36 (8): 98-102.

Majumdar, S.K. (1995) "Does technology adoption pay? Electronic switching patterns and firm-level performance in US telecommunications." *Research Policy* 24: 803-822.

Majumdar, S.K. (1997) "Modularity and productivity: assessing the impact of digital technology in the U.S. telecommunications industry." *Technological Forecasting and Social Change* 56: 61-75.

Malecki, E.J. (1998) Telecommunications Technology and American Rural Development in the 21st Century, in D. Freshwater (ed.) *Rural America at the Crossroads: Networking for the Future (OTA Follow-Up Report)*. Lexington, KY: TVA Rural Studies, pp. 65-91.

Moss, M.L. and A.M. Townsend (1998) "Spatial analysis of the Internet in U.S. cities and states." Paper prepared for the 'Technological Futures - Urban Futures' Conference, Durham, England, April 1998; Electronic publication http://urban.nyu.edu/research/newcastle/newcastle.html

Northern Telecom (1998) "Remote Switching Center-S." Electronic publication http://www.nortel.com/pcn/products/rscs.html

Parker, E.B., H.E. Hudson, D.A. Dillman, and A.D. Roscoe (1989) *Rural America in the Information Age: Telecommunications Policy for Rural Development.* Lanham, MD: University Press of America.

Salomon, I. (1996) "Telecommunications, cities and technological opportunism." *Annals of Regional Science* 30: 75-90.

Sassen, S. (1995) Urban impacts of economic globalisation, in J. Brotchie et al., eds. *Cities in Competition: Productive and Sustainable Cities for the 21st Century.* Melbourne: Longman Australia, pp. 36-57.

Warf, N. (1995) "Telecommunications and the changing geographies of knowledge transmission in the late 20th century." *Urban Studies* 32: 361-378.

Zanfei, A. (1992) Collaborative agreements and innovation in the U.S. telephony industry, in C. Antonelli (ed.) *The Economics of Information Networks*. Amsterdam: North-Holland, pp. 229-251.

Table 1 Most Common Models of Central Office Switches Installed in Tennessee

Switch manufacturer and model	Number installed in Tennessee (%)
Northern Telecom Remote Switching Center (RSC)	60 (12.17%)
Northern Telecom DMS100 (Digital) Host (DMH)	51 (10.34%)
Northern Telecom DMS10 (Digital) (DMT)	46 (9.33%)
WECO 5ESS Digital (5E)	45 (9.13%)
45 other models	291 (59.03%)

Table 2 Hierarchy of Digital Capability in Central Office Switches

Hierarchy level	Characteristics
Level 5	Multi-rate ISDN
Level 4	Primary-interface and basic-rate ISDN
Level 3	Switched 56 Kbps
Level 2	Signaling system 7 (SS7)
Level 1	International direct long-distance dialing
Level 0	None of the above

Table 3 Metro and Nonmetro Characteristics and Telephone Switches in Tennessee

	Metro areas	Nonmetro areas	Statewide
Land area (sq. mi.)	12,475	29,699	42,174
Population (1990)	3,300,009	1,639,476	4,877,195
Population density (pop./sq. mi.)	226.23	55.49	115.64
Number of CO switches	246	247	493
Average area per CO switch (sq. mi.)	50.71	120.24	85.55
Customers per CO switch	13,415	6,638	9,893

Table 4 Percentage of Switches at Each Level of the Hierarchy, by Metro and Nonmetro Location

	Metro	Nonmetro
Level 0 (no IDDD)	12 (75%)	4 (25%)
Level 1 (IDDD)	58 (47%)	66 (53%)
Level 2 (SS7)	61 (33%)	117 (67%)
Level 3 (Switched 56 Kbps)	16 (73%)	6 (27%)
Level 4 (Primary-interface and basic-rate ISDN)	48 (65%)	26 (35%)
Level 5 (Multi-rate ISDN)	5 (100%)	0 (0%)
Nonconforming switches	46 (62%)	28 (38%)
All switches	246 (49.9%)	247 (50.1%)

Table 5 Percentage of Switches Conforming and Not Conforming to the Proposed Hierarchy, by Level-of-Service

	Switches that conform	Switches that do not conform
Level 5	5 (50%)	5 (50%)
Level 4	79 (62.70%)	47 (37.30%)
Level 3	101 (78.91%)	27 (21.09%)
Level 2	284 (89.31%)	34 (10.69%)
Level 1	403 (85.38%)	69 (14.62%)
Level 0	16 (76.19%)	5 (23.81%)

Table 6 Characteristics of Switches that Conform and Do Not Conform to the Proposed Hierarchy

	Statewide	Switches conforming to hierarchy	Switches not conforming to hierarchy
All switches	493	419	74
Remote switches	206 (41.78%)	161 (38.42%)	45 (60.81%)
Host switches	99 (20.08%)	87 (20.76%)	12 (16.22%)
End office switches	421 (85.40%)	352 (84.01%)	69 (93.24%)
BellSouth switches	240 (48.68%)	195 (46.54%)	45 (60.81%)
Non-BellSouth switches	253 (51.32%)	224 (53.46%)	29 (39.19%)

Table 7 Determinants of the Number of CO Switches per County in Tennessee

All Counties (n=95)					
Constant	1.9759	1.0225	11.5155	1.4111	-70.7653
Population	.00006239			0.00003080	-0.00006784
	(t=23.598)			(t=3.421)	(t=0.465)
Population Density		0.03863863		0.02032587	7.126415
		(t=23.812)		(t=3.650)	(t=9.136)
Beale code			-1.15321261		0.864235
			(t=4.295)		(t=2.781)
R^2	0.857	.859	0.166	.875	.574
Nonmetro Counties (n=69)					
Constant	1.9319	3.2312	7.6989	2.0433	2.8022
Population	0.00007199			0.00013241	-0.090308
	(t=4.341)			(t=5.697)	(t=0.374)
Population density		0.006116		-0.026223	0.0001263
		(t=1.008)		(t=3.466)	(t=4.416)
Beale code			-0.60216401		-0.02623
			(t=3.228)		(t=3.444)
R^2	.219	.015	.135	.340	0.341
Metro Counties (n=26)					
Constant	1.3378	-1.0341	24.9020	-1.229105	-94.1368
Population	0.00006374			-0.00000766	-0.000281
	(t=14.170)			(t=0.807)	(t=1.219)
Population density		0.04324109		0.048066871	10.64991
		(t=27.726)		(t=7.772)	(t=8.867)
Beale code			-8.04901961		-4.19712
			(t=1.935)		(t=2.058)
R^2	.893	.970	0.135	.971	.818

Table 8 Population and Central Office Switch Characteristics of Tennessee Counties, by Rural-Urban Continuum (Beale) Code

Beale code	Number of counties	Mean population	Number of switches	Mean number of switches	Mean population per CO switch
0/1	3	296,485	49	16.3	18,152
2	21	106,186	186	8.9	11,989
3	2	89,240	10	5.0	17,848
4	4	55,516	23	5.8	9,655
5	3	47,397	16	5.3	8,887
6	26	23,329	92	3.5	6,593
7	14	27,452	59	4.2	6,514
8	11	12,208	37	3.4	3,629
9	11	8,174	20	1.8	4,496
All counties	95	51,339	492	5.2	9,913

Table 9 Highest CO Switch Level, by Metro or Nonmetro County

Highest level switch	Metro (number of counties)	NonMetro (number of counties)
Level 1	0	6 (11.3%)
Level 2	1 (2.4%)	24 (45.3%)
Level 3	5 (11.9%)	4 (7.5%)
Level 4	33 (78.6%)	18 (34.0%)
Level 5	3 (7.1%)	1 (1.9%)
All counties	42 (100%)	53 (100%)

Table 10 Highest Level of CO Switch by Category, Metro and Nonmetro Counties

	Metro	**Nonmetro**
Level 1 or 2	1	30
Level 3, 4 or 5	41	23

Chi-square analysis significant at the 0.001 level.

Table 11 Population Density and Highest Central Office Switch Level of Tennessee Counties, by Rural-Urban Continuum (Beale) Code

Beale code	**Mean population density (population per square mile)**	**Highest switch level (number of switches at each level in parentheses)**
0/1	404.3	**4 (2)**, 5 (1)
2	226.1	5 (2), **4 (14)**, 3 (4), 2 (1)
3	163.2	**5 (2)**
4	130.3	**4 (4)**
5	178.6	**4 (2)**, 2 (1)
6	51.7	5 (1), **4 (14)**, 3 (3), 2 (5), 1(3)
7	56.5	**4 (6)**, 3 (1), 2 (5), 1(2)
8	37.7	4 (4), 3 (1), **2 (6)**
9	29.5	4 (3), **2 (7)**, 1(1)

Note: Most common switch level for counties in each Beale code is shown in bold.

Table 12 Determinants of the Highest Level of CO Switch in a Tennessee County

All Counties (n=95)				
Intercept	3.0418	2.9764	4.3355	4.0139
Population	.00000370			.000001183
	(t=3.709)			(t=0.346)
Population density		0.00237257		0.0004294
		(t=3.872)		(t=0.197)
Beale code			-0.2009	-0.1618431
			(t=5.052)	(t=3.478)
R^2	.129	.139	.215	.240
Nonmetro Counties (n=69)				
Intercept	2.2535	2.5532	4.7681	2.4619
Population	0.00003198			0.00003148
	(t=3.767)			(t=1.977)
Population density		0.007588		-0.00051
		(t=2.618)		(t=0.121)
			-0.26059	-0.02454
			(t=2.754)	(t=0.182)
R^2	.175	.093	.102	.175
Metro Counties (n=26)				
Intercept	2.66367	3.59832	4.43137	3.3830
Population	.000001978			0.000043956
	(t=3.239)			(t=1.461)
Population density		0.00118383		-0.001465
		(t=2.881)		(t=0.800)
			-0.2843	0.1552
			(t=1.233)	(t=0.578)
R^2	.304	.257	.060	.325

Figure Captions

Figure 1

Level 1 Switches

Figure 2

Level 3 Switches

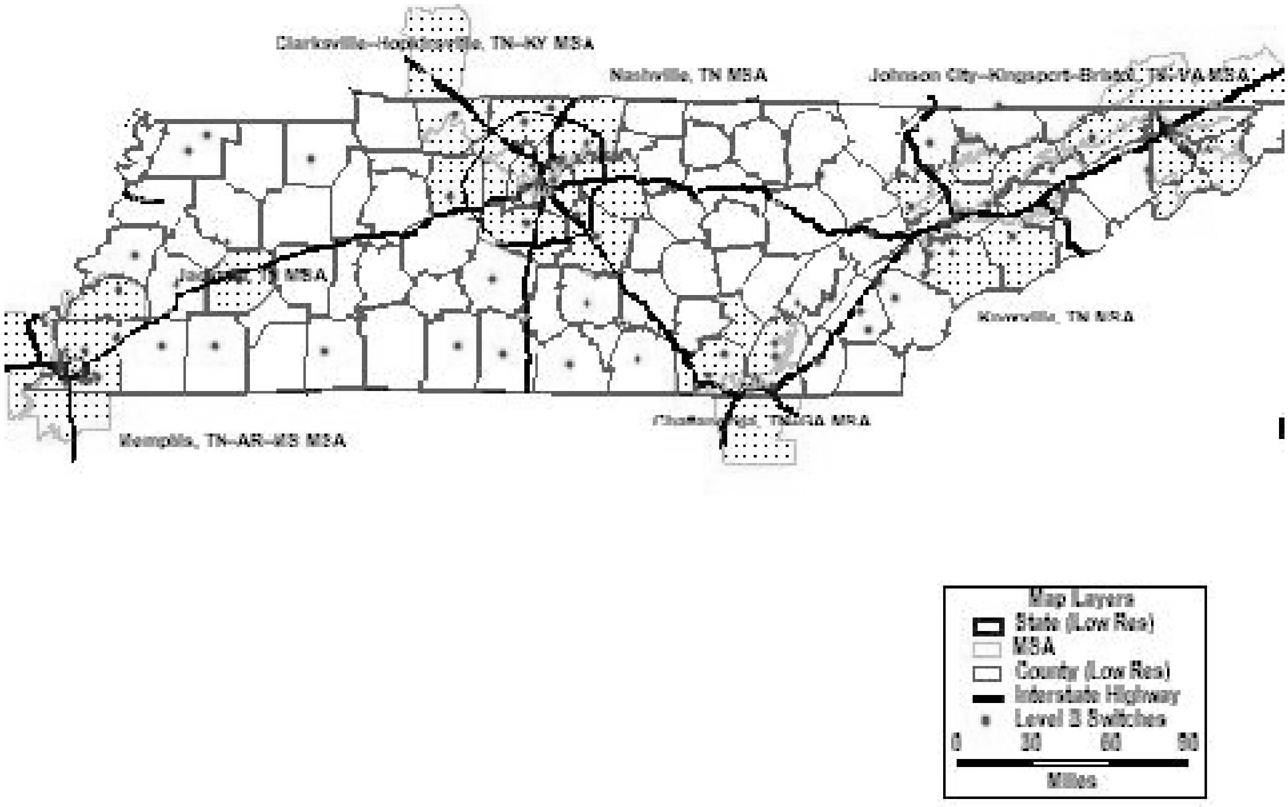
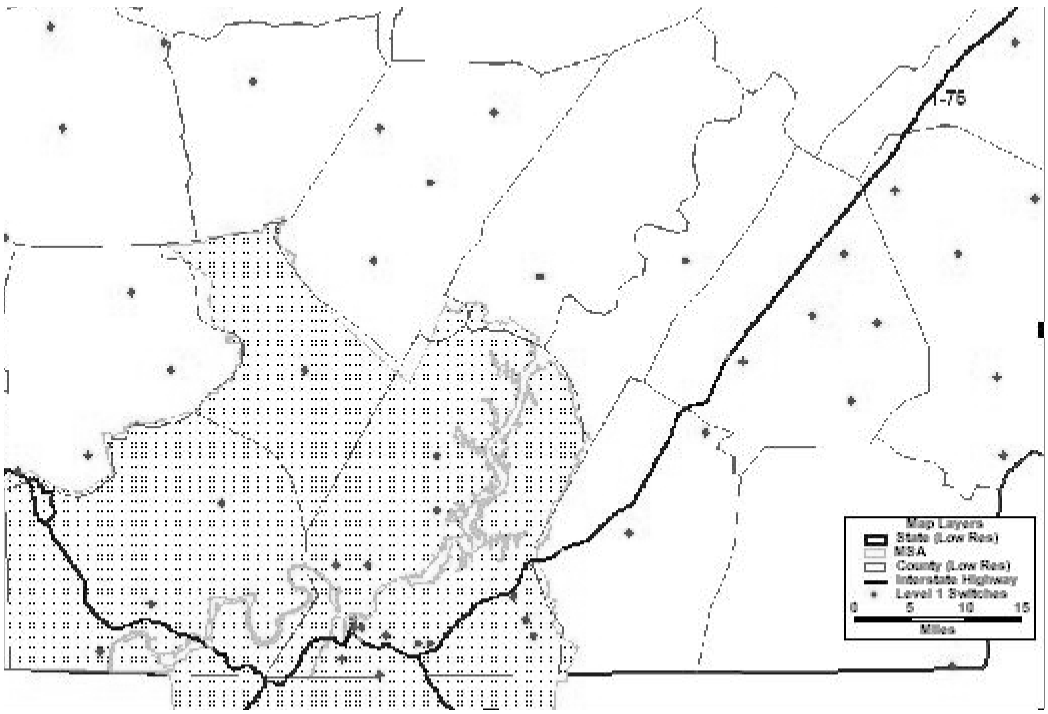


Figure 3

Chattanooga MSA Level 1 Switches



Chattanooga MSA Level 3 Switches

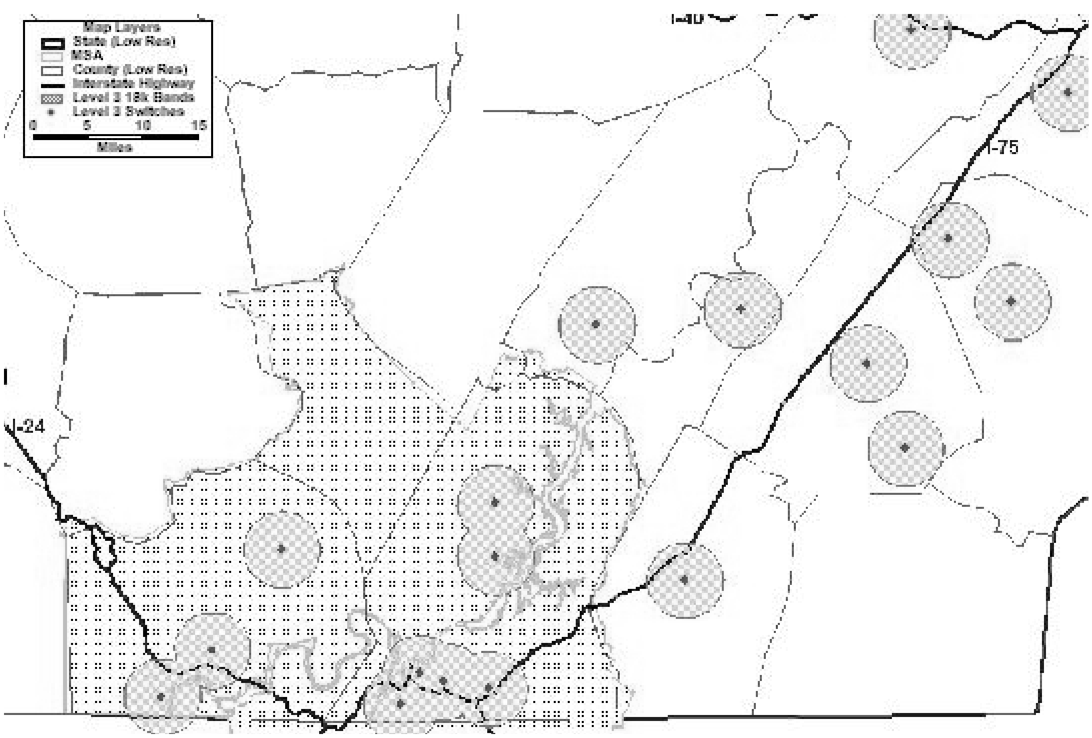


Figure 4

Number of Switches and Population by County: Tennessee

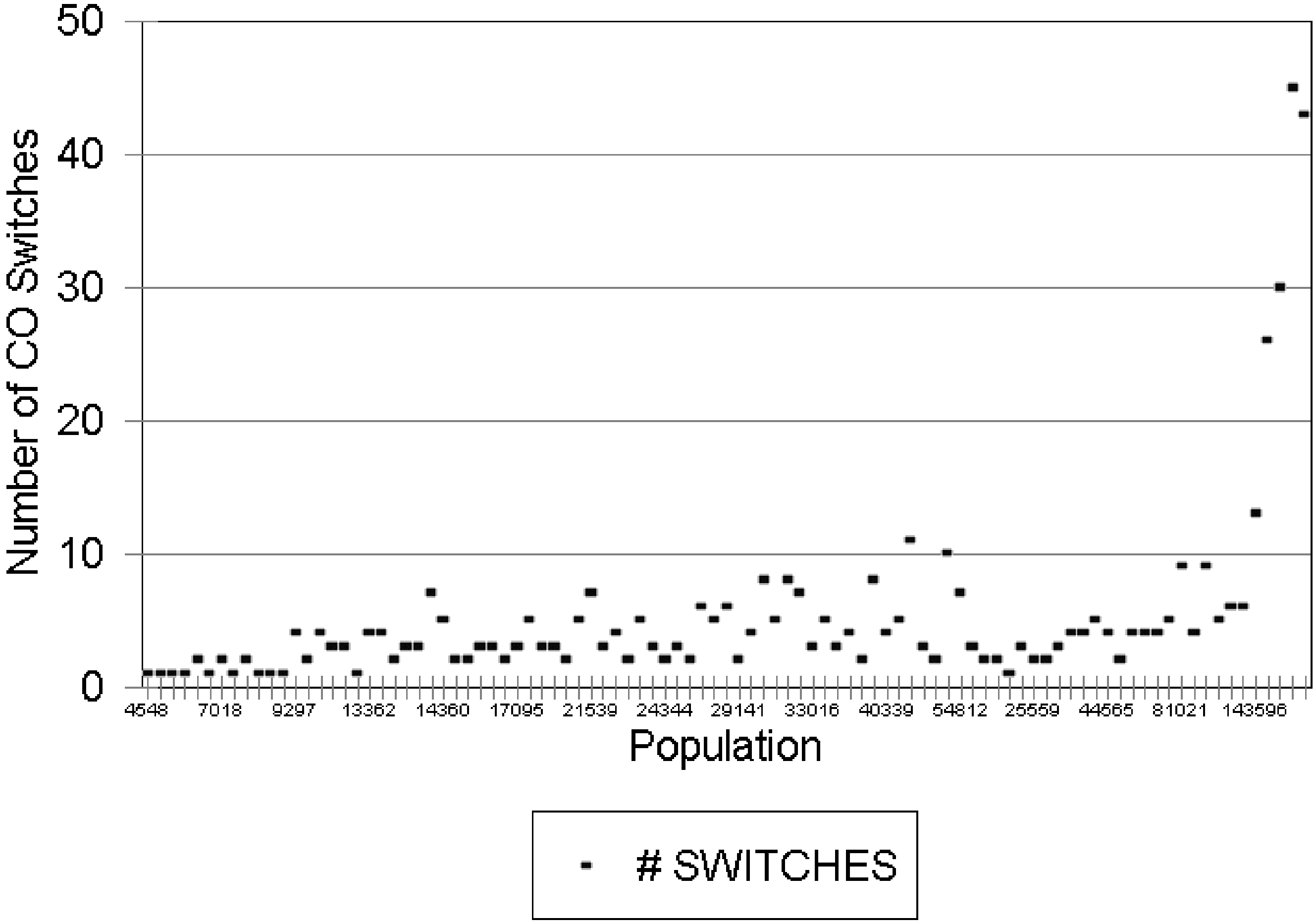


Figure 5

Number of Switches per County, by Beale Code: Tennessee

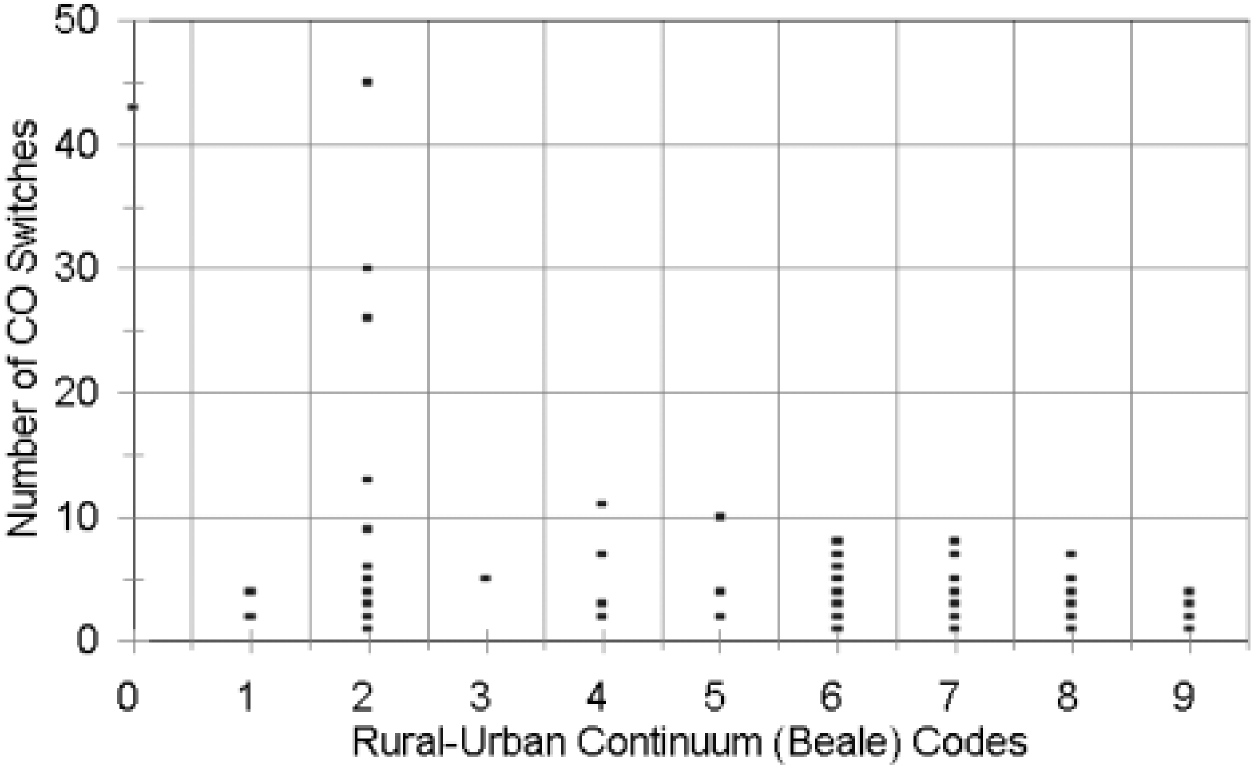


Figure 6

High Switch Level by Beale Code for Counties in Tennessee

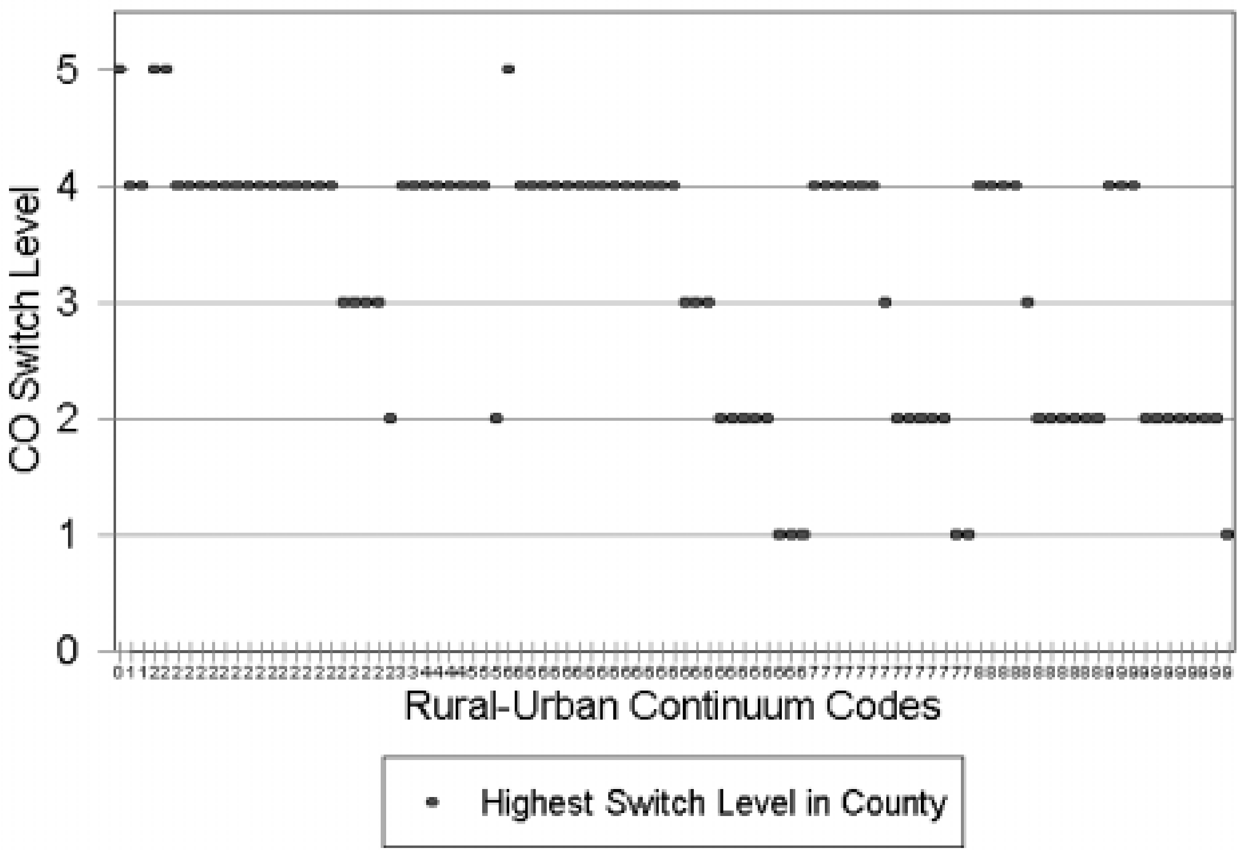


Figure 7

Employment by ZIP for SIC 73