The Organizational Ecology of a Technological System

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This paper investigates organizational mortality in the early American telephone industry, in which thousands of companies proliferated and failed under conditions of technological change. Drawing on the theory of community ecology, it is predicted that when technologies are systemic, technological change does not necessarily favor advanced organizations. Instead, mutualism is predicted among both advanced and primitive firms, as long as they are technologically standardized and differentiated. Competition is expected when organizations are technologically incompatible or noncomplementary. The hypotheses are supported by dynamic models of organizational mortality, estimated using archival data describing the life histories of all telephone companies that operated in Pennsylvania up to 1934 and in southeast Iowa from 1900 to 1930.•

Often there is no clear boundary around an organization's technology. Separate chemical refiners physically connect to each other's facilities, computer manufacturers assemble hardware systems using components produced by various organizations, and transportation companies ship standardized containers to and from one another. Because of this, many technologies can be thought of as systems that cut across formal organizational boundaries. How does technological change in such a system affect organizational interdependence? When does it generate competition? Does it ever increase "mutualism," or positive interdependence, among organizations? If we knew the answers to these questions, then we could predict when an organization in such an industry improves or threatens its viability by changing its technologies. We could also predict when an organization's viability is improved or threatened due to technological change by others. However, the literature on technological change has paid little attention to the unique properties of systemic technologies. Consequently, despite the potential value of such predictions, these questions have remained unanswered.

They are addressed in this study as part of a broader investigation of the early American telephone industry. In the first three decades of this century, thousands of telephone companies co-existed under conditions of technological change. These companies often connected their systems, resulting in mutualism as they decreased each other's failure rates. But in other cases they competed, increasing the chances that one or another would fail (Barnett and Carroll, 1987). This paper investigates how two important developments in power and transmission technology affected these relations.

Hawley's (1950) ecological framework suggests that systemic technologies can be usefully studied in terms of their more elemental systems. These elemental systems are distinguished according to whether they are uniform or differentiated. Uniform systems require standardization throughout, as with the operating system of a computer. Differentiated systems, in contrast, comprise parts that work together because they are different in a complementary way, as with the hardware components of a microcomputer. Because it is based on ecological principles, this approach differs funda-

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mentally from the prevailing Schumpeterian approach to the study of technological change and competition.

Technological Superiority and Competition

It is commonly thought that technological change generates competition and that this competition works to the benefit of technologically advancing organizations. The idea is often attributed to Schumpeter (1950: 84):

> . . . in capitalist reality as distinguished from its textbook picture, it is not [price] competition which counts but the competition from . . . the new technology . . . —competition which commands a decisive cost or quality advantage and which strikes not at the margins of the profits and the outputs of the existing firms but at their foundations and their very lives.

From this view, an industry's prevailing technology is conceived as a benchmark (Schumpeter, 1934). Organizations that do not keep up with this benchmark are at a competitive disadvantage. And because technological change advances this benchmark, it generates competiton that favors technologically superior organizations.

This reasoning remains largely unquestioned in the various approaches to the study of technological change. At the organization level of analysis, Thompson and McEwen (1958) and Dill (1958) argued that managerial discretion is constrained by competition from technologically advancing organizations. Burns and Stalker (1961) and Hage and Aiken (1969) considered technological competition to be a problem of structural adaptation. Pfeffer and his colleagues found that organizations use bridging strategies, such as executive recruitment and joint ventures, to protect themselves from competition due to technological change (Pfeffer and Leblebici, 1973; Pfeffer and Nowak, 1976).

A common subject of contingency theory research was the problem of coordinating technological systems (Woodward, 1965; Perrow, 1967; Hickson, Pugh, and Pheysey, 1969). But as Scott (1975) observed, contingency researchers were concerned with a "rational" solution to the problem of technological interdependence. This confined attention to the case of a single organization coordinating the entire system. Thompson (1967: 74), drawing from Chandler (1962), stated so explicitly. He argued that, under "norms of rationality," when an organization's "technical core" is not "isolated from boundary spanning" it will attempt to coordinate the entire operation using an "overarching" hierarchy. In this way, contingency theory assumed away the problem of multiple organizations within a common technological system.

More recent work extends Schumpeter's original theme, specifying the conditions under which organizations are likely to become technologically superior. Brittain and Freeman (1980) found that "r-form" organizations, which require less initial capital and have simple formal structures, proliferate more quickly into "niches" (market segments) opened by new technologies. As a result, this organizational form gains competitive advantage by remaining technologically advanced. Aldrich and Whetten (1981) argued that "dominant" organizations, which are powerful due to network centrality, resist technological change unless it works to their competitive advantage. And Tushman and Anderson (1986) found that whether an organization can gain technological superiority depends on whether the new technology enhances or destroys the organization's existing competencies.

Schumpeter has also greatly influenced research on the technological development of industries. It is widely held that new, radically superior technologies displace old, inferior ones—a process described by Schumpeter (1950) as "creative destruction." Following this reasoning, Nelson and Winter (1982) and Dosi (1984) conceived of the status quo as a "technological trajectory" that increases gradually until a major advancement introduces a new trajectory (see also Sahal, 1980; Steindl, 1980). Tushman and Anderson (1986) presented empirical evidence of such development in three industries. They found that long periods of gradual technological change were occasionally interrupted by "technological discontinuities," which redefined the dominant technology of each industry, and Anderson (1988) found that organizational mortality rates were higher during these technological reorientations.

Overall, there is broad consensus that technological change causes competition as advancing organizations displace outdated ones. The idea is both intuitively appealing and empirically supported, so its popularity is not surprising. However, the history of the American telephone industry suggests that this view may not apply to all types of technological change.

COMPETITION, MUTUALISM, AND TELEPHONE TECHNOLOGIES

The American telephone industry expanded rapidly around 1896. Thousands of independent telephone companies were founded after two Bell Telephone Company patents expired, ending 15 years of patent monopoly (Danielian, 1939). By 1902, telephone companies numbered about 9,000 nationwide (U.S. Bureau of the Census, 1906), and by 1903 the independent companies controlled more of the market than did the Bell System (Brooks, 1976).

The two samples collected for this study reflect the national pattern. Figure 1a illustrates the population of telephone companies that operated in Pennsylvania at any time from the commercialization of the telephone in 1877 until 1934. Among the 707 organizations in this sample, 431 (61 percent) terminated operations by 1934. Figure 1b illustrates the timing of these deaths.

A secondary sample, illustrated in Figure 2a, includes the 298 companies that operated in southeast Iowa at any time from 1900 to 1930.[1] As Figure 2b illustrates, 129 (43 percent) of these organizations dissolved by the end of the period. As these samples illustrate, telephone companies faced a great danger of failure during the first decades of this century. Coincidentally, they faced an environment of dramatic technological development.

Technological Change

According to the historical record, two technological changes were especially important during this period. Transmission technology was revolutionized by the use of wire coils to increase the inductance of the transmission line. This innova-

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I am very grateful to Roy Atwood for making his dissertation data available for analysis and for directing me to the original Iowa tax documentation. His data included most of the companies in the Iowa sample region from 1900 to 1917. The entire sample was re-coded from the original data source for this study, to include additional variables and ensure uniformity in sampling procedures.

Figure 1a. Operating telephone companies in Pennsylvania.

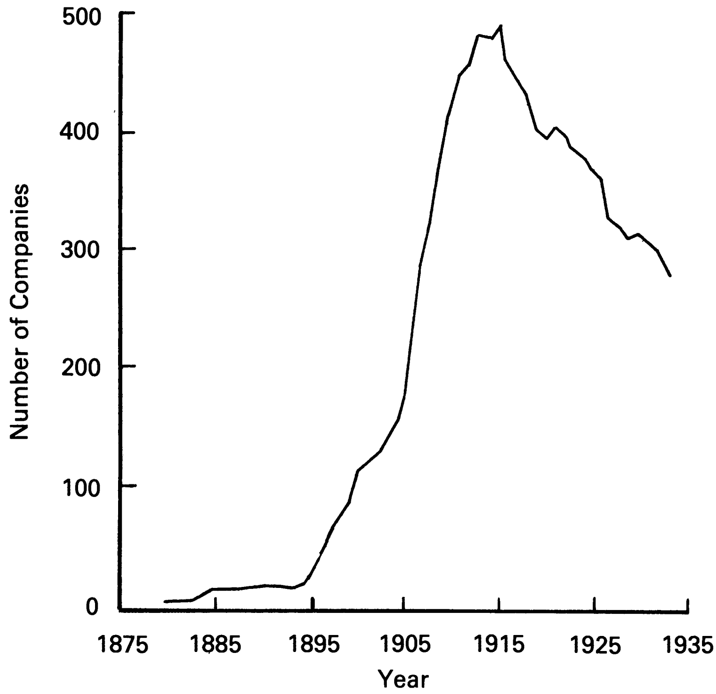
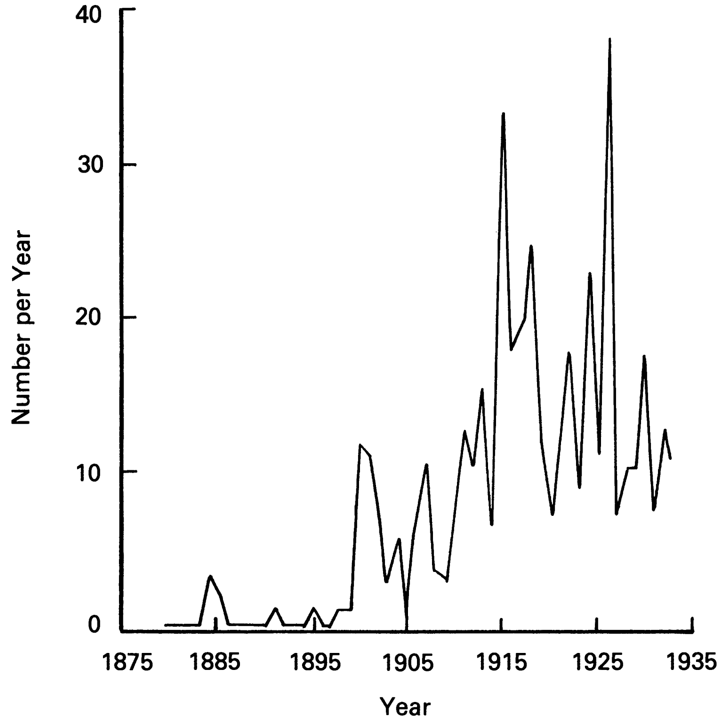


Figure 1b. Deaths of telephone companies in Pennsylvania.



tion, known as "line loading," reduced the proportion of the telephone signal wasted as heat energy during transmission. As a result of loading, the range of a central office increased from 30 to over 300 miles (Bell Labs, 1975). This develop-

Figure 2a. Operating telephone companies in southeast Iowa.

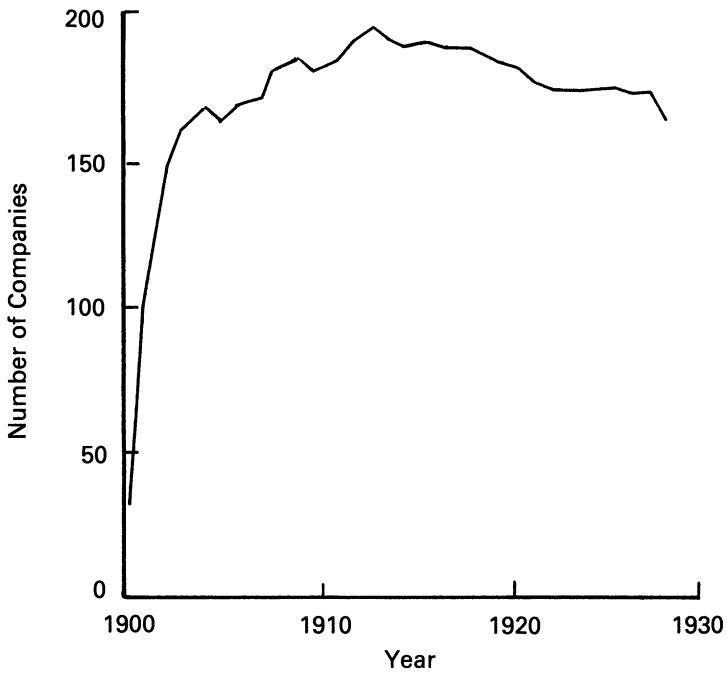
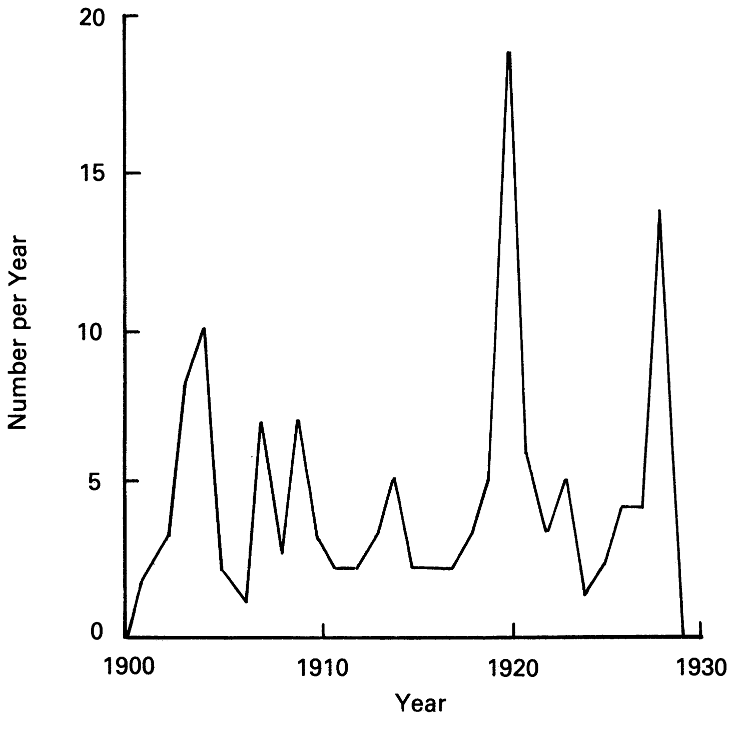


Figure 2b. Deaths of telephone companies in southeast Iowa.



ment made possible long-distance systems, as companies expanded their networks geographically to include multiple exchanges (Wasserman, 1985). This innovation was among the most important in the history of the industry because of its profound effects on the range, cost, and quality of service, as Wasserman (1985:5) explained:

> This change in the quality of the line profoundly altered the commerical development of long-distance communications; it lowered the cost of aerial cable lines because a lighter grade of wire could be used, and it extended the distance over which efficient transmission could take place. . . . Before loading, a Boston to Washington, D.C. cable was not even a remote possibility; with loading, the range of transmission was extended from some thirty miles to intercity distances of several hundred miles.

For the subscriber, line loading transformed the telephone from a limited way to contact neighbors to the most direct means available for communication over great distances. For the independent telephone company, it expanded the potential geographic markets of competitors. Literally overnight, a geographically isolated local company could encounter direct rivalry from a distant but innovative competitor. Consequently, many in the industry concluded at the time that this technology was crucial to organizational survival among the independents (MacMeal, 1934).

Over the same period, telephone power technology was radically changed by Hayes's "common battery," a power source located within the central office used for voice transmission among all telephones connected there (American Telephone and Telegraph, 1983). Before this innovation, each telephone instrument carried its own battery. This method was commonly referred to as the "magneto" system because of the hand-cranked magneto that supplied ringing current. Although it was adequate for limited networks, the magneto system faced serious standardization problems when combined into larger networks. The power level of transmitted signals had to be standardized to the resistance level of the central office switchboard. As a result, magneto instruments of different power levels could not be connected to one another (Homans, 1904). Furthermore, each instrument was only useful to the rest of the system if its battery was properly maintained by the subscriber. As a result, magneto systems often resulted in limited, low-quality service (Dunsheath, 1962).

By contrast, the common-battery system provided consistently high-quality service, since it was maintained within the central office (Dunsheath, 1962). Furthermore, because this technology provided power centrally, all telephones in the system were necessarily standardized to the same power level (Homans, 1904). Combined, these advantages made common-battery systems superior to magneto systems both in quality and extensiveness of service. In many cases, this superiority was critical to organizational survival. For example, memoranda found in the AT&T archives describe the strategic predicament of magneto companies plagued by incoherent voice transmission. When faced with direct competition from common-battery systems, these companies sometimes survived by relying on customer loyalty. Otherwise, they were forced either to abandon operations or to provide service at little or no charge until they could adopt common-battery power.[2]

Despite the clear merits of these new technologies, not all companies adopted them. From a Schumpeterian perspec-

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American Bell internal memo, October 24, 1895. Box 1156, AT&T Corporate Archives.

tive, this would help to explain the industry's high rate of organizational failure: Organizations adopting the innovations would outcompete—and displace—those that did not. To investigate this idea, I created graphs of the numbers of companies with each transmission or power technology in Pennsylvania over the study period. Figure 3a shows that after 1915, as the number of common-battery companies increased steadily, the number of magneto companies declined sharply. This suggests that the fates of these companies may have been inversely related, consistent with the idea that the superior technology displaced the inferior one.

In contrast, Figure 3b shows the proliferation of single-exchange companies compared to the spread of multi-exchange companies made possible by line loading.[3] Each type of organization proliferated and declined together over time, suggesting that the multi-exchange firms did not displace the single-exchange companies. To the contrary, organizations with primitive and advanced transmission capabilities appear to have shared the same fates.

How can these inconsistent patterns be explained, and how are they related to the industry's high failure rates? Judging by the institutional development of the industry, the answers depend on a logic other than technological displacement. A more appropriate logic would emphasize technological integration, since the industry changed over this period from a collection of autonomous competitors to rival networks made up of cooperating, technologically integrated companies.

Changing Patterns of Competition and Mutualism

Initially, the telephone industry comprised a large number of technologically separate price competitors. In part, this resulted from technological factors. Very early, telephone equipment was in short supply (MacMeal, 1934; Atwood, 1984). Companies often used whatever equipment they could obtain, regardless of whether it was consistent with any standard. The resulting incompatibilities often prevented companies from connecting their systems to other systems (MacMeal, 1934). This problem was made worse by the use of the often-incompatible magneto instruments. In fact, the early industry was so fragmented that head-on price competition between rival companies existed in nearly half of the nation's incorporated places by 1902 (Gabel, 1969).

Within the industry, many became concerned about coordinating these separate organizations. After the turn of the century, membership in two independent telephone associations grew rapidly, and in 1915 they merged into one national association. This helped the independents to coordinate regional long-distance networks (MacMeal, 1934). Meanwhile, in 1907 Bell policy changed to one of "systems awareness." Bell System companies began connecting with and selling equipment to the independent companies. And rather than engaging in price competition, they moved instead to acquire their direct competitors (Gabel, 1969).

Formal and informal public policy changes also encouraged coordination among these companies. Thirty-four states passed laws requiring the connection of proximate telephone systems (Barnett and Carroll, 1989). Often, these laws gave

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Ideally, one would distinguish companies according to whether or not they adopted line loading, but that information is not available. However, archival records do show which companies operated in only a single community versus those that operated multiple-exchange systems across geographically separated communities. Since the development of these multiple-exchange systems was made possible by line loading, this distinction was used as an indirect measure of the adoption of the innovation, as explained in the method section.

Figure 3a. Pennsylvania telephone companies by power technology.

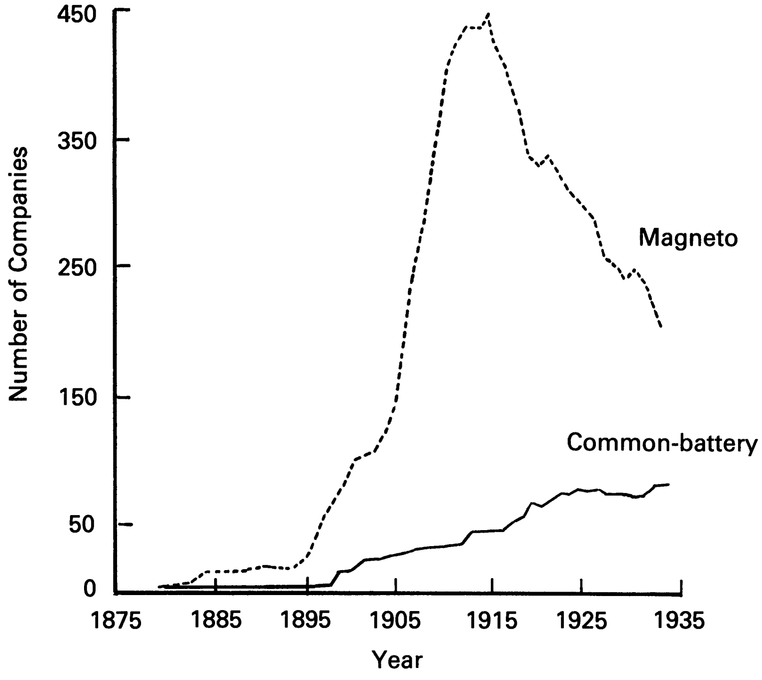
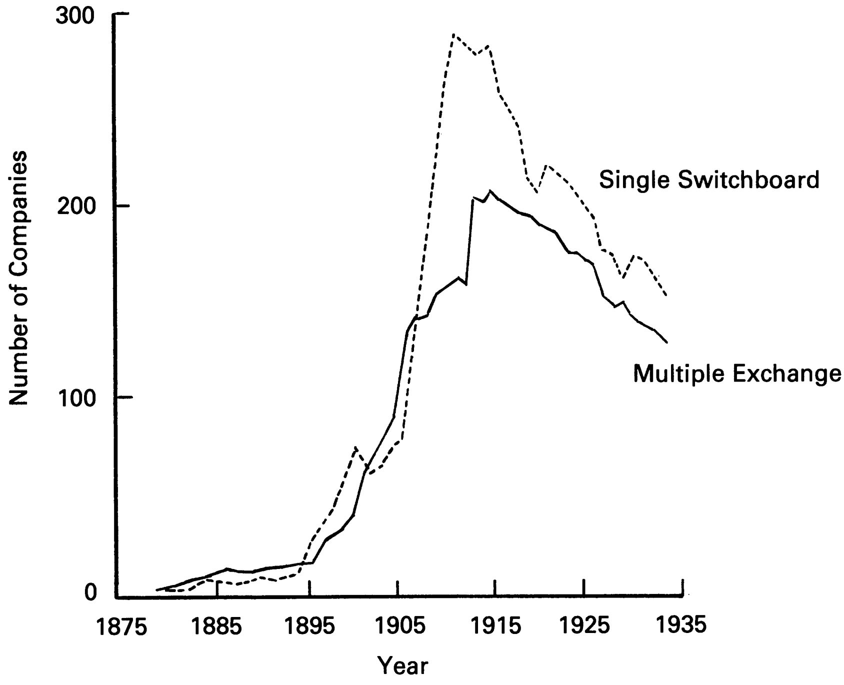


Figure 3b. Pennsylvania telephone companies by transmission technology.



local governments the ability to grant exclusive franchises for local telephone service (Lavey, 1987). And in 1913, the Bell System made the "Kingsbury Agreement" with the Department of Justice in order to avert antitrust action. Among other concessions, this agreement stated that Bell would connect its system to those of its direct competitors (MacMeal, 1934).

Together, these institutional changes helped to develop systems of legally separate but technologically integrated companies (U.S. Federal Communications Commission, 1938). In many cases, this meant that neighboring companies became mutualistic, increasing one another's survival chances by directly connecting their systems (MacMeal, 1934). However, diffuse mutualism—indirect positive interdependence among numbers of companies—also resulted, since geographically remote companies improved each other's viability by contributing to the viability of their common network (Barnett and Carroll, 1987). For example, it is well known that companies benefitted from direct connection to the large independent companies and the Bell System (MacMeal, 1934). However, large companies also generated diffuse mutualism, lowering the failure rates of companies that had only indirect access to them through the networks of other companies (Barnett and Amburgey, 1990).

Despite these developments, divisions remained throughout the telephone industry. Often, independent commercial firms formed networks with neighboring mutual companies but refused to connect to rival networks in adjacent areas (Atwood, 1984). In other cases feuds developed among companies, resulting in disconnections within networks (Atwood, 1984). In these ways, many companies remained disconnected from the wider telephone system, and their subscribers remained without long-distance service (Barnett and Carroll, 1987).

Indeed, while the formation of networks made price competition less prevalent (Gabel, 1969), it did not end competition in the industry altogether, as is commonly thought (e.g., Brooks, 1976; Phillips, 1985). Instead, competition changed form, resulting from several processes other than price rivalry: when companies acquired neighboring companies; when companies did not connect, reducing each other's viability by fragmenting the telephone system; and when networks themselves competed over service areas or access to other networks (Barnett and Carroll, 1987).

The American telephone industry thus emerged from a period of extreme organizational and technological volatility. Thousands of companies proliferated at the turn of the century, and many adopted revolutionary transmission and power technologies. However, competitive advantage did not appear to result simply from adopting these innovations. Rather, organizational viability depended on membership in viable technological systems. Sometimes competing and sometimes cooperating, these companies attempted to survive by forming networks. Nevertheless, by the 1930s most companies failed.

These events do not fit neatly into a Schumpeterian interpretation. Schumpeter had in mind markets in which all firms can engage in direct rivalry with one another (Schumpeter, 1950:85), and Schumpeterian models have been most powerful when applied to industries marked by such organization-level rivalry (e.g., Nelson and Winter, 1982; Tushman and Anderson, 1986). By contrast, the geographic network structure of the telephone industry severely limited direct rivalry between individual firms. Instead, the telephone industry evolved through a complex pattern of network interdependencies—mutualistic as well as competitive—with organization-level competition more the exception than the rule. Unfortunately, we lack an alternative perspective that can explain how technological change affects this type of industry. Ecological principles can be used, however, to create a perspective from which to interpret these events.

An Ecological View of Technological Interdependence

Organizational ecology provides both an operational method and a theoretical framework for the study of interdependence. Operationally, researchers have studied competition and mutualism using the "density-dependent" mortality model (Barnett and Carroll, 1987; Tucker et al., 1988; Carroll and Hannan, 1989; Delacroix, Swaminathan, and Solt, 1989). This model, originated by Hannan and Freeman (1988, 1989), permits organizational mortality rates to vary according to the number of organizations in the population. Under some conditions, an increase in density has a positive effect on mortality, indicating competition. Under others, an increase in density has a negative effect on organizational mortality. This indicates mutualism, where organizations improve one another's survival chances.

In a useful extension of this model, density is disaggregated to detect whether specific types of organizations generate competition or mutualism. For example, Hannan and Freeman (1988) disaggregated the density of national labor unions in order to model competition among and between craft and industrial unions. A similar approach was used in this study. Densities according to each type of technology were calculated. If the density of organizations with a specific technology increased failure rates, then there is evidence that those organizations generated competition. Conversely, if failure rates decreased as those organizations became more numerous, then there is evidence that they generated mutualism.

Hypotheses in this study were developed from Hawley's (1950:209) ecological framework. He argued that mutualism results from two different conditions: when units have supplementary similarities or complementary differences. I propose that among organizations, mutualism often results from their technological similarities and differences.

A systemic technology is made up of more elemental systems, some of which, referred to here as uniform, cohere on the basis of similarity throughout. This is the case with the telephone power system, which must be standardized to the same power level. Other elemental systems, referred to here as differentiated, cohere on the basis of complementary differences among components. The telephone transmission system is a differentiated technology; local service and long-distance technologies work together due to their complementary differences. This distinction can be used to predict when technological change in a systemic industry will lead to competition or to mutualism.

Uniform systems. Standardized organizations can work together in the same technological system. This type of relationship is common and is a major reason that each year firms voluntarily set and adhere to hundreds of thousands of industry standards (American Society for Testing and Materials, 1986). However, organizations not conforming to the same standard have incompatible technologies, so their products or processes cannot work together. In this way, organizations with incompatible technologies reduce each other's viability. In ecological terms, such organizations are said to compete. This issue is often discussed as if the standards themselves are in competition (e.g., David, 1985), however, it is a mistake to interpret the problem solely in terms of competing, substitutable standards. Especially early in an industry's development, competition may result from the lack of any standard. Nonstandardized organizations fragment an industry, making it less likely that any set of organizations can work together technologically. As a result, organizations throughout the industry are less viable than they would have been otherwise. In this way, organizations with nonstandardized technologies generate diffuse competition throughout a technological system.

In terms of the early telephone industry, this implies that the nonstandardized telephone companies—those with magneto power systems—generated competitive pressure on all telephone companies. Furthermore, because it resulted from fragmenting the entire telephone system, this competition should not have been limited in its effects to the vicinity of magneto companies. Rather, it would have been diffuse competition, affecting all companies regardless of geographic proximity to the magneto firms.

This prediction was tested by measuring the density of magneto companies. For each organization in the sample, this density was measured using two terms: *local density,* the number of magneto companies in its geographic area, and *nonlocal density,* the number of geographically distant magneto companies. If the logic of nonstandardization is correct, then the following hypothesis should be supported:

Hypothesis 1: The greater the density of magneto companies (both local and nonlocal), the higher the mortality rates of all telephone companies.

This hypothesis is consistent with the inverse patterns shown in Figure 3a. However, hypothesis 1 explains these patterns with a logic directly contrary to the logic of displacement. It was the primitive, nonstandardized technology that inhibited the advanced, standardized innovation. Consequently, not until the numbers of magneto companies declined did the common-battery companies proliferate.

Differentiated systems. For differentiated systems, a contrary line of reasoning is appropriate. In this case, differences brought on by technological change make organizations complementary. As a result, such organizations are mutualistic, increasing each other's viability. For example, computer hardware is a differentiated system, since hardware components are complementary. Consequently, as technological changes have spawned a greater variety of manufacturers, the population of such manufacturers as a whole has become more viable (Brock, 1975). However, organizations can be technological complements only if their uniform systems are standardized. In the previous example, computer-component producers must also be standardized to the same operating system for their technologies to be complementary. In another example, modern transportation systems are made up of a variety of complementary operations over rail, on roads, on water, and by air. Organizations that are dissimilar in this system work together, since each can compensate for an inability of another. Again, however, this relationship requires that the containers shipped by these organizations be standardized.

By contrast, when standardized organizations are not differentiated, they operate in the same part of the technological system. As a result, they are likely to compete (Hannan and Freeman, 1977). Transportation companies that conform to industry standards but are not differentiated (e.g., "piggyback" trucking companies) share a common technological niche. Consequently, these organizations are direct competitors.

Together, these arguments imply that among standardized organizations, both competition and mutualism will occur: Those that are differentiated will be mutualistic, but those that are not will compete. In the case of the telephone industry, this implies that both competition and mutualism occurred among the standardized, common-battery companies. The deciding factor was whether they were differentiated. Specifically, the multi-exchange companies are predicted to have competed among themselves, as were the single-exchange companies. But the relationship between these populations is predicted to have been mutualistic:

Hypothesis 2: Among the common-battery companies, the multi-exchange and single-exchange populations each increased its own mortality rate but decreased the mortality rate of the other.

This prediction is consistent with the patterns in Figure 3b. The population of multi-exchange companies did not displace the single-exchange population but, instead, appears to have shared its fate. According to hypothesis 2, this was due to their technological complementarity.

Ecological dominance. According to ecological theory, mutalism favors some populations more than others. This is because as differentiation occurs, some populations will operate in a more central part of the organizational community, while others will operate in more peripheral parts. The more central population is considered ecologically "dominant," since it coordinates and thereby controls the flow of resources into and through the community (Hawley, 1963; Lincoln, 1976). Applying this reasoning to technological differentiation extends hypothesis 2. In the early telephone industry, the multi-exchange companies coordinated the operations of each network. As a result, they should have been ecologically dominant, benefitting disproportionately from the positive relationship with the more peripheral single-exchange companies. Scarce human and physical capital, information about local markets, and rights-of-way could be obtained from the single-exchange companies. These resources would increase significantly the viability of the multi-exchange companies:

Hypothesis 3: In the mutualism predicted by hypothesis 2, the multi-exchange mortality rates would be reduced more than the single-exchange mortality rates.

If supported, this hypothesis strengthens an assertion made in an earlier study (Barnett and Carroll, 1987). In that paper, it was observed that commercially owned telephone companies were ecologically dominant; however, it was also asserted that this dominance resulted from centrality to the telephone network rather than from ownership form per se. Hypothesis 3 explicitly tests this assertion.

An Alternative Explanation: "Network Externalities"

An alternative view of technological interdependence has developed in neoclassical economics. From this approach, the salient feature of technological systems is that they display "positive consumption externalities" (Katz and Shapiro, 1985: 424). This means that the marginal utility of using such a technology increases with the number of other users. Adopting this perspective, Katz and Shapiro argued that technological compatibility determines whether firms are members of the same or of competing networks. Among organizations with compatible technologies, mutualism is predicted. But when organizations have incompatible technologies, competition is expected to result. This reasoning is consistent with hypothesis 1. However, it implies an alternative to hypothesis 2, predicting that mutualism existed among the common-battery companies without regard for differentiation:

Hypothesis 2_{alt}: The density of common-battery companies will decrease the death rates of all common-battery companies.

A comparison of hypotheses 2 and 2_{alt} reveals a subtle but critical difference between the ecological and economic approaches to this issue. Ecological theory identifies the importance of competition within and mutualism between environmental niches. Consequently, technological compatibility is not enough. As hypothesis 2 states, compatible organizations may either compete or be mutualistic, depending on whether they are in the same niche or in differentiated niches. Nonetheless, hypothesis 2_{alt} is a plausible alternative, and the network externalities perspective has been fruitfully applied to network price theory (Artle and Averous, 1975) and to the problem of new-subscriber membership (Oren and Smith, 1981). Rather than belabor its fundamental differences with the ecological view, I consider the empirical question of whether either approach can account for organizational survival.

METHOD

Sample

The life history of each telephone company in each sample region was recorded. Pennsylvania was selected for study because, among the more urban states, it had by far the lowest organizational size concentration in the industry. According to *Telephony's Directory,* Pennsylvania had between 30 and 40 companies of over 1000 subscribers and over 100 companies with more than 250 subscribers at all times between 1912 and 1935. Southeast Iowa was selected because of the availability of data on the geographic operating areas of these companies. This information distinguished companies that operated in the same counties from those that operated in different counties. This distinction permitted separate tests for direct interdependence between neighboring companies and diffuse interdependence among geographically removed companies.

Table 1 shows descriptive statistics for each of these sample populations. Although the Pennsylvania sample was the largest in number, the Iowa sample was remarkably big considering its smaller land area, the shorter sample period, and its sparse, rural settlement pattern. This, however, reflects the national pattern: Rural areas tended to have the largest numbers of telephone companies. According to *Telephony's Directory,* the state of Iowa has had the greatest number of telephone companies every year since just after the turn of the century.

Table 1

Descriptive Statistics for the Early Telephone Industry in Pennsylvania and Southeast Iowa

Descriptive statistics	Pennsylvania 1879–1934	Southeast Iowa 1900–1929
Organizational foundings	707	279
Organizational deaths	431	129
Total number of companies	707	298
Mutual companies	463	259
Commercial companies	244	39
Multi-exchange companies	289	19
De novo	191	14
By adoption	98	5
Single-exchange companies	516	288
Common-battery companies	131	15
De novo	38	11
By adoption	93	4
Magneto companies	669	292
Multi-exchange common-battery companies	100	9
Multi-exchange magneto companies	249	12
Single-exchange common-battery companies	38	8
Single-exchange magneto companies	506	287

In both samples, there was more than satisfactory variation of several organizational characteristics. Each had a large number of mutual companies, owned and often operated by their subscribers. A greater proportion of the Iowa sample was mutual companies, illustrating the strength of the mutual form in rural areas.

The two technologies under study, transmission and power, each had two forms during this period, which makes four technological combinations possible. As the table shows, companies of each variety existed in each sample, although the Pennsylvania sample was considerably more balanced. This suggests that the strongest tests of the hypotheses come from the Pennsylvania sample.

Sources

Most of the data are found in three sources. The primary source for Iowa is the *Annual Assessment of Telephone and Telegraph Companies of the State of Iowa* for each year from 1900 to 1930. This publication is an exhaustive census of companies, including those with less than one mile of line and only a few instruments. For Pennsylvania, one primary source is the *Annual Report of the Department of Internal Affairs, Part IV, Railroad, Canal, Navigation, Telegraph, and Telephone Companies,* which was published from 1874 (before the commercialization of the telephone) to 1917. This census is also exhaustive, including the very smallest companies. For the remaining years, the Pennsylvania telephone company census appears in the *Industrial Directory of the Commonwealth of Pennsylvania,* which was published in 1914, 1916, 1919, 1922, 1925, 1931, and 1935. For both states, *Telephony's Directory* was used for each year from 1907 through 1935. *Telephony's* is an industry directory that lists detailed information—including technological information—on telephone companies with more than 25 subscribers.

Variables

Vital events and organizational age: For Iowa, the year of founding or mortality is the first or last year a company is listed in the *Annual Assessment.* For Pennsylvania, the *Annual Report* lists the exact founding date for each company. For companies of over 25 subscribers founded after 1917, the first year of appearance in *Telephony's Directory* was considered their founding year. For a few extremely small companies founded after 1917, the *Industrial Directory* isolates their founding date to within two or three years. Mortality is recorded for the year of disappearance from all data sources. Organizational age was computed by subtracting the year of founding from the year of each observation.

Population density: Density was defined as the number of organizations in each sample area at the start of each year. Local density was computed separately for each organization for each year, calculated as the number of telephone companies within the organization's counties of operation. Nonlocal density was calculated as the number of telephone companies not operating in the same county or counties as a given organization.

Technological characteristics: A technological life history was recorded for each company in both samples. *Telephony's Directory* explicitly states which type of power technology was used by each firm in each year. However, because it does not tell whether companies did or did not use line loading in their transmission system, the adoption of line loading was measured indirectly. According to Bell Labs (1975), transmission systems without loaded lines were confined to a 30-mile range of the central office exchange. With this in mind, companies that operated multiple exchanges in communities more than 30 miles apart were considered multiple-exchange firms. Companies operating in only one community, or in geographically adjacent communities within a 30-mile radius, were considered single exchange. Nearly all companies began with remote (magneto) power and local transmission. But over time, many companies adopted or were founded with common-battery power or with multiple exchanges. *Telephony's Directory* is only available back to 1907. However, looking at the 1907 volume reveals that very few companies had adopted any of the more modern technologies by then. Thus, the left-censoring on technology adoption is very minor.

Organizational-level variables: Three types of companies appeared in the early industry: farmer lines, mutual systems, and commercial systems (Fischer, 1987). Commercial companies were organized in order to make profits. By contrast, the farmer lines were operated and owned by their subscribers, as were the cooperative mutual systems. Thus, companies are distinguished according to whether they were operated for profit or as cooperatives. On this basis, farmer lines are included with mutual systems, and companies are distinguished according to ownership form. *Organizational size* is recorded as the number of subscribers to each company in each year. Each data source includes a measure of subscribership.

Industry characteristics: Using this measure of organizational size, *industry size* was computed for each year for each sample area. Similarly, *market share variance* was computed for each year for each sample to capture the effects of industry concentration. Market share variance plus the reciprocal of density is the Herfindahl-Hirschman concentration index (Adelman, 1969).

Environmental factors: Population statistics, rural and urban, were found for both states in the decennial census. Urbanization was measured by urban population, indexed average wage per worker, and the number and average size of manufacturing establishments in each sample area. Also measured was the number of electrical equipment manufacturers in each sample area. This variable was used to reflect the availability of telephone equipment—vital to these companies, according to some historians (MacMeal, 1934). The census also provided information on the number of manufacturing workers, the average value of farm land and buildings, the number of farms, and the area of farmland. For the Pennsylvania sample, these variables were recorded at the state level. For Iowa, they were recorded separately for each of Iowa, Johnson, and Washington counties. In both samples, intervening years' data on all these variables are linearly interpolated. For multicounty companies in the Iowa sample, these variables were averaged across counties.

Different definitions of urban and rural populations were used for the two samples. For the Pennsylvania sample, the definition used was that from the decennial census. However, the Iowa sample had only one incorporated place considered urban by the census definition, Iowa City. Yet the entire sample area had a number of other incorporated places. These towns were the center of commerce for the area and, so, had a more highly concentrated population. To capture this fact, urban population was defined as the sum of the populations of each incorporated place for each county in the Iowa sample as listed in the decennial census. Rural population was then calculated as total population minus the population of incorporated places.

Model

Organizational mortality was modeled in terms of the instantaneous mortality rate. It is defined as

$$r_j(t) = \lim\, [q_j(t, t + \Delta t)/\Delta t],$$

where t is the age of organization j, q is the probability of j dying between t and $t + \Delta t$, and the rate r for j is allowed to vary as a function of t. Because it is explicitly time-dependent, the rate is especially appropriate for the analysis of organizational mortality, which has been found to vary as a function of age in a large number of populations (Freeman, Carroll, and Hannan, 1983; Carroll, 1983).

The rate was modeled using the generalized Gompertz specification:

$r_j(t) = \exp[\beta' X(\tau)] \exp[\gamma t]$.

In this model, γ represents the coefficient of organizational age (t), and $\beta' X(\tau)$ includes an intercept and the effects of the covariates. When appropriate, covariates were permitted to vary as a step function over calendar time (τ) by segmenting the life history of each organization into one-year intervals, with each segment treated as an observation in the statistical estimation; this permitted time-varying covariates to be updated from year to year. The Gompertz model separates the effects of age-dependence from the effects of the covariates in $X(\tau)$. And because it is exponential, the Gompertz model also has the advantage that it cannot yield meaningless, negative predicted rates.

Estimating the parameters of this model from the samples used here poses a problem, since 39 percent of the Pennsylvania sample and 57 percent of the Iowa sample remained in operation at the end of the study period. Because this problem, known as "right censoring," has been shown to result in biased estimates of the rate (Tuma and Hannan, 1984), the models were estimated using Tuma's (1979) maximum-likelihood program, RATE, which reduces right-censoring bias by modeling the cumulative survival time of censored cases (Tuma and Hannan, 1984).

The estimated parameters of several models are reported in the results, along with their estimated standard errors. To evaluate the statistical significance of each model as a whole, the likelihood-ratio X^2 is reported, comparing the model to a fully constrained model with only an intercept.

RESULTS

Baseline Model

There is evidence that density-dependent models may be very sensitive to specification error. In fact, both the direction and significance of density dependence have been shown to change when three types of factors are controlled: organizational characteristics, exogenous environmental characteristics, and characteristics of the organizational population other than density (Barnett and Amburgey, 1990). With this in mind, great care was taken to build a baseline model for each sample that controlled for these types of variables. To control for organizational characteristics, four variables were available and each was included in all models: organizational size in subscribers, commercial vs. mutual ownership, common-battery vs. magneto power technology, and single- vs. multi-exchange transmission technology.

For the environmental controls, separate urban and rural variables were modeled, since each of these markets developed within distinct resource constraints (Barnett and Carroll, 1987). Rural development was measured using rural population, indexed average farm value, the number of farms per sample area, and the average size of farms in each sample area. Urbanization was measured by urban population, indexed average wage per worker, the number and average size of manufacturing establishments in each sample area, and the number of electrical equipment manufacturers in each sample area.[4]

Finally, four variables describing the industry were then added to the model. Calendar year (measuring industry age) was added to control for institutional factors that increased mutualism in the industry over time, such as the development of company associations. A dummy variable for the post-1912 period was also added to control for the formation of networks due to the Kingsbury Agreement (and the 1912 Pennsylvania law requiring proximate systems to connect). However, models with both of these variables would not converge for either sample. Since the period dummy was not significant when modeled alone in either sample, but calendar year was, the calendar trend was retained in the baseline models.

The other industry characteristics were industry size and market share variance. Industry size has been found to reduce failure rates in these samples, reflecting greater mutualism generated by larger organizations (Barnett and Amburgey, 1990). Market share variance was modeled to capture the benefits of increasing network concentration over and above industry size.[5] However, this variable was retained only for the Pennsylvania sample, since it prevented convergence in the Iowa models.

Aggregate density was then added to the models both in the quadratic and as a monomial. As shown in Table 2, the main effect of density was nonsignificant in the quadratic specifications for both samples. Without the squared density terms, models 2 and 4 indicate that overall density dependence in both samples was competitive and strictly monotonic.

According to the hypotheses, these aggregate density effects conceal differing technology-based patterns. To investigate this, the density measures were disaggregated according to technology and the models were re-estimated, beginning with a test of the fragmentation hypothesis.

Fragmentation

Hypothesis 1 predicted that the nonstandardized magneto companies generated competition affecting all telephone companies. As Table 3 indicates, this hypothesis was strongly supported. Models 5 and 6 show that statistically significant competition was generated by the magneto companies in both samples. In contrast, the more sophisticated common-battery companies did not generate a significant density effect in either sample.

According to hypothesis 1, the competition from magneto companies resulted because they fragmented the telephone system as a whole. Consequently, each company's survival should have been threatened by competition from both neighboring and geographically removed magneto companies. Model 7 tests this prediction on the Iowa sample by further disaggregating each density into local density and nonlocal

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Unfortunately, estimates of the mortality rate models would not converge for either sample when all of these variables were included together. Consequently, each environmental variable was retained only if it was statistically significant when modeled individually or in conjunction with other variables. Because it was inductive, this approach may have exaggerated the overall statistical significance of the baseline model. However, it should also have resulted in less-biased estimates of competition and mutualism, since the coefficients of density were less likely to be spuriously affected by significant but uncontrolled factors.

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The ideal control variable would indicate whether or not a company's system was connected to those of other, large companies, especially to the Bell System. Unfortunately, an exhaustive search of library records, FCC records and data, archival data at the AT&T Corporate Archives in New York, and the holdings of the Telephony Publishing Company in Chicago failed to uncover such data for the study period. The only data found were cross-sectional for isolated years, and even those data did not include information on small telephone companies. For this reason, the survival advantages due to interconnection can only be controlled indirectly using the time trend, the period effect, industry size, and market share variance.

Table 2

Baseline Gompertz Models of the Mortality Rate*

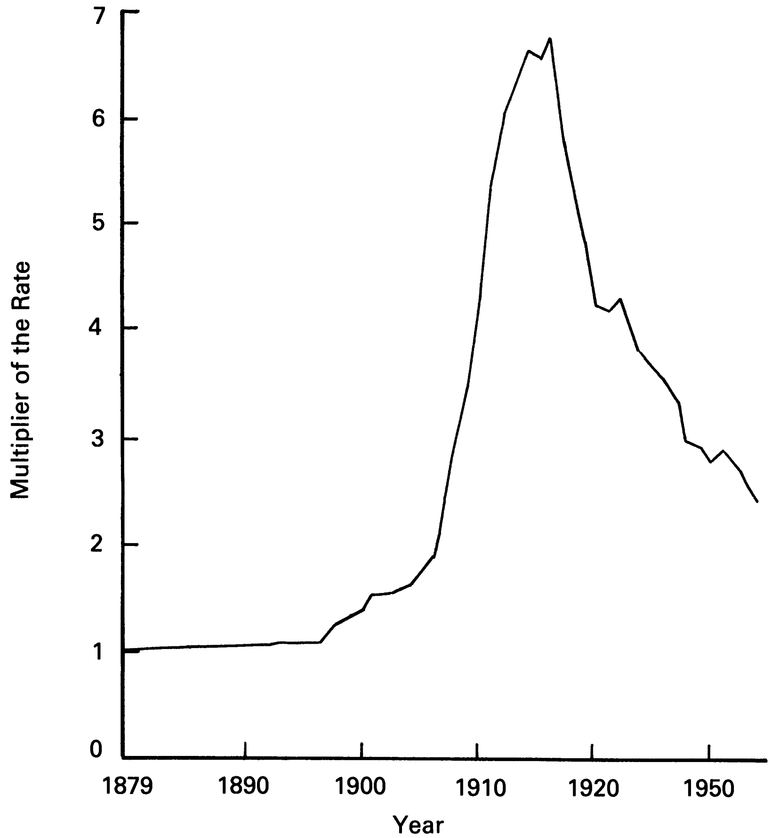
Independent variable	Iowa sample Model (1)	Iowa sample Model (2)	Pennsylvania sample Model (3)	Pennsylvania sample Model (4)
Constant	10.11	7.200•	3.394	3.928
	(6.157)	(3.145)	(2.856)	(2.774)
Organizational age	.0078	.0079	.0475•	.0484•
	(.0154)	(.0154)	(.0086)	(.0086)
Organizational size/1000	−1.340	−1.336	−.0014	−.0014
	(.7997)	(.7987)	(.0013)	(.0013)
Commercial	.8612•	.8598•	−.4036•	−.4132•
	(.2988)	(.2984)	(.1147)	(.1146)
Multi-exchange	−.1029	−.1026	−.2912•	−.2961•
	(.4655)	(.4657)	(.1104)	(.1104)
Common-battery	−.5805	−.5814	−.1886	−.1909
	(.6621)	(.6622)	(.1625)	(.1625)
Calendar year	−.0023	−.0015	−.0264	−.0134
	(.0039)	(.0039)	(.0667)	(.0696)
No. of farms†	−.0043•	−.0042•	.0105	.0107
	(.0016)	(.0015)	(.0064)	(.0061)
Mean farm value	−.0033	−.0026		
	(.0022)	(.0018)		
No. of manufacturing establishments	.0227•	.0219•	−.0001	−.0001
	(.0113)	(.0112)	(.0001)	(.0001)
No. of electrical equipment manufacturers			.0317•	.0283•
			(.0113)	(.0125)
ln (market size)	−.7816•	−.7461•	−.4987•	−.8200•
	(.1991)	(.1876)	(.2304)	(.1662)
Market share variance			−5.512•	−3.601•
			(1.643)	(1.506)
Density	.0097	.0390•	−.0096	.0039•
	(.0535)	(.0162)	(.0053)	(.0012)
$(\text{Density})^2/1000$	.1070		.0916•	
	(.1963)		(.0076)	
X^2	37.37	37.11	97.26	90.62
Df	12	11	13	12
Dissolutions	129	129	431	431
Censored cases	169	169	276	276
Total 1-year spells	5071	5071	11842	11842

• $p < .05$.
* Standard errors are in parentheses.
† The number of farms was divided by 1000 in the Pennsylvania sample.

density. The results offer convincing support for the hypothesis, with nearly identical competitive effects generated by local and nonlocal magneto density. As predicted, the magneto companies generated diffuse competition, felt by other organizations regardless of their geographic proximity.

Whether this competition was substantively important depends on the level of analysis used to interpret the results. Thinking at the organization level, the magneto density effect was not exceptionally large. Based on model 5, one additional magneto company in the Pennsylvania sample caused failure rates to be only .004 times higher than they would have been otherwise. However, when considered as a population, the magneto companies had a much more substantial competitive effect. As Figure 4 illustrates, failure rates in the Pennsylvania sample were considerably higher over the period as a result of the combined competition generated by all magneto companies in the state. In fact, by 1915 the hazard rate

Figure 4. Estimated effects of magneto density on organizational mortality, Pennsylvania sample.



was accelerated to nearly seven times what it would have been otherwise because of competition from the magneto companies.[6] Seen at the population level, technological fragmentation generated substantial competitive pressure.

Competition, Mutualism, and Standardization

According to the results in Table 3, the standardized, common-battery companies were competitively ineffectual. However, hypothesis 2 predicted that common-battery companies actually generated both competition and mutualism (but only among themselves), depending on whether or not they were differentiated. Alternatively, the network externalities hypothesis (2_{alt}) predicted mutualism among the common-battery companies regardless of differentiation. This prediction was tested first, but with data only from the Pennsylvania sample, since too few organizations in the Iowa sample had adopted common-battery technology during the period to permit a test. The models reported in Table 4 isolate the effects of common-battery and magneto density. Each density term was modeled as a main effect and also interacted with the common-battery dummy variable. As models 9 and 10 indicate, common-battery density did not affect other companies uniformly. Its main effect remained nonsignificant, while its interaction with the common-battery dummy variable was positive and statistically significant. Directly contradicting the network externalities hypothesis, this

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In a Gompertz model, covariates are assumed to be exponentially related to the death rate. To determine precisely the substantive effect of an estimate at any value of a covariate, the estimated coefficient must be multiplied by that value and then exponentiated. The result represents the multiplicative increase or decrease in what the estimated death rate would have been without the effect.

Table 3

Gompertz Models of the Mortality Rate; the Effects of Density by Power Technology*

Independent variable	Pennsylvania sample Model (5)	Iowa sample Model (6)	Iowa sample Model (7)
Constant	5.460	8.036•	8.124•
	(3.024)	(3.297)	(3.361)
Organizational age	.0486•	.0079	.0071
	(.0086)	(.0154)	(.0155)
Organizational size/1000	−.0014	−1.346	−1.352
	(.0013)	(.7991)	(.8101)
Commercial	−.4155•	.8681•	.8509•
	(.1146)	(.2989)	(.3004)
Multi-exchange	−.3006•	−.1084	−.1084
	(.1104)	(.4666)	(.4666)
Common-battery	−.1935	−.5737	−.6216
	(.1625)	(.6627)	(.6655)
Calendar year	−.1312	.0787	.0829
	(.1128)	(.0775)	(.0781)
No. of farms	.0120•	−.0042•	−.0042•
	(.0061)	(.0015)	(.0016)
Mean farm value		−.0032	−.0033
		(.0019)	(.0020)
No. of manufacturing establishments	−.0001	.0214	.0214
	(.0001)	(.0112)	(.0114)
No. of electrical equipment manufacturers	.0395•		
	(.0156)		
ln (market size)	−.6415•	−.9436•	−.9458•
	(.2096)	(.2601)	(.2606)
Market share variance	−2.370		
	(1.751)		
Magneto density	.0043•	.0375•	
	(.0013)	(.0164)	
Common-battery density	.0200	−.1676	
	(.0118)	(.1739)	
Local density, magneto			.0384•
			(.0166)
Nonlocal density, magneto			.0373•
			(.0167)
Local density, common-battery			−.1612
			(.1749)
Nonlocal density, common-battery			−.1989
			(.1867)
X^2	92.51	38.56	38.97
Df	13	12	14
Dissolutions	431	129	129
Censored cases	276	169	169
Total 1-year spells	11842	5071	5071

• $p < .05$.
* Standard errors are in parentheses.

indicates that the standardized, common-battery companies generated competition among themselves.

In addition, the main effect of common-battery density remains nonsignificant with or without the interaction terms in the model. Despite their technological superiority, the common-battery companies do not appear to have generated competition for the less-sophisticated magneto firms. Instead, the common-battery companies increased failure rates only among themselves.

Furthermore, these models reveal an unexpected relationship between competitive hazard and the organization-level effects

Table 4

Gompertz Models of the Mortality Rate, Pennsylvania Sample*

Independent variable	Model (8)	(9)	(10)
Constant	5.557	5.382	5.486
	(3.020)	(3.023)	(3.016)
Organizational age	.0481•	.0479•	.0474•
	(.0086)	(.0087)	(.0087)
Organizational size/1000	−.0014	−.0014	−.0014
	(.0013)	(.0013)	(.0013)
Commercial	−.4163•	−.4183•	−.4194•
	(.1147)	(.1144)	(.1145)
Multi-exchange	−.3026•	−.2909•	−.2920•
	(.1105)	(.1103)	(.1104)
Common-battery	−.7847	−1.376•	−2.692•
	(.5558)	(.6403)	(1.272)
Calendar year	−.1335	−.1341	−.1349
	(.1127)	(.1125)	(.1123)
No. of farms/1000	.0120•	.0124•	.0125•
	(.0061)	(.0061)	(.0061)
No. of manufacturing	−.0001	−.0001	−.0001
establishments	(.0001)	(.0001)	(.0001)
No. of electrical equipment	.0402•	.0402•	.0410•
manufacturers	(.0156)	(.0155)	(.0155)
ln (market size)	−.6355•	−.6332•	−.6280•
	(.2096)	(.2099)	(.2098)
Market share variance	−2.362	−2.359	−2.332
	(1.750)	(1.752)	(1.751)
Magneto density	.0041•	.0044•	.0042•
	(.0013)	(.0013)	(.0013)
Common-battery density	.0197	.0189	.0176
	(.0118)	(.0118)	(.0118)
(Magneto density)	.0020		.0034
× (common-battery)	(.0018)		(.0024)
(Common-battery density)		.0191•	.0239•
× (common-battery)		(.0096)	(.0117)
X^2	93.81	97.05	99.29
Df	14	14	15

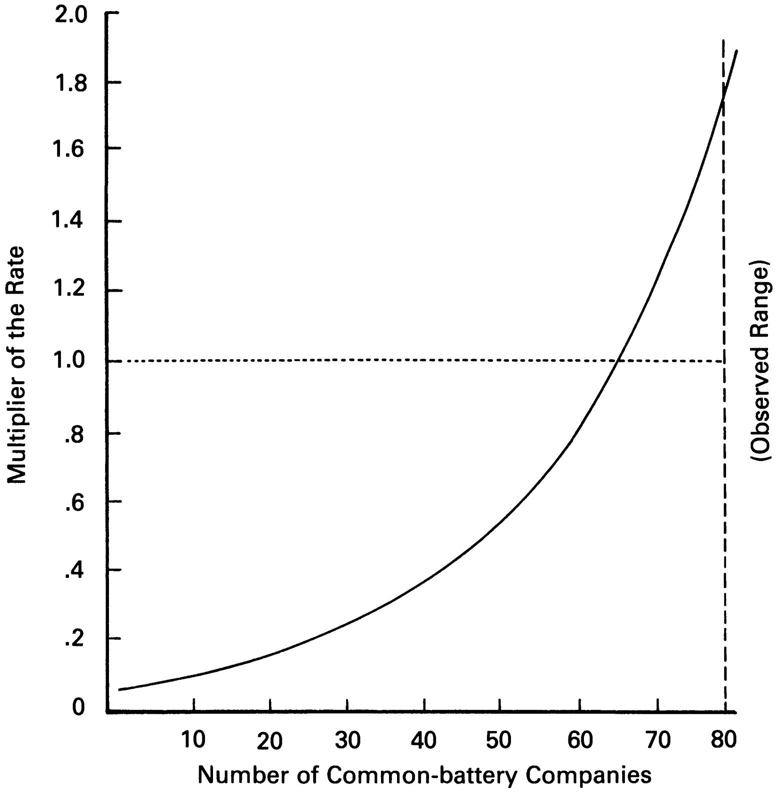
• $p < .05$.

* There were 431 deaths, 276 censored cases, and 11,842 total one-year spells. Standard errors are in parentheses.

of common-battery power. The main effect of the common-battery dummy variable is not significant until the interaction is included in models 9 and 10. This means that controlling for competition within their niche, common-battery companies had a significantly lower failure rate than magneto companies, but their survival advantage was concealed in model 8, which did not control for being in a hazardous niche.

Figure 5 illustrates the importance of this hazard. It combines two effects from model 10: the common-battery dummy variable effect (capturing the relative survival advantage intrinsic to these companies) and the common-battery density interaction (capturing competition among common-battery companies). By combining these effects, this figure shows how the relative survival advantage of a common-battery company was offset by competition in its niche. Initially, a common-battery company had a failure rate 94 percent lower than a magneto company, but after only 65 common-battery companies existed, this advantage was fully offset by niche competition. And at the maximum observed common-battery

Figure 5. Estimated effect of common-battery density on common-battery death rates, Pennsylvania sample.



density of 79, these companies are predicted to have had a failure rate almost twice than would otherwise have been the case. In this way, the common-battery companies generated for themselves a hazard that more than outweighed their intrinsic survival advantage. However, hypothesis 2 suggests that this result conceals two opposing effects. Competition should have occurred only among companies that were not differentiated: among single-exchange companies and among multi-exchange companies. Between these differentiated populations, however, mutualism should have occurred. To test this, the models shown in Table 5 estimate the effects of technological differentiation among only the standardized, common-battery companies. These models include separate densities for single- and multi-exchange companies, along with density interactions. They are estimated on a subset of the data that includes only common-battery companies.

The specification in model 14 includes both the main and the interaction effects of the density terms. Dropping the nonsignificant control variables results in model 15, which is a statistical improvement over model 14. In both models, the interaction effects support hypothesis 2. Among the common-battery companies, multi-exchange density reduced the relative death rates of single-exchange companies.[7] Similarly, single-exchange density reduced the relative death rates of multi-exchange companies. As suspected, standardized but differentiated telephone companies were mutualistic.

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The interaction term (common-battery/multi-exchange density) × (multi-exchange) can be interpreted as the relative effect of multi-exchange density on single-exchange companies. This effect is simply the converse of the estimated coefficient, since single-exchange companies are the omitted category in the dummy variable. Thus the relative effect of multi-exchange density on single-exchange companies as estimated in model 15 is −.2318, in the direction predicted by hypothesis 2.

Table 5

Gompertz Models of the Mortality Rate among Common-Battery Companies, Pennsylvania Sample*

Independent variable	Model (11)	(12)	(13)	(14)	(15)
Constant	14.38	14.95	15.54	12.00	18.39•
	(33.16)	(33.21)	(33.14)	(33.57)	(8.873)
Organizational age	.0283	.0241	.0267	.0258	.0264
	(.0244)	(.0245)	(.0245)	(.0243)	(.0245)
Organizational size/1000	−.0043	−.0040	−.0042	−.0040	−.0040
	(.0056)	(.0053)	(.0056)	(.0053)	(.0052)
Commercial	−.2097	−.2199	−.2146	−.2181	−.2299
	(.3240)	(.3213)	(.3229)	(.3221)	(.3222)
Multi-exchange	.0374	−3.816•	−.9092	−6.054•	−7.930•
	(.3678)	(1.572)	(.9954)	(2.190)	(2.349)
Calendar year	−1.070•	−1.048•	−1.072•	−1.054•	−.4041•
	(.4648)	(.4642)	(.4640)	(.4662)	(.1367)
No. of farms/1000	.0289	.0297	.0292	.0311	
	(.0271)	(.0273)	(.0272)	(.0279)	
No. of manufacturing establishments	−.0008•	−.0008•	−.0008•	−.0008•	−.0003•
	(.0004)	(.0004)	(.0004)	(.0004)	(.0001)
No. of electrical equipment manufacturers	.1109•	.1018	.1103•	.0936	
	(.0515)	(.0524)	(.0515)	(.0547)	
ln (market size)	1.345	1.510	1.339	1.944	
	(1.851)	(1.853)	(1.852)	(1.888)	
Market share variance	−.1660	−.1945	−.2080	−.3670	
	(4.852)	(4.839)	(4.847)	(4.815)	
Common-battery multi-exchange density	.1853•	.1225	.1842•	.0252	−.0212
	(.0886)	(.0920)	(.0885)	(.1096)	(.0549)
Common-battery single-exchange density	.1270	.1334	.0738	.3523•	.2638•
	(.0876)	(.0882)	(.1042)	(.1489)	(.1279)
(Common-battery multi-exchange density) × (multi-exchange)		.0751•		.1878•	.2318•
		(.0307)		(.0712)	(.0738)
(Common-battery single-exchange density) × (multi-exchange)			.0687	−.2560•	−.2855•
			(.0699)	(.1300)	(.1302)
X^2	31.41	37.05	32.31	40.93	33.40
Df	12	13	13	14	10

• $p < .05$.

* There were 52 deaths, 79 censored cases, and 1,692 total one-year spells. Standard errors are in parentheses.

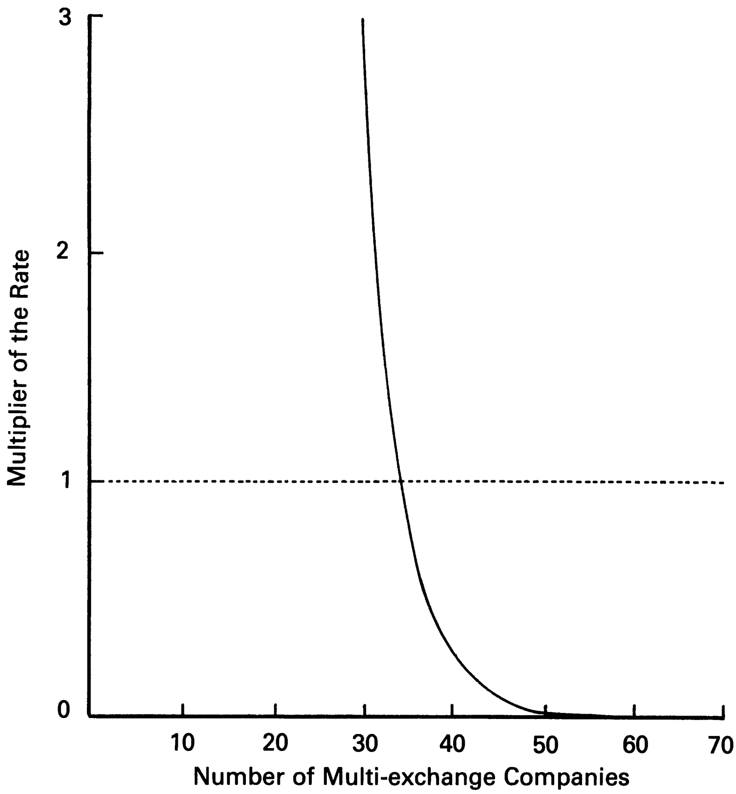
By contrast, in models estimated on the entire sample (not shown), the single- and multi-exchange companies were found to have increased each other's relative death rates. Without accounting for standardization, the mutualism effect in model 15 becomes competitive. Taken together, these results indicate that neither technological standardization nor technological differentiation alone are enough. As hypothesis 2 stipulates, both must be modeled together for mutualism to be detected.

Because they measure relative effects, the interactions in Table 5 also capture competition among single-exchange companies and among multi-exchange companies. This competition appears to have been especially strong among the multi-exchange companies. In models 11 and 13, which do not include the (multi-exchange density) × (multi-exchange) interaction term that controls for competition among multi-exchange companies, the dummy variable for these companies is nonsignificant. Yet in models 12, 14, and 15, which do control this competition, the multi-exchange dummy is strongly negative and significant. Apparently, competition among the multi-exchange companies concealed their lower relative death rates. This is the exact pattern of results found for all common-battery companies in Table 4. But as hypothesis 2 predicted, competition was not among all common-battery companies, but only among those that were not differentiated, especially the multi-exchange companies.

Figure 6 illustrates the importance of these effects, and the counterintuitive nature of hypothesis 2. Based on model 15, it plots the effect of the multi-exchange population on the hazard faced by a single-exchange company. Initially, the single-exchange company had a very high relative mortality rate (according to the dummy variable). But the proliferating multi-exchange companies quickly eliminated this disadvantage. As the thirty-fifth multi-exchange company appeared, the single-exchange company's initial disadvantage was completely offset, and above that point, the advanced multi-exchange companies caused the technologically primitive single-exchange company to have a relative survival advantage.

Finally, hypothesis 3 was tested by comparing the mutualistic effects between the single- and multi-exchange companies. According to this hypothesis, the multi-exchange companies were ecologically dominant and so should have benefitted more than the single-exchange companies from this mutualism. Based on the interaction effects in model 15, the mutualism generated by a single-exchange company for a multi-exchange company was exp[.2855]. As predicted, this was greater than the mutualism generated by a multi-exchange firm for a single-exchange company, estimated to have been

Figure 6. Relative effect of multi-exchange density on single-exchange death rates (standardized firms).



exp[.2318]. However, the difference between these estimates was not statistically significant at the .05 level, so support for hypothesis 3 is only suggested.

DISCUSSION AND CONCLUSION

These findings strongly support the ecological approach to technological interdependence. Both dimensions emphasized by the theory—standardization and differentiation—helped determine when early telephone companies would compete and when they would be mutualistic. For mutualism to occur, these organizations had to be both standardized and differentiated, and when competition developed, it was because organizations were either incompatible or noncomplementary.

In particular, hypothesis 1 predicted that the nonstandardized, magneto companies generated competition because they fragmented the telephone system. This hypothesis was supported with data from both samples. In fact, the strongest source of technological competition found in the study was not a large, advanced firm but the large population of small organizations with primitive magneto-power technology. Furthermore, because fragmentation affected the telephone system as a whole, this effect was felt by companies regardless of geographic proximity.

Concentrating on the standardized, common-battery companies, hypothesis 2 predicted both mutualism and competition. Mutualism was expected between the single- and multi-exchange populations because they were technologically complementary. However, within each population competition was expected, since members of each operated within the same parts of the technological system. This hypothesis was supported: Single- and multi-exchange companies decreased each other's failure rates while increasing their own. Furthermore, these patterns were found only when both standardization and differentiation were modeled together. Ignoring standardization, differentiated companies appeared to compete. And without considering differentiation, only competition was found among standardized companies, contrary to the network externalities hypothesis. When both dimensions were modeled together, however, mutualism as well as competition was revealed.

Hypothesis 3 expanded on hypothesis 2, speculating that the multi-exchange companies were ecologically dominant compared to the single-exchange companies, since they coordinated and controlled information and resource exchange in the industry. Consequently, it was predicted that the multi-exchange companies would benefit more than would the single-exchange companies from their mutualistic relationship. Support for this hypothesis was only suggested, since the results were as predicted but were not statistically significant.

Taken together, these findings demonstrate that technological advancement should not be equated unthinkingly with competitive advantage. The most technologically advanced companies in this study—those with multiple exchanges and common-battery power—actually reduced the death rates of the primitive, single-exchange companies. Ironically, this meant that a single-exchange company was at a competitive advantage when surrounded by more advanced, multi-exchange firms. Furthermore, it meant that a single-exchange company that changed its technology—adopting the transmission system required for multiple exchanges—increased its death rate substantially. Although as a multi-exchange company it had a lower intrinsic death rate, the intense competition from other multi-exchange companies quickly outweighed this advantage. When the multi-exchange company was advantaged at all, it was not because of its technology's intrinsic benefits, but because of its mutualistic relationship with the population of single-exchange companies.

Taken together, these results show that technological change affects systemic industries in ways not predicted by the Schumpeterian model. Because of their network structure, systemic industries—telecommunications, airlines, railroads, microcomputers—evolve in ways not discussed by Schumpeter. In such industries, mutualism among complementary organizations limits the importance of organization-level rivalry—the kind of rivalry that concerned Schumpeter. As a result, technological reorientation may be less important to such industries than are technological complementarity and uniformity.

It should not be concluded, however, that Schumpeterian dynamics never occur in systemic industries or that the ecological perspective explains all changes in such industries. To the contrary, systemic industries often experience dramatic technological reorientations that do not affect standards or patterns of differentiation. We should expect that such changes will trigger Schumpeterian dynamics, with effects that depend on whether the competencies of existing companies are enhanced or destroyed (Tushman and Anderson, 1986). For example, long-distance microwave transmission became commercially viable during the 1940s. By then, the telephone industry had been fully differentiated into long-distance and local niches, so the innovation did not increase complementarity. It did, however, threaten existing companies that were distinctly competent at land-based long-distance transmission, especially the Bell companies. As a result, the diffusion of microwave transmission was slowed by the strategic resistance of established firms, but the technology eventually provided an opening for entrants into the modern, deregulated telephone system (Brock, 1981). As this example illustrates, one should observe boundary conditions when studying the effects of technological change. The Schumpeterian perspective can be fruitfully applied to systemic industries, including the telephone industry. However, Schumpeter's model was not intended for changes that primarily affect technological uniformity or differentiation. For changes of this kind, the theory presented here should have predictive power.

Additionally, this study demonstrates how population-level thinking is important to understanding the effects of technology. Ordinarily, technology is thought of as an organizational characteristic. But an organization's technology also helps to define its niche and, therefore, the competition it faces. For this reason, technology measured as an organizational characteristic had little effect in this study until competition in the technological niche was controlled. Then it was clear that technologically advanced companies were inherently more viable but that they also faced considerably more competition. Evidently, the population-level effects of technology had to be controlled before its organization-level effects could be detected.

Overall, these findings suggest how technological change can be incorporated into the ecological theory of organizational adaptation. Thus far, researchers have been concerned with predicting when organizational changes are disruptive or adaptive (Hannan and Freeman, 1984; Singh, House, and Tucker, 1986). This study suggests that whether technological change is adaptive depends on the combination of two opposing effects. The benefits of the organization's technological improvement must be weighed against the hazard of entering a niche occupied by other technologically advancing organizations. Whether or not technological change is adaptive depends on which of these two effects is stronger.

These findings also raise a question about the advantages of dominance. In most current conceptions—especially in the network literature—dominance is considered an organization-level property, and the dominant organization is considered advantaged over other organizations in the network. But from a population perspective, dominance also implies operation in the dominant niche and, therefore, the hazard of competition from other dominant organizations. In the early telephone industry, this hazard was so great that a member of the dominant population was not necessarily more viable than were peripheral organizations. Defined at the population level, dominance implies hazard as well as advantage.

More generally, the theory and findings of this study suggest that a community-level perspective can help us to understand the development of systemic industries. In an earlier work, it was shown that competition among telephone companies occurred at two levels: at the community level between networks of organizations and at the organization level among members of common networks (Barnett and Carroll, 1987). This study reveals that the industry's technological structure was responsible for those dynamics. However, this study was of a very young industry. In more mature industries the problem of multiple, competing standards arises. I suggest that a community-level view may also help to analyze this problem. Community-level competition can be expected to occur between competing standards, while organization-level competition should take place within standards. The former competition should be felt by all organizations on a common standard. The latter competition, meanwhile, should occur only between organizations that share a common standard but are not differentiated.

This study was limited to competition and mutualism in terms of organizational mortality, but ultimately, technological change is important because of what it initiates and expands, rather than what it ends. For this reason, the full value of these ideas depends on whether they can also explain the technological sources of organizational founding and growth.

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