THE CO-EVOLUTION OF TECHNOLOGY

AND INDUSTRIAL CLUSTERS:

THE RISE AND FALL OF THE AKRON TIRE CLUSTER

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ABSTRACT

Strategy scholars argue that industrial clusters foster technical innovation, citing examples such as Silicon Valley. Leading firms embedded in once-innovative clusters, such as Detroit's automobile manufacturers and Switzerland's watch makers, have failed to adapt to competitive changes and been accused of organizational inertia. This paradox raises two related questions: how do industrial clusters contribute to inertia as well as innovation, and how might industrial clusters evolve to promote inertia rather than innovation. This paper presents findings from a historical analysis of the American tire industry concentrated in Akron, Ohio from its inception in 1900 to its demise in the late 1980s. The tire industry was among the most innovative sectors in the U.S. economy between 1900 and 1935, providing dramatic improvements in both product performance and manufacturing process efficiency, and Akron-based firms accounted for most of this innovation. Faced with the introduction of radial tire technology pioneered by French tire maker Michelin, however, the Akron tire companies faltered in the 1970s and 1980s, and in the span of eighteen months, three of the four Akron tire manufacturers ceased to exist as independent corporations. This paper presents a framework grounded in the historical data, that suggests that geographic co-location facilitates knowledge spillovers, but the value of these spillovers decrease as the technology matures. The cost of geographic co-location increases, however, as the cluster's shared cognitive models assume a taken-for-granted quality. The institutionalization of organizational routines leaves the cluster vulnerable to environmental jolts.

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THE CO-EVOLUTION OF TECHNOLOGY AND INDUSTRIAL CLUSTERS: THE RISE AND FALL OF THE AKRON TIRE CLUSTER

Industrial clusters have recently emerged as an important topic for both scholars and policy makers (Porter, 1990). Porter (1998:199) defines an industrial cluster as "a geographically proximate group of interconnected companies and associated institutions in a particular field, linked by commonalties and complementarities," and argues that clustering can spur innovation. Examples of innovative clusters include financial services in New York and London, electronics in Silicon Valley (Saxenian, 1996), film production in Hollywood (Faulkner & Anderson, 1987), machine tools in Sakaki Township in Japan (Friedman, 1988), and the aerospace electronics complex in Southern California (Scott, 1991). Despite the advantages they derive from geographic proximity, cluster members may also be more prone to inertia than organizations outside a cluster (Porter, 1998:243; Pouder & St. John, 1996), and the possibility of cluster inertia is supported by historical evidence from the Pittsburgh steel cluster (Hall, 1997), Detroit's automotive industry (Abernathy, 1978; Helper, 1990), minicomputer firms located in the Route 128 area (Saxenian, 1996:18), and once-dominant clusters including cotton textiles in Lancashire (Lazonick, 1981), specialty steel in Sheffield (Lloyd-Jones & Lewis, 1994), copper smelting in Swansea, Wales (Newell, 1990), and watch making in Jura, Switzerland (Glasmeier, 1991). This paper addresses the research question of why industrial clusters sometimes evolve from a community of innovation to a community of inertia.

This paper presents findings from a historical analysis of a single industrial cluster—the American tire industry concentrated in Akron, Ohio—from its inception in about 1900 to its demise in the late 1980s. The tire industry was among the most innovative sectors in the U.S.

economy between 1900 and 1935, providing dramatic improvements in both product performance and manufacturing process efficiency. Akron-based firms accounted for most of this innovation. Faced with the introduction of radial tire technology pioneered by French tire maker Michelin, however, the Akron tire companies faltered in the 1970s and 1980s, and in the span of eighteen months, three of the four Akron tire manufacturers ceased to exist as independent corporations.

To help explain why the Akron cluster evolved from a community of innovation to a community of inertia, I introduce a grounded theory that disentangles two distinct consequences of geographic co-location—i.e., the benefit of knowledge flows and the liability of inertia. Although this conceptual model emerged from my empirical research, it is informed by existing theory. In the early days of a technology-intensive industry, geographic co-location increases the ease with which "communities of practice" can form, and these tightly interwoven social and professional networks provide the conduits through which tacit knowledge flows (Marshall, 1890; Brown & Duguid, 2000). These knowledge flows, in turn, contribute to cumulative incremental innovations in both product and process technology among firms embedded in the cluster. The benefits of these knowledge flows, however, decline over time as the industry settles on a dominant design and converges on the optimal production process. While the knowledge sharing benefits of clusters decline with time, the liability of inertia rise steadily as a function of time. These costs consist primarily of foregone flexibility resulting from persistence of established behaviors and taken-for-granted assumptions that may outlive their usefulness as the competitive environment changes (Zucker, 1977; Pouder & St. John 1996). When the liability of inertia exceeds the benefits of knowledge flows, firms within a cluster are susceptible to an environmental jolt.

METHODS

This study adopts an embedded case study design (Yin, 1984) that explores the evolution of the U.S. automotive tire industry at the level of the industry as a whole, the cluster centered in Akron, Ohio, and constituent firms. This study takes a historical perspective, covering the period between the emergence of the automotive tire industry in the early 1900s through to 1988, by which time only a single major U.S. tire manufacturer remained after all others had been acquired by European or Japanese competitors. The long time horizon provided by historical analysis offers a powerful lens for studying the evolution of institutional processes over time (Aldrich & Fiol, 1994; Barley & Tolbert, 1997).

Historical archives were the primary source of data for the period between the industry's founding and initial concentration in Akron and the introduction of radial tire technology to the U.S. market approximately 65 years later. I secured full or limited access to the corporate archives of the four major U.S. tire producers located in Akron. I also examined archival data from several organizations located in Akron which served the tire industry, including the city's newspaper, the tire industry labor union, the leading independent tire testing laboratory, and the local university. These archival data were supplemented with secondary sources including government documents, previous histories of the tire industry, doctoral dissertations, and scholarly articles. Approximately 40 taped interviews were conducted with former tire industry executives, union officials, and industry experts covering the period between the late 1960s and the 1990s. The interviews were open-ended ethnographic in format (Spradley, 1979), but informants were encouraged to choose episodes which they considered important in understanding the evolution of the U.S. tire industry. All interviews were tape recorded and fully or partially transcribed.

To analyze the data, I created a database of key events indexed by level of analysis—including tire industry, Akron community, and individual firm. I then generated a set of conceptual labels to code the events. These categories were not derived from existing theories, but emerged inductively from the data (Strauss & Corbin, 1990:61-74). Some categories, such as firm entry and exit, emerged naturally from my framing of the phenomenon. Other categories were unexpected, however, including the importance of process (rather than product) innovation, the difficulty of exiting from old technology when adopting new technology, and the central role played by social institutions like the Akron residential neighborhoods and country club.

After the preliminary coding, I created a time-ordered matrix (Miles & Huberman, 1994:119-122) for the tire industry as a whole, each of the Akron clusters, the four large Akron-based tire firms, and two tire firms outside of Akron—i.e., U.S. Rubber and Michelin. For each matrix, I labeled the rows by categories. To test the validity of my emerging eras and categories, I gathered quantitative data at this point. The eras for the industry time-ordered matrix, for example, consisted of four eras—entry, shakeout, stability, and jolt. I gathered data on firm entry and exit by year to test and refine my emerging eras and categories. I then used these matrices to structure and write individual case studies and then compared across these case studies (Eisenhardt, 1989), and used these comparisons as a basis for a matrix for the cluster as a whole.

At this point, I began to explore theoretical perspectives that might help sharpen my emerging framing (Strauss & Corbin, 1990:50-51). I found institutional theory (Meyer & Rowan, 1977; Zucker, 1977; DiMaggio & Powell, 1983) and recent writing on communities of practice (Saxenian, 1996; Brown & Duguid, 2000) to be particularly useful. While analyzing my data, I read Pouder & St. John (1996) that introduces a three-phase model of the evolution of "hot spots," a construct which corresponds closely to the construct of industrial clusters. Pouder & St.

John draw on diverse literatures to argue that geographic concentration initially promotes innovation by agglomerating critical resources, providing legitimacy to firms, and increasing the salience of local competitors. In the second phase, the benefits of agglomeration decline, firms within the cluster display mimetic isomorphism, and managers converge on shared mental models. Following a jolt in the competitive environment, diseconomies of resource agglomeration emerge, constituent firms exhibit structural inertia, and managers' entrenched mental models prevent them from responding effectively to changes in their environment. Pouder & St. John's framework provided a solid foundation for understanding the evolution of the tire industry, but it failed to address the issue of timing—specifically, what triggers the transition from the initial phase when the benefits of geographic co-location outweigh their costs to the convergence phase. The evolution of product and process technology provided a theoretical lens to understand the evolution of the cluster as a whole. After including the evolution of technology in my analysis, I generated the time-ordered matrix for the Akron tire cluster as a whole between 1900 and 1988 (see Table 1).

INSERT TABLE 1 ABOUT HERE

COMMUNITY OF INNOVATION: 1900-1935

Marshall (1890:226) wrote the seminal theory on geographic concentration of industries, and argued that clusters promote the transfer of knowledge:

> The mysteries of the trade become no mysteries; but are as it were in the air, and children learn many of them unconsciously. Good work is rightly appreciated, inventions and improvements in machinery, in processes, and the general organization of business have their merits promptly discussed; if one man starts a new idea, it is taken up by others

> and combined with suggestions of their own; and thus it becomes the source of further new ideas.

Marshall's quote evokes an image of the industrial cluster as a geographically co-located community of experts whose shared understanding of an industry allows them to rapidly evaluate and extend innovations arising within the cluster. This rapid knowledge transfer contributes to an ongoing cycle of cumulative innovation. Marshall's description is consistent with recent empirical research. Saxenian (1996:29-57) describes how the tightly knit community of semiconductor engineers and executives in Silicon Valley cumulatively built on one another's process and product innovations through close monitoring and frequent collaboration across firm boundaries. Brown & Duguid (2000:141-143) use the term "community of practice" to describe face-to-face communities which "form the social networks along which knowledge about that practice can both travel rapidly and be assimilated readily," and use this construct to help explain how other Silicon Valley-based firms were able to understand and build upon innovations originating in Xerox PARC, while managers in Xerox's Connecticut headquarters and development engineers in Dallas research labs were unable to leverage these innovations (Brown & Duguid, 2000:150-151). Analyzing a large sample of patent citations, Jaffe et al. (1993) established that knowledge spillovers are geographically localized. Consistent with Marshall's theory, these studies suggest that geographic concentration can result in a community that facilitates the transfer of knowledge and thereby promotes cumulative innovation.

Between 1900 and 1935, the tire industry was comparable to Silicon Valley's semiconductor industry in the 1960s and 1970s. Like semiconductor companies, tire manufacturers produced a critical component to one of the fastest growing products in the world, in Akron's case, the automobile rather than the computer. Unit production of automobiles increased one-thousand fold from approximately 4,000 automobiles in 1900 to over four million by 1923 (A.A.M.A., 1994:3). Like semiconductors, both the design and production of tires were technically sophisticated. The rubber industry ranked fourth among all U.S. industries in the total number of scientific personnel employed (after chemicals, electrical machinery, and metals) and second in research intensity measured by research personnel as a percentage of total employees (Chandler, 1990:108). The tire industry attracted hundreds of entrepreneurs between 1900 and 1927, with the total number of firms peaking in 922 at 273 firms (Figure 1). New entrants were attracted by the possibility of entrepreneurial profits. In 1920, two Akron-based journalists estimated that 122 tire industry entrepreneurs and investors had achieved millionaire status in that city alone (Allen, 1949:175-176), and the most successful entrepreneurs, including Harvey Firestone and B.F. Goodrich, became household names.

INSERT FIGURE 1 ABOUT HERE

The period of entry was followed by a "shakeout" marked by a sharp decline in the number of producers (Klepper & Graddy, 1990). By the mid-1930s, the total number of tire manufacturers declined to 53 (see Figure 1), with 81% of the exits resulting from failed firms and 19% from mergers and acquisitions (French, 1986:33). These exits were concentrated in the period between 1921 and 1931, and most occurred prior to the onset of the Great Depression in 1929, although the number of firms continued to decline throughout the 1930s. As the industry as a whole experienced a shakeout, the four largest competitors gained market share. In 1919, the four largest tire manufacturers were among the largest 100 U.S. industrial corporations measured by assets and accounted for 55% of tire unit shipments. By 1935, the four largest firms accounted for 80% of shipments.

Not only was the tire industry concentrated among a few firms, it was also concentrated geographically. Although Akron-based firms represented only 8-13% of total tire producers throughout the 1920s, three of the four largest tire producers (i.e., Goodyear, Firestone, and B.F. Goodrich) had their headquarters in Akron. Akron was known as America's "Rubber Capital" and grew faster than any other U.S. city between 1910 and 1920 (Gaffey, 1940:161). By 1930, Akron factories produced approximately 65% of all tires manufactured in the United States (Sobel, 1951:12).

Scholars have offered alternative hypotheses to explain the emergence of the leaders in the tire industry. Chandler (1990:105-106) argues that the leading tire manufacturers succeeded in part through their early investment in large factories, which conferred manufacturing economies of scale. Careful estimates of the economies of tire manufacturing, however, suggest that tire factories achieve minimum efficient scale at 4,000 to 10,000 tires per day, which translated into approximately 2-3% of total domestic production (Bain, 1956:72, 238; F.T.C., 1966:20). Akron's large factories may have resulted in diseconomies of scale (Reynolds, 1938:466). Chandler and others (Chandler, 1990:107; Knox, 1963:157-158) argue that Firestone, Goodyear, and B.F. Goodrich succeeded in part by investing heavily in distribution, but French (1986:40-41) demonstrates that the tire company-owned retail stores accounted for less than 1% of industry sales as late as 1928. The tire firms' investments in building a controlled retail distribution network began in earnest in 1929 and 1930, after the Akron firms had already established their preeminence.

The ability of Akron-based firms to consistently innovate in product and manufacturing process technology provides a more promising lens for understanding why Akron firms came to lead the tire industry (Stern, 1933; Carlsmith, 1934:124-127; Fraser & Doriot, 1932:100-103;

Warner, 1966; Klepper & Simons, 1997:2000). A series of innovations in raw materials, tire construction, and rim design yielded dramatic improvements in product performance between 1900 and 1937. The average tire manufactured in 1900 lasted approximately 500 miles, while the typical tire produced in the mid-1930s lasted more than 20,000 miles (Jeszeck, 1982:396). Tire performance also improved in terms of smoothness of ride, ease of changing, fuel efficiency, and safety over this period (Warner, 1966). Increased product performance was accompanied by lower prices, and the U.S. Bureau of Labor Statistics calculated that the price of the average tire declined by 80% between 1913 and 1933 (U.S. Bureau of Labor Statistics, 1934).

The dramatic improvements in tire performance did not result from a single innovation, but rather from a steady stream of incremental improvements in design that cumulatively increased tire performance (Reynolds, 1938:463; Gaffey, 1940:90). Automotive tires were initially constructed with thin strips (or plies) of cotton fabric, which were impregnated with rubber then coated with a thicker layer of rubber to form the tread surface that meets the road. The cross threads of the woven fabric, however, rubbed against one another when the tire moved, and the heat from the resulting friction capped the tire's maximum useful life at 2,000 to 4,000 miles. The cord tire, which was introduced in the United States in 1920 by Diamond—a small Akron-based competitor—removed the cross threads from the woven fabric, thereby reducing friction and increasing the potential maximum life of a tire to 10,000 miles. In 1922, Firestone introduced the balloon tire, which used fabric dipped in rubber (known as "gum-dipped") to allow a wider tire with lower air pressure that increased the maximum potential life to 15,000 to 20,000 miles. Three years later, Goodyear introduced a modification of the balloon tire with 6 to 8 plies (instead of the customary 4 plies), which offered the possibility of longer useful life. Figure 2 graphs the percentage of domestic tire shipments by construction from 1910 to 1933 and demonstrates that the tire industry moved through two tire constructions in that period before settling on the balloon tire as the dominant design by the mid 1930s.

INSERT FIGURE 2 ABOUT HERE

Changes in tire construction offered the potential for improved performance, but realizing this potential required a host of innovations in complementary technologies (Rosenberg, 1979), especially the raw materials needed to construct a tire—i.e., chemical additives, steel wire, and textiles (Warner, 1966). Cord tires, for example, reduced tire failure resulting from fabric friction, but not from rubber degradation. The gas and carbon blacks developed by Diamond between 1910 and 1912, however, significantly increased the durability of tread rubber (Warner, 1966:82). Advances in steel wire were necessary to allow the balloon tire to attach to a rim (Dick, 1980). Tire manufacturers also innovated in the design of the rim, which connects the tire to the wheel of the automobile. Goodyear, for example, developed the Universal Rim, to stimulate demand for its straight-side tire, which could not attach to the clincher-style rim that represented the industry standard interface until the mid-1920s (O'Reilly, 1983:18-23). Table 2 summarizes the major innovations between 1899 and 1939 and demonstrates that Akron-based tire firms accounted for the majority of innovations in tire construction, rim design, and raw materials.

INSERT TABLE 2 ABOUT HERE

In addition to product innovations, the tire industry also experienced improvements in manufacturing process technology that dramatically increased labor productivity between 1914 and 1937. Between 1914 and 1927, the tire industry experienced the largest percentage increase in labor productivity in a sample of eleven manufacturing industries selected for their rapid growth in productivity (U.S. Bureau of Labor Statistics, 1930:501-517). An analysis of 135 manufacturing process innovations studied by the Bureau of Labor Statistics supports the Bureau's conclusion that improvements in labor productivity resulted from a series of small process innovations rather than a single radical change in the production process (Stern, 1933). The largest single process innovation accounted for only 8.5% of the total increase in labor productivity, and the remainder of the productivity gains resulted from a large number of small innovations. Like improvements in product design, the majority of these innovations originated with Akron-based firms.

Local institutions facilitated the transfer of technical knowledge among Akron's tire firms. In 1909, a consortium of executives from Akron's tire companies funded the construction of America's first laboratory devoted to rubber chemistry at Buchtel College (the precursor of the University of Akron), and this laboratory served as a focal point for collaboration among the local tire companies on basic and applied research (Love & Giffels, 1999:303). The *Akron Beacon Journal*, the flagship paper of the Knight family newspaper chain, provided in-depth coverage of Akron's tire industry beginning in 1903 and quickly emerged as the industry's journal of record. In the early 1920s, Akron-based Smithers Scientific began providing independent technical analysis of tire design and performance by reverse engineering tires, a service which helped competitors track and understand one another's product innovations.

The Akron-based tire firms also appeared to follow an "open-door" policy in which executives "did not worry too much about patents and trade secrets. One company got an idea, another improved on it, and a third brought in a new variation, with the result that the whole industry went ahead, virtually pooling ideas which would expand the business." (Allen, 1949:167). When companies did attempt to patent their innovations, their applications were generally denied as a logical extension of the current state of the art or granted for very narrow protection which other firms easily circumvented (Warner, 1966:298). The Akron tire firms often collaborated on technical projects. B.F. Goodrich and Diamond jointly formed a company to reclaim used rubber in 1904 (Blackford & Kerr, 1996:50), and Goodyear and Firestone collaborated closely to create a common standard for rims that would allow them to mount their straight-side tires (O'Reilly, 1983:41). Goodyear's P.W. Litchfield, who initiated Goodyear's research department in 1900 and later rose to the presidency, believed that "a company which closed its doors was apt to lock out more information than it locked in." (Allen, 1949:167).

Local social networks also created personal relationships among tire industry executives that cut across firm boundaries. Tire industry junior and senior executives congregated in the same residential neighborhood in West Akron, which had emerged as the primary residential section for Akron's tire industry (Allen, 1949:175). The Portage Country Club, which was founded by two B.F. Goodrich executives in 1894, provided a setting where tire industry entrepreneurs, executives, and financiers regularly socialized (Zonsius, 1994:vii-viii). A cross check of the Portage Country Club 1906 membership roster against company histories reveals that the four major Akron tire companies were well represented among club members. The living founders of the three largest Akron tire companies were members. Ten executives from B.F. Goodrich were members in 1906, seven from Goodyear, as were three of Firestone's four top executives.

By 1935, the major U.S. tire manufacturers had converged on a dominant design for the construction of a tire, which consisted of multiple strips of fabric (or plies) placed at an angle (or bias) to the direction of travel. This construction became known as the bias ply tire. The industry also settled on the universal rim, which allowed tires to attach to the rim without clinchers. Major competitors also converged on similar manufacturing processes to produce the tire (Stern, 1933). By 1935, 80% of domestic tire shipments were accounted for by the four largest competitors. Three of the four—i.e., B.F. Goodrich, Goodyear Tire, and Firestone—had their headquarters in Akron, and these Akron-based competitors accounted for approximately 65% of U.S. tire production (Federal Trade Commission, 1966).

COMMUNITY OF INERTIA: 1935-1990

If a group of Akron tire industry executives were transported from the 1930s to the 1960s, they would have found that remarkably little had changed in the intervening decades. The same four tire companies still accounted for more than 70% of U.S. sales, and no new domestic tire producer had entered the market since the 1920s (Federal Trade Commission, 1966). Goodyear, Firestone, and B.F. Goodrich retained their headquarters in Akron, which remained America's undisputed "Rubber Capital." The product and process technologies were also stable, and the typical tire manufactured in the United States in the 1960s had the same basic construction, lasted as long, and was produced using essential the same manufacturing processes as a tire produced three decades earlier (Jeszeck, 1982:396).

While geographic co-location initially spurred innovation, this same clustering contributed to organizational inertia after the mid-1930s. Pouder & St. John (1996) argue that common sources of information and frequent interaction with like-minded managers will induce executives within a cluster to converge on a shared mental model. The tire data support this hypothesis. The top executives of Akron's tire firms shared the assumption that tires was a growth business. The tire industry had indeed enjoyed brisk growth in demand after the Second World War, with total industry shipments increasing from 43 million units in 1935 to 146 million units in 1965. The Akron tire companies responded to this growth in demand by constructing new tire factories. Table 3 lists each U.S. passenger tire plant built by year, location, and competitor for the three largest Akron-based tire companies as well as two non-Akron competitors—i.e., U.S. Rubber and Michelin. Table 3 shows that the three Akron firms constructed 18 factories between 1935 and 1971, while U.S. Rubber built only two new plants over that period. Table 3 also reveals that the Akron-based competitors clustered their new plant construction both temporally and geographically. Three of the Akron companies built factories in Los Angeles in the early 1920s, and in the Midwest in 1937; then again the Midwest in the mid-1940s. Plant construction in the 1960s was concentrated in the South and Midwest.

Further evidence of the managers' shared assumptions of industry growth come from their consensus forecasts. By the mid-1960s, Akron tire makers officially collaborated through the Rubber Manufacturers' Association to develop consensus projections of industry growth that consistently forecast steadily rising demand (Shleifer, 1981). Based on their consensus forecasts, the Akron firms accelerated their rate of new plant construction. A former president of Firestone characterized the industry in this period as "a no-brainer industry … planning consisted of deciding where to put up the next factory." (Brodeur, 1994:3).

INSERT TABLE 3 ABOUT HERE

In addition to converging on shared mental models, the Akron-based tire companies demonstrated evidence of mimetic isomorphism, particularly in their manufacturing and new product development processes. The major tire companies tracked each others' process improvements through a variety of sources including equipment suppliers, the United Rubber Workers union, raw material suppliers, technical conferences at the University of Akron, and other sources (Kovac, 1978). These data sources allowed the tire companies to rapidly imitate local competitors' improvements to the manufacturing process. Akron's largest tire companies also shared similar research and development processes. The major tire companies focused their new product development on incremental innovations in tire design. Warner (1966:276-277) identifies an average of one design innovation per year for the period between 1940 and 1965, but each of these were incremental extensions of the bias ply tire, such as changes in the tire's diameter, tread design, and fabric ply composition. Many of these innovations were merely cosmetic—e.g., raised white letters. Goodyear, Firestone, and B.F. Goodrich all located their research and development labs in Akron, and their technical employees closely monitored one another's research initiatives, created parallel programs, and imitated local competitors' innovations (Warner, 1966:232).

The executives at the helms of Akron's tire firms in the early 1970s were deeply steeped in the cluster's shared mental models and common processes. An Akron native led Goodyear as either president or chairman of the board continuously between 1940 and 1983 (Love & Giffels, 1999:80). In 1972, between one-third and two-thirds of the executives at Goodyear and Firestone were Akron natives; between one-third and one-half had risen through the ranks of the domestic tire industry; and a significant percentage had followed in their fathers' footsteps as executives in the same company. Industry insiders referred to these homegrown executives as "gum-dipped," in reference to the production process developed by Firestone in the 1920s in which fabric strips were dipped in rubber and thereafter took on a uniform shape (Millis, 1994). Most of these executives lived within a five block radius of one another (Nevin, 1994), socialized at the Portage Country Club (Zonsius, 1994; Stoyer, 1995), and relied on the *Akron Beacon Journal* for their news (Millis, 1994).

By the mid-1960s, the U.S. tire companies were faced with an alternative tire design—the radial tire—that had been pioneered by French tire maker Michelin immediately after the Second

World War. The radial tire, which reinforced the tire's plies with steel wire, increased useful life from 20,000 to 40,000 miles, reduced a driver's gasoline consumption by 5-10%, improved handling, and dramatically reduced the likelihood of a catastrophic tire failure, known as a "blowout." Michelin leveraged its lead in radial product and process technology to increase its share of the major European tire markets from under 10% in the early 1960s to nearly 30% by 1972 (Harkelroad, 1978). Between 1960 and 1972, Michelin built 26 greenfield radial tire factories, 14 of which were outside France (Harkelroad, 1978:10). Incumbent tire makers in Europe embarked on a crash course to adopt radial tire technology, but could not close the technical gap quickly enough to halt their relative decline. The Akron tire companies witnessed Michelin's success firsthand. Goodyear, Firestone, and B.F. Goodrich had all operated in Europe since the 1920s, and the leading U.S. tire producers together owned 29 factories in Europe, placing them among the 10 largest European tire companies (Harkelroad, 1978).

The Akron-based tire companies did not ignore the radial tire, nor did they respond slowly. Rather, they responded to the new technology quickly, but did so in a manner consistent with their mental models of competition and established processes. Goodyear responded to the radial tire in 1967 by further extending the core bias tire design with its introduction of the belted bias tire (O'Reilly, 1983:156). The belted bias tire featured a strip or "belt" of polyester fiber or fiberglass that ran along the tire tread, and represented only a slight modification to the traditional bias design (Kovac, 1978). Although the belted bias only incrementally extended the existing tire design, Goodyear aggressively promoted it as an alternative to radials and claimed significant performance improvements (Denoual, 1980:279). The other leading tire companies quickly followed Goodyear's lead and introduced belted bias offerings of their own. Firestone's Research and Development Group, for example, matched Goodyear's belted bias tire within a few months and developed a second-generation belted bias tire within one year (Sull, 1999:441). The belted bias tire won rapid acceptance among automobile OEMs and end-users, and accounted for more than one-half of all tire shipments by 1971.

Although belted bias tires initially gained significant market share, they provided few tangible benefits to consumers and quickly fell out of favor with OEMs and end-users. In a 1971 *Consumer Reports* evaluation, five of the seven belted bias tires failed at high-speed and tread-life tests and under-performed bias tires in safety, cost effectiveness, and handling (Consumer Reports, 1971). The OEMs were actively evaluating radials as an alternative to belted bias tires, and a 1971 internal study by General Motors concluded that radial technology conferred compelling advantages to both the automobile manufacturers and end users, and the company formed a central Tire Group to persuade the U.S. tire manufacturers to develop radial tires.

In 1972, General Motors announced its intention to place radial tires on all models over the next few years, following a similar decision that Ford made a few months earlier (Denoual, 1980:20). Although tire executives were well aware of the OEMs' interest in radials, they had apparently expected a more gradual transition and were caught off guard by the abruptness of General Motors' and Ford's decision and the planned pace of radial adoption (Denoual, 1980:206). Once the major OEMs switched, both the ultimate level and pace of radial adoption were very predictable. The tire manufacturers, which accounted for approximately one-third of the market, essentially dictated their planned radial placements to the suppliers. Replacement market penetration was also highly predictable based on the rapid and similar radial diffusion patterns across several European countries in which Michelin had introduced the radial (Sull et al., 1997:475). The major tire companies invested heavily to install capacity to produce radial tires.

Although the tire manufacturers invested heavily and quickly once the OEMs switched to radials, they delayed closing the bias tire plants rendered unnecessary by their investment in the new technology. Radial tires lasted approximately twice as long as the bias and bias-belted tires they replaced, which implied that incumbent tire makers would need to close approximately one-half of their existing factories to align production with demand. The tire manufacturers did ultimately close 29 of the 57 passenger tire factories operating in the United States in 1972, but they dragged these closures out over a decade. Delays in closing redundant bias factories depressed industry-wide capacity utilization to 46-65% and triggered a price war that drove the price of bias tires to within one dollar of their variable cost (Firestone Minutes of the Board, March 13, 1980: Exhibit 11).

The combination of low prices and low capacity utilization severely depressed bias factories' operating profits prior to their ultimate closure. Given the foreseeable decline in bias demand and industry-wide overcapacity, there was no plausible argument for firms to keep plants open after they began incurring operating losses. Yet the U.S. tire companies appear to have delayed closing their bias tire factories at great economic cost. I estimated the financial costs resulting from delays in closing bias plants, where a delay is measured as the time elapsed in years between the first year a factory experiences a negative operating profit and the year in which the factory was ultimately closed.[1] The three largest Akron tire companies closed 17 bias factories between 1972 and 1987 (competitors accounted for the other plant closures). No tire

[1] To estimate these losses, I calculated annual plant-level cash profitability (defined as plant-level revenues less the factory's direct and indirect labor expenses, raw material costs, and facility overhead) for every U.S. tire factory between 1974 and 1987. The Rubber Manufacturers' Association provided annual plant-level capacity and the individual tire companies provided data on each factory's annual product mix and level of capacity utilization. The National Tire and Retreader Association provided a data series on annual mean wholesale tire prices based on a national survey. The United Rubber Workers provided annual data on the numbers of employees, hours worked, and hourly wage and benefit costs for each factory. Firms supplying materials accounting for 95% of a tire's material costs furnished historical prices to the tire industry. Plant-level overhead costs were calculated based on corporate archival data while tax, insurance, and utility costs were gathered from corporate and governmental data sources.

plant in the sample was closed the first year it lost money, and the average delay ranged from 1.8 years for Goodyear to 3.4 years for Firestone. The total pre-tax losses incurred by delays in closing all 17 tire factories totaled $725 million, which exceeded one-third of the combined market capitalization of the three large Akron-based tire companies in 1974.

Part of the explanation for tire companies' delays in closing factories may lie in executives' taken-for-granted assumption that tires was a growth industry that required capacity additions. Figure 3 plots the Rubber Manufacturers' Association's forecasts made in the years 1971 through 1975 (as well as actual tire shipments between 1970 and 1977). The forecasts made in 1971 are fairly close to actual shipments in 1972 and appear to extrapolate historical demand for the following three years. Forecasts made in November of 1972 occurred after the OEMs' decision to switch to radials but do not appear to reflect the decreased demand resulting from radial adoption. While the 1973 and 1974 forecasts steadily reduce forecast demand, it is not until 1975, three years after the OEMs announced their intention to switch to radials, that the forecasts began to approach actual shipments again. The belief that tires was a growth industry apparently influenced the thinking of Firestone president Richard Riley, who listed growth as the company's primary objective in six of his seven annual addresses to shareholders between 1972 and 1979, although he confided to his board that he "felt somewhat uncomfortable" trying to reconcile his growth projections with market realities in the wake of the radial tire (Sull, 1999:446).

INSERT FIGURE 3 ABOUT HERE

While Firestone, Goodyear, and General Tire responded to radial technology by initially promoting the belted bias tire then investing in radial capacity to meet OEM's demand and delaying closure of unnecessary bias factories, B.F. Goodrich responded to the radial tire very differently from its Akron-based competitors. In 1969, B.F. Goodrich was the target of a hostile takeover led by Ben Heinemann (Blackford & Kerr, 1996:290-292). While Goodrich management successfully defended the company against the hostile takeover bid, the board lost confidence in the CEO and replaced him with an oil industry executive from Texas. The new CEO tapped outsiders to staff his management team, and by 1972, fewer than one-half of the B.F. Goodrich executives had spent their entire careers in the company and none were Akron natives or veterans of the domestic tire business.

The B.F. Goodrich top management team responded very differently than the executives at the other Akron-based tire companies (Sull, 1999:455-459). Goodrich executives did invest in converting bias capacity to radial production, but they carefully monitored the financial returns on their investment and, alone among the major tire companies, avoided the investment in a greenfield radial tire factory. B.F. Goodrich was also the most aggressive competitor in closing plants, closing two bias tire plants in 1975 (two years before any of the other majors closed plants), and incurred the smallest average loss from delay in plant closures of any tire company. While the other tire companies aggressively pursued OEM business, B.F. Goodrich focused on the more profitable replacement business, and in 1981, took the dramatic steps of exiting the OEM business altogether, although automobile manufacturers accounted for 10% of sales. The Goodrich management ultimately adopted an explicit strategy to milk the tire division and invest only as much as was necessary to maintain the tire operations as an attractive acquisition candidate for another tire company. B.F. Goodrich did eventually sell its tire business, as did Firestone and Uniroyal (the renamed U.S. Rubber) in the late 1980s, leaving Goodyear as the only Akron-based tire company remaining.

DISCUSSION

The findings from a historical analysis of the U.S. tire industry from 1900 to 1990 suggest that the firms clustered in Akron initially led the industry in innovation but later failed to respond effectively to the introduction of radial tire technology. To recap the central finding of this historical analysis, geographic co-location increased the ease with which a "community of practice" formed in Akron's tire cluster. The tightly interwoven social and professional networks provided conduits through which tacit knowledge about tire design and production flowed. These knowledge flows, in turn, contributed to cumulative incremental innovations in both product and process technology among firms embedded in the cluster and allowed Akron's tire firms to survive the shakeout and gain share. The benefits of this knowledge sharing, however, declined over time as the industry settled on a dominant design and converged on a shared production process. While the knowledge sharing benefits of clusters decreased, the liability of institutionalization rose steadily as a function of time. These costs consisted primarily of foregone flexibility resulting from persistence of established processes and taken-for-granted mental models that outlived their usefulness as the competitive environment changed. This institutionalization left the firms within the cluster susceptible to an environmental jolt when the radial tire entered the market.

The findings from the study contributes to our understanding of organizational inertia. Hannan & Freeman (1984:151) define inertia in terms of the relative speed of adaptation and argue that organizations suffer inertia when they fail to change as quickly as the environment. Although the tire firms delayed closing redundant capacity, they responded fairly quickly to the introduction of radial tires by extending bias technology with the belted bias tire. The tire firms also invested rapidly to build radial tire production capacity once the OEMs switched to the new technology. In the case of investment in radial manufacturing capacity, the tire firms may have actually acted too hastily, given the high capital investment costs and predictably low return. The tire companies did not respond to radial technology by doing nothing or by delaying necessary actions, but rather responded by accelerating activities—such as incremental extensions of the existing product and building new plants—that had worked in the past and were based on assumptions that had at one point been consistent with the competitive environment. I use the term "active inertia" to describe the tendency of firms to respond to changes in their competitive environment not by doing nothing, but by accelerating past organizational routines based on established assumptions and entrenched routines (Sull, 1999). The tire makers more closely approximated the construct of strategic momentum introduced by Amburgey & Miner (1992).

The tire industry data also provide insights into the micro-processes that contribute to inertia. Taken-for-granted shared assumptions about the industry were enacted through established organizational routines, and these assumptions and routines mutually reinforced one another (Barley & Tolbert, 1997). Tire executives apparently assumed that the bias tire would continue as the dominant design, and this assumption was enacted through their company's well-honed new product development process which had produced a steady flow of incremental extensions to the dominant design throughout the preceding decades. Similarly, the assumption that tires was a growth industry was enacted through the capital budgeting process that resulted in a steady stream of new factories being built to meet rising demand. When faced with the radial technology, executives responded with investments in new plants that resulted from their well-honed capital budgeting process and was consistent with their assumption that tires was a growth industry. Because none of the four Akron tire companies had closed a factory prior to 1975, these firms lacked a process for disinvestment, and their capital budgeting process stalled in reverse.

This study suggests opportunities for future empirical research. Future studies could analyze the evolution of once-comparable clusters such as the financial centers in Paris and London or shoemaking districts in different regions of Italy. Comparative historical case analysis could also explore how differing trajectories of technological development influence the evolution of industrial clusters. It would also be interesting to chart the attempts by many regional development boards and business associations to capture the benefits of clustering by imitating Silicon Valley. A broader extension of this study would explore how various contexts contribute to entrepreneurship and innovation and compare industrial clusters with other possible contexts, such as incubators or large corporations. Future clinical research could compare, for example, similar entrepreneurial ventures within an industrial cluster, an incubator, and a large corporation to understand how each context promoted or hindered the venture. An empirical study might categorize different contexts and analyze how they contribute to survival rates. Future theoretical research could elaborate the dimensions along which contexts for entrepreneurship vary and how these contribute to or hinder the pursuit of opportunity.

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