Journal of Technology Management & Innovation

J. Technol. Manag. Innov. 2007, Volume 2, Issue 4

Received June 6, 2007 / Accepted October 14, 2007

NATIONAL INNOVATION SYSTEM AND DISRUPTIVE INNOVATIONS IN SYNTHETIC RUBBER AND TIRE TECHNOLOGY

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Abstract

The current models of National Innovation Systems (NIS) are based on interactions and learning across three institutions: government, university and industry. This empirical study of the evolution of innovations in rubber and tire technologies such as the collaborative innovative suppliers (of raw materials and human capital) and disruptive rival innovators to the traditional tri-helical model of National Innovation System. This was empirically examined for the evolution of rubber and tire technology and the rise and decline of its innovative region: the Rubber Capital of the World in Akron, Ohio.

Keywords: Product Innovation; Process Innovation; Technology Innovation; National Innovation System; Regional Innovation System; Innovation Policy; Industrial Policy; Rubber Technology; Tire Industry; Rubber Capital of the World; Akron, Ohio

Introduction

Schumpeter (1950) described "creative destruction," as creating new value with a higher consumer welfare that destroys the economic returns for producing the older or prevailing products. The resource-based view of strategy underscores the strategic significance of innovative capabilities of an enterprise (Grant, 1991; Gehani, 1998). The evolutionary economic approach proposed by Nelson (1996) combined the firm's formulation of innovation strategy with a higher level aggregation of resources and capabilities to examine the dynamic changes driven by technological innovations. This was a distinct new approach from the mainstream equilibrium approach based in the Industrial Organization (IO) economics (Porter, 1991).

The tri-helical National Innovation System (NIS) emphasizes the dynamic interactions and learning across government, university, and industry - the key institutions driving risky innovations (Freeman, 1987; Nelson, 1993; Ohmae, 1995). The National Innovation System, however, does not protect enterprises from attacks from emerging disruptive innovators (Christensen, 1997).

Bower and Christensen (1995) and Foster (1986) noted that as markets shift, the industry leaders, with large investments sunk in their existing technologies, tend to become complacent and fail to recognize the emerging disruptive innovations by new challengers. The incumbent leaders resist making large investments in new technological innovations to reach out to the emerging new customers because these innovations demand developing a portfolio of new value-adding capabilities that are different from those needed for the incumbent technological innovations and the existing customers (Gehani, 1998).

This phenomenon, vividly illustrated by the evolution of innovations in rubber and tire industry, supports that the current tri-helical model of the National Innovation System is inadequate, and deserves careful re-examination and redefinition.

This study examined the relationship between the National Innovation System and the emergence and evolution of innovations in synthetic rubber and tire technology. This relationship was established by reviewing how different national innovation policies in different countries were linked to the evolution of synthetic rubber technology from its birth in early twentieth century to the oil crises in the 1970s.

This empirical study helped develop an extended model for the National Innovation System. The impact of innovation policies by national government on an innovative enterprise was examined alongside other important innovative actors, such as (1) the regional innovation institutions including regional research laboratories, (2) the research universities, (3) the collaborative innovation suppliers (of raw materials or human capital), and (4) the competing innovative enterprises.

The underlying hypothesis of this empirical study was that whereas the macro government-level policies and regional innovation institutions facilitate the development of a radically innovative technology, but when considering the sustainability of competitiveness of an innovative technology, it is also important to take into account the role and interactions of the collaborative innovation suppliers and the disruptive innovative rivals. For example, in the case of the evolution of innovations in synthetic rubber and tire technology, a key role was played in the 1870s by the regional Board of Trade in the emergence of major rubber enterprises such as Goodrich and Goodyear (Love and Giffels, 1999). This led to the emergence of Akron region in Ohio as the Rubber Capital of the World. At other times, significant roles were played by the local workers' unions and disruptive radial tire technology from rival Michelin in the demise of rubber tire industry in Akron in the 1970s. These effects are not easily explained by the prevailing models of National Innovation System (Nelson, 1993).

COMPETITIVE ADVANTAGE OF ENTERPRISES AND TECHNOLOGICAL INNOVATION STRATEGY

The resource-based view of strategy underscores the significance of capabilities and resources of an enterprise in formulating its business and corporate strategies deployed to gain sustainable competitive advantage (Grant, 1991; Gehani, 1998). This view is different from the environmental determinism for firms in an industry that was presented by Harvard Professor Michael Porter in his five force competitive analysis (Porter, 1991). According to this theory, the potential profitability (and innovativeness) of an enterprise depends on the power of the five structural forces in its industry. The evolutionary economic approach proposed by Nelson (1996) and others combined the firm-level approach to formulation of strategy with a higher level aggregation of resources and capabilities. This approach examines the dynamic changes driven by technological innovations, and distances itself from the mainstream equilibrium approach in the Industrial Organization (IO) economics.

Schumpeter in *The Theory of Economic Development*, and *Capitalism, Socialism, and Democracy*, proposed that innovation is the activity for developing an invented entity into a commercially useful entity that becomes socially accepted. In *Capitalism, Socialism, and Democracy*, Schumpeter also proposed that innovations, in the form of new products, new production processes, new modes of transportation, and new forms of industrial organization, drive the competitive advantage of an enterprise competing under capitalism. Innovations disrupt and "revolutionize… the economic market structure from within, …destroying the old one (and) …creating a new one" (Schumpeter, 1950). This was described as "creative destruction," creating new value with higher consumer welfare, and destroying the economic returns for producing the old products (Schumpeter, 1950)..

At first, Schumpeter's innovation included "mega" developments, such as the introduction of railroad transportation technology in a new society. Later in 1950s, he included micro developments in innovations such as new products and services - motorcars, electric appliances, and railroad services, as well as new methods of production – the mechanized factory, the electrified factory, chemical synthesis and the like (Schumpeter, 1950).

Freeman and Soet (1977) endorsed Schumpeter (1950) by defining the scope of innovation to include invention with product and process commercialization. Many years later, Drucker (1985) highlighted that the two basic functions of a business firm are marketing and innovation.

NATIONAL INNOVATION SYSTEMS, REGIONS, AND TECHNOLOGICAL INNOVATION

Typically, technological innovation drives a nation's technological progress (Drucker, 1985). However, innovations, particularly radical disruptive innovations, have excessive risks. Their potential returns are uncertain and unpredictable. This risk is especially high for R&D intensive complex technologies, such as semiconductors, polymers (including rubber elastomers), and biogenetic pharmaceuticals (Gehani, 1998). For technological innovation in such high-tech areas, government guidance is necessary and sometimes essential.

The understanding of the drivers of innovation has evolved over time in different phases (Gehani, 1998). The earliest understanding of the source of innovation was the "science and technology push" approach. Charles Goodyear, Thomas Edison, and Alexander Graham Bell first invented their technologies for vulcanization of rubber, light bulb, and telephone, respectively. These innovators set out to diffuse these innovations to the reluctant potential consumers in the market.

Schmookler (1966), turned this process 180 degrees around into "market-pull method," and suggested that the market and not R&D should be the key driver for technological innovations. He noted that innovative enterprises identified the gaps in their potential markets for any unmet demands, and filled these gaps with their technological innovations.

Both these sequential sources of technological innovation were criticized for using simplistic one-dimensional approaches for a multi-dimensional and highly interactive process. The attention of researchers then focused on a firm's capabilities as the primary source of technological innovation (Grant, 1991). It was noted that an innovative firm benefited immensely from its interactions with its macro national-level and micro industry-level environments (Utterback, 1986). This gave birth to the development and discussion of the National Innovation System.

National Innovation System (NIS) emphasizes the systems approach for the innovation process, actor institutions, and the learning across these (Nelson, 1993). NIS includes all the inter-related institutional actors involved in exploring, generating, diffusing, and exploiting technological and organizational innovations (Freeman, 1987; Nelson, 1993; Ohmae,1995). Most of these NIS researchers emphasized interactions between three major actor groups: national government, research universities, and innovative enterprises. Interactive learning between knowledge producers and knowledge consumers plays a significant role in a National Innovation System. Figure – 1 shows a tri-helical model of National Innovation System.

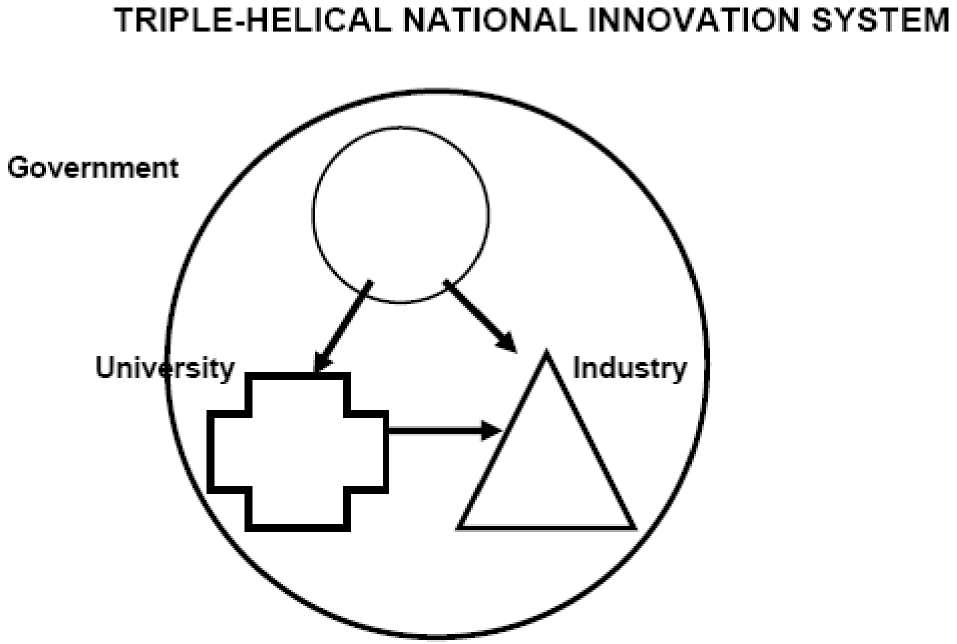

Figure – 1: Tri-Helical National Innovation System

More recently, Chung (2002) and Oughton et al. (2002) have pointed out that usually the National Innovation Systems aggregate and encompass the regional innovation systems. They noted vast differences in the innovative capabilities and earning potential of different regions. National Innovation Systems often operate through their subsidiary regional institutions.

This study, proposed that the regional institutions sponsoring innovation (such as regional research laboratories) play a significant role, and must be highlighted separately. The traditional triple helix model for National Innovation System, comprising of government, university, and industry, seemed insufficient to explain the emergence of a variety of innovations and strategic shifts in rubber and tire technology..

EXTENDED NATIONAL INNOVATION SYSTEM

The proposed Extended National Innovation System (ENIS) is shown in Figure-2. This new model expands the traditional National Innovation System (Nelson, 1993) by including the regional actors such as the regional/state innovation institution including regional research laboratories. This extended model also specifically includes the industry level institutions such as the collaborative innovating suppliers. This extended model was developed and validated empirically by examining the historical evolution of innovations in rubber and tire technology.

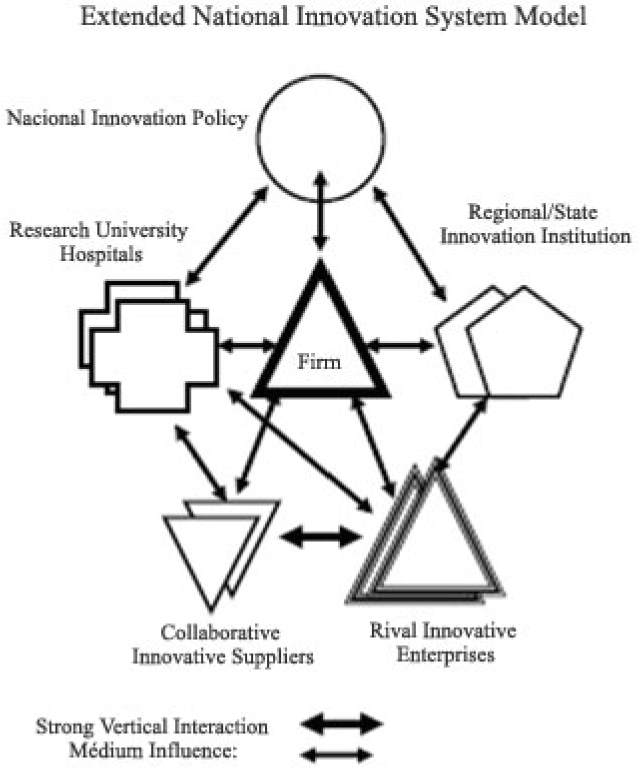

Figure-2: Extended National Innovation System Model

NATURAL AND SYNTHETIC RUBBER TECHNOLOGY

Rubber is a highly elastic material that enhances the quality of modern life. It is a unique material in that it stretches many times its length without breaking, and it recovers to its original shape. This, therefore, makes rubber an indispensable material for many key applications such as automobile tires, conveyor belts, gloves, and many more. The top five largest consumers of rubber are the United States, Russia, Japan, China and Germany (Barlow et al., 1994). The world-wide per capita consumption of rubber is over 3.0 kilograms, though in Japan it is almost five times this amount, Germany uses four times, and the United States uses three times as much per capita rubber. China, a top-5 consumer by volume, uses only one third, and India uses only one sixth as much rubber per head as the world average.

NATURAL RUBBER TECHNOLOGY

Traditionally, natural rubber (NR) was harvested from the ***Havea Brasiliensis*** tree of the Amazon basin in Brazil (Onokpise, 2004). Long slanted cuts are made in the trunk of the rubber tree for latex to flow into a cup. Despite the technological innovations for synthetic rubber, natural rubber continues to account for 30-40% of the total world consumption of all types of rubber (Barlow et al., 1994). Rubber grows only in the tropical high rainfall regions within 10 degrees of the equator. Most of the natural rubber is produced in small estate plots of 2-3 hectares. Rubber planters rely on traders who consolidate their raw rubber production, grade it, process it, and ship it to rubber goods manufacturers.

Raw natural rubber is plastic and not elastic. Raw rubber had to be first processed and made elastic by innovating the “vulcanization” process in order to innovate a large variety of industrial product applications.

VULCANIZATION OF RUBBER

Charles Goodyear spent many years and all his family's resources to innovate the process of making physically stable goods out of natural rubber. According to the industrial legend, in January 1839, Charles Goodyear accidentally dropped sulfur wrapped in a sheet of raw natural India rubber on a hot kitchen stove at his New Haven, Connecticut home (Gehani, 1998). His years of research had prepared his mind to instantly recognize that at the fringes the charred rubber was stabilized. In the past, natural rubber had just melted with heat. Goodyear did a few more experiments to perfect the vulcanization process so that rubber could be processed into rubber goods with stable physical properties. Unfortunately, Goodyear never saw the financial fruits of his technological innovations, and he died penniless in 1860.

Technological innovations have played key roles throughout the history of the worldwide rubber industry (Barlow et. al, 1994). The yield of natural rubber plants in Amazon was improved over the years. In 1915, the natural rubber plants were introduced in the East Indies (now Indonesia). These plants had 2-3 times more yield. Roads and railways were built into rubber plantations (Thee, 1979). Colonists migrated South Asian and Chinese workers to these plantations. These migrant workers had high mortality because of poor housing conditions (Szekely, 1979). In the 1920s and 1930s, many effective methods of weeding, controlling disease, fertilizing, and better trapping were innovated and introduced. Thicker jungles were cleared for plantation of more rubber trees. To recover these expenses, the colonists levied high land and export taxes on the local natives. This was a major source of their revenue in 1920. Until the Second World War, the East Indies and Malaysia were the major producers of natural rubber in the world (See Table-1).

Table - 1 Worldwide Production of Natural Rubber, 1916-47, '000 Tons

	Malay -sia	Indo-Thai nesia	India -land	Sri	Asia Lanka	Brazil	Latin	World Amer.	
1916	101	24	-	3	24	152	n/a	46	199
1917	141	46	-	3	33	224	33	47	279
1918	114	44	-	4	21	184	23	33	222
1919	209	89	-	7	46	354	33	45	405
1920	183	77	-	6	41	310	24	42	357
1921	158	73	-	6	41	310	17	21	303
1922	213	105	1	6	48	378	17	21	401
1923	195	139	2	4	38	383	14	20	407
1924	190	153	3	5	38	395	20	26	426
1925	228	197	5	6	47	492	23	34	533
1926	296	211	4	6	60	587	22	31	626
1927	253	236	5	7	57	568	26	38	613
1928	316	232	5	7	58	629	18	25	661
1929	482	259	5	8	81	846	18	23	874
1930	467	245	4	9	77	813	12	16	834
1931	445	261	5	5	63	792	10	12	807
1932	422	214	3	1	50	705	6	6	713
1933	470	285	7	1	65	846	n/a	10	858
1934	518	386	18	6	80	1030	8	10	1043
1935	404	292	28	8	55	818	10	13	837
1936	394	316	36	9	51	851	13	18	877
1937	550	441	37	10	71	1156	15	21	1188

1938	378	306	43	8	50	848	14	19	879
1939	415	376	43	10	63	976	4	10	1000
1940	603	546	45	13	89	1365	19	26	1407
1941	544	660	46	17	102	1470	16	18	1504
1942	167	203	n/a	16	104	583	27	37	650
1943	81	102	n/a	16	108	384	30	43	483
1944	25	51	n/a	17	101	260	30	51	366
1945	9	10	n/a	17	100	151	24	48	247
1946	419	178	n/a	16	96	765	24	41	850
1947	694	282	n/a	16	90	1205	26	36	1281

Source: Adapted from Barlow, Jayasuriya, and Tan. (1994). Appendix A3.

During the Second World War, the technological progress in natural rubber in the south-east Asia came to a stand still. Americans tried to develop alternate guayule cultivation, but progress was slow, and the initiative was abandoned in 1946 (Barlow et. al, 1994). The subsequent technological development in ***Havea*** natural rubber, took place in Malaysia in the 1950s, in Thailand in the 1960s, and in Indonesia in the 1970s. In tire applications, the natural rubber has low heat build up, high tensile strength, and higher resistance to fatigue. Natural rubber is, therefore, particularly suited to applications in heavy-duty commercial vehicles.

KEY STRUCTURAL COMPONENTS OF THE EXTENDED NATIONAL INNOVATION SYSTEM

In this section, the role of old and newly proposed structural elements related to an extended national innovation system will be empirically examined and integrated.

1. NATIONAL INNOVATION POLICIES FOR SYNTEHETIC RUBBER INNOVATION

Synthetic rubber is produced by polymerizing monomers made from petroleum oil or natural gas. High natural rubber prices in the early 1900s motivated intensive research for innovating the process for making synthetic rubbers.

In most countries national government policies have guided the innovation, development, and production of natural and synthetic rubber in many significant ways. During the 1930s, the growth of natural rubber was stifled by rival foreign government restrictions and tariffs (Barlow et. al, 1994). Early innovation of synthetic rubber technology was subsidized by governments. Yield and plantation of natural rubber was also supported by governments in the 1960s.

German National Innovation Policy

In 1910, a commercial production process for synthetic rubber was innovated in Germany after it was discovered that sodium helped accelerate its polymerization. In the First World War of Europe from 1914 to 1918, Germany was cut off from the natural rubber supply chain by British enemy blockade. Prices and demand of natural rubber rose. This drove the innovation, development, and production of small quantities of synthetic rubber. German government heavily subsidized the development and production of the polybutadiene 2,3-dimethyl butadiene or methyl rubber (Barlow et. al, 1994). It took 2-3 months to process it, and the finished goods made from methyl rubber were inferior to those made from natural rubber.

By the end of the First World War, Friedrich Bayer & Co. produced more than 2,300 tonnes of methyl rubber, costing $2.80-3.20 per kg (Naunton, 1952). The tires made from methyl rubber had some serious weaknesses. The methyl rubber tires flattened due to creep, and had to be lifted to avoid the same. But, it was the first technological breakthrough for a synthetic rubber innovation.

After the First World War, the sodium process for methyl rubber was replaced with emulsion polymerization of gaseous butadiene monomer, with peroxide as catalyst (Barlow et al., 1994). This process innovation had many advantages. The reaction speed was faster and this process produced more homogenous product.

In the mid-1920s, Bayer and Co. started collaborating with IG Farben, partly owned by German government. The German four-year Self-Sufficiency Plan of 1933, imposed heavy tariff duties and tight quotas on imports of natural rubber, and encouraged innovation of

Buna S (SBR), Buna R (NBR), and other synthetic rubbers such as Numbered Bunas (Barlow et. al, 1994). By 1937, approximately 2,000 tonnes of Buna-S were produced for general-purpose applications (See Table – 2). This increased to 37,100 long tonnes by 1940 (Barlow et. al, 1994). Their unit cost, however, was much higher than the international rubber prices.

Table - 2 Worldwide Production of Synthetic Rubber, 1933-1956, '000 tons

	Germany	USSR	East Germany	USA	Canada	Worldwide
1933	--	2	--	--	--	2
1934	--	11	--	--	--	11
1935	--	26	--	--	--	26
1936	--	44	--	--	--	44
1937	3	25	--	1	--	29
1938	5	54	--	1	--	60
1939	22	80	--	2	--	104
1940	40	80	--	3	--	123
1941	70	71	--	8	--	150
1942	99	n/a	--	22	--	121
1943	118	n/a	--	235	3	356
1944	103	n/a	--	776	36	915
1945	-	n/a	--	833	47	880
1946	16	125	24	852	52	970
1947	8	155	25	516	43	747
1948	3	178	29	496	41	747
1949	-	200	33	400	48	681
1950	-	205	40	484	59	788
1951	1	228	50	859	63	1201
1952	5	245	57	812	75	1194
1953	6	293	64	862	82	1307
1954	7	368	68	633	88	1164
1955	11	368	72	986	106	1543
1956	11	373	73	1097	123	1677

Source: Adapted from Barlow, Jayasuriya, and Tan. (1994). Appendix A4

For different applications, many different types of synthetic rubbers were innovated and produced commercially. A major process innovation was emulsion copolymerization of 3 parts of butadiene with 1 part of styrene. Germans called it Buna-S and the Americans renamed it government rubber styrene, or GR-S. It is known around the world as styrene butadiene rubber or SBR.

These copolymers were produced at hotter 40-60 ^{0}C temperatures (Barlow et. al, 1994). SBR had better properties than emulsion poly-butadienes. The use of styrene-butadiene rubber (SBR) gives tires good wet grip, and is extensively useful in treads for passenger tires. These synthetic rubbers were technically inferior to natural rubber, and were considered general-purpose rubber materials.

Soviet National Innovation Policy

During the inter-war period, the largest producer and user of synthetic rubber was the former Soviet Union (Barlow et. al, 1994), under the policy of self-sufficiency (which continued until its breakdown in 1989). By 1934, the Soviet production of the sodium polybutadiene rubbers reached 11,000 tonnes, and increased to 79,700 long tonnes by 1939 (Barlow et. al, 1994, p. 70). Small quantities of other synthetic rubbers were also made. This met roughly three quarters of the national rubber requirements in the Soviet Union.

From 1929 to 1936, The Great Depression reduced the new planting and production of natural rubber around the world. The government support and protection in Germany and former Soviet Union boosted the innovation and production of synthetic rubber.

American National Innovation Policy And Synthetic Rubber Innovations

At first there was limited interest in the United States in innovating process for making synthetic rubber for general-purpose applications. In 1929 there was an agreement between Standard Oil of New Jersey and IG Farben to share technological know-how about buna rubbers and the rubber markets (Barlow et. al, 1994; Love and Giffels, 1999). IG Farben persuaded the US tire makers to use Buna S rubber in tires, but the price was higher and the properties were inferior. Buna S was hard to process, it had lower tack, and it was more likely to delaminate. In the 1930s, the US consumption of Buna S was negligible.

In the 1930s, Du Pont developed neoprene for applications requiring higher resistance to oil, flame, and solvents, than natural rubber. Its production increased to 2,500 tonnes by 1940 (Barlow et. al, 1994).

In 1937, as the war seemed imminent for the involvement of the United States, it realized that its army soldiers may travel short distances on their stomachs, but to run long distances they needed rubber. A rising Nazi Germany owned and protected most of the secrets for mass-producing synthetic rubber, Buna-S. Their supporter in the East, Japan, was likely to invade the South-East Asia and control the supply chain from the natural rubber plantations.

Outbreak of the World War II in September 1939, and the Japanese invasion and occupation of the South-East Asian rubber plantations in early 1942, cut off the global supply-chain for natural rubber to the Western world. These developments forced the United States to carefully reconsider its strategic rubber requirements. By 1939, knowledge about Buna S and Buna N was limited in the United States (Barlow et. al, 1994). There were only small quantities of synthetic rubber produced in 1940.

With the imminent shortage of natural rubber, all the major tire and rubber companies, concentrating in Akron, Ohio, were keen on developing synthetic rubber technology (Love and Giffels, 1999). Their senior executives had visited Germany but the Germans knew their strategic advantage with synthetic rubber technology, and were not interested in sharing their technological lead. In 1937, the President and the Director of Research at Goodrich visited Germany but came back empty handed. They turned to their ace rubber chemist, Waldo Semon to discover the secrets of Buna-S (SBR) rubber, with potential use in tires. He had researched and improved the ageing of rubber goods (Love and Giffels, 1999). Semon innovated adhesives that bonded rubber linings to metal tanks. This led to his invention of polyvinyl chloride (PVC), one of the most popular plastics in use in the 20th century.

Semon, fluent in German, French, and many other languages, studied the existing technical and patent literature on synthetic rubber. He narrowed down on some German patents and recommended to the Goodrich management to license the production of Buna-S patents. Adolph Hitler refused, and he limited the use of synthetic rubber for Germany only. Next, Goodrich sent Semon to Germany to trade PVC technology know-how for synthetic rubber technology know-how. Germans extracted a lot of information from Semon, with different researchers interrogating him in shifts. In return, Semon gathered very little additional information about synthetic rubber production process from his German counterparts (Love and Giffels, 1999). On return, Semon recommended that Goodrich must develop the synthetic rubber technology in-house.

A number of scientists at Goodrich, Firestone, Goodyear, and other research institutions were encouraged by their employers to work hard to unravel the secrets of innovating a process for making synthetic rubber. (Love and Giffels, 1999).

The US government sponsored a big surge in the innovation of synthetic rubber technology. The government sponsored Rubber Reserve Company coordinated research and production across multiple enterprises (Dunbrook, 1954). Large-scale plants were built to manufacture GR-S. The styrene-butadiene rubber (SBR), produced with a hot process, had lower viscosity than Buna S, and did not require pre-heat softening like Buna-S. A number of GR-S rubbers were developed, but they had difficulty for use in tire application (Dinsmore and Juve, 1954). The production of GR-S was standardized in most plants. Within months, and with an accelerated program of development of synthetic rubber, the production of GR-S increased to 833,500 tonnes by 1945 – making US the largest producer of synthetic rubber and natural rubber (See Table-1 and Table-2). By 1945, the ratio of the use of natural rubber in total rubber production declined to 13 percent (Barlow et. al, 1994).

By the end of World War II in 1945, as the supply-chain for natural rubber was reestablished, the pressure to produce and use synthetic rubber declined. The world production of synthetic rubber declined to 787,900 tonnes in 1950, with the US production of synthetic rubber falling to 483,000 tonnes (Barlow et. al, 1994).

After the Second World-War, there was socio-political upheaval in South-East Asia. This depressed the further growth of natural rubber production there, and boosted the development and growth of production of synthetic rubber in North America, Europe, and Japan. Gradually, different types of synthetic rubbers were custom-innovated to target commercialization in specific market segments. World production of synthetic rubber overtook the world production of natural rubber in the 1960s.

In Canada, the government had helped a number of American companies produce 46,000 tonnes by 1945. The production of SR declined a little after the war, with significant export to the United States and Europe.

The occupied allied powers dismantled the synthetic rubber plants in Germany, and their synthetic rubber production disappeared. The production of synthetic rubber in the former USSR and East Germany increased to 205,000 tonnes and 39,800 tonnes respectively (Barlow et. al, 1994).

The political situation in South-East Asia stabilized gradually in the 1960s, and the production of natural rubber started growing again. In the 1970s, as the price of gasoline increased, the cost of producing synthetic rubbers increased. The innovation of radial tires, using more natural rubber, boosted its demand at the expense of use of styrene butadiene rubber (SBR) (Barlow et. al, 1994). During the 1980s, the increase in wages and cost of planting natural rubber increased the price of natural rubber. In the early 1990s, lower prices reduced the production of natural rubbers as well as most of the synthetic rubbers. The worldwide production of all types of rubbers matured and became static. By then, the American National Innovation Policy for synthetic rubber had firmly established this key industry in the U. S. economy.

2. REGIONAL RESEARCH UNIVERSITY

The innovations and growth of the rubber industry has been closely connected with the role the University of Akron has played since its inception in 1871, around the time when rubber industry started in Akron, Ohio. On the U.S. Independence Day, July 4, 1871, about 45 years after the City of Akron was established in 1825, a cornerstone was laid by the liberal Universalists to start a new Buchtel College to mark the centenary of the progressive Universalism in America (Knepper, 1990).

Until 1907, Buchtel College remained a private, church-related liberal arts college. It severed its close affiliation with the Ohio Universalist Convention, and remained a private college for six years before becoming the Municipal University of Akron in 1913. In the early 1960s, this was recognized as one of the nation's best municipal universities. In 1963, it became an Ohio state-assisted municipal university, converting into a full-fledged state university of Ohio in 1967.

From early years, the University of Akron played a key catalytic role in the growth of rubber industry. In 1908, Charles M. Knight, professor of chemistry at Buchtel College, predecessor of the University of Akron, not only taught chemistry but heavily consulted with the emerging rubber industry (Love and Giffels, 1999). Knight motivated his students to get out of their university research laboratory and apply their knowledge to the emerging challenges in the rubber industry. Knight helped raise money for a building to house his rubber chemistry laboratory. The building was built in 1909, and Knight taught there the world's first course in rubber science on September 13, 1910. In 1913, Knight retired as Buchtel professor of chemistry and installed one of his early students, Hezzleton E. Simmons, as his successor.

Simmons taught rubber chemistry, and continued to put emphasis on rubber chemistry when he took over as the President in 1951. He hired G. Stafford Whitby during the World War II to focus on synthetic rubber research. The research studies at the University of Akron complemented the research done by the Akron's four major tire companies, Firestone, General, Goodrich, and Goodyear. The U.S. government funded research helped establish new laboratories to do research on synthetic rubber. The University of Akron was one of the major centers to do research on synthetic rubber that helped the Allied forces in World War II to keep rapidly rolling towards victory.

The Rubber Society of the American Chemical Society awarded Whitby its highest Charles Goodyear Award. For his contributions to rubber industry, he was inducted into the International Rubber Science Hall of Fame. In 1948, Whitby persuaded Maurice Morton from McGill University in Montreal, Canada, to take over as the assistant director of the Rubber Research Laboratory at the University of Akron. Morton wrote and received a lot of grants from military to fund his research. This helped him establish a world-class technological center, and helped Akron emerge and sustain as the Rubber Capital of the World.

Then, in 1952, Morton set his goal to start an unprecedented Ph.D. degree granting research program in rubber polymers. To continue his world-class research in rubbers, he needed a regular stream of graduate students and research associates. He reasoned that the growing professionalism in the rubber industry would provide the demand for the polymer graduates. Morton approached President Norman Auburn persuasively, and was persistent till he got what he wanted. The University of Akron started its first Ph.D. program based on its most sophisticated research program in rubber, and admitted the first five students in 1956 to do their studies in polymer science.

In 1978, Dr. Frank Kelley, an alumni of the University of Akron, with many family members working at Goodyear, left a highly successful career in the Air Force to take over as the director of the Institute of Polymer Science. He became the dean of the world's first College of Polymer Science and Polymer Engineering created in 1988. It consolidated rubber and polymer related activities carried out in many different academic units of the University of Akron (Knepper, 1990). Kelley managed to increase the external grant funding for research from US$ 400,000 to US$ 9 million a year in 1996 (Love and Giffels, 1999).

President William V. Muse joined the University of Akron in 1984. Akron seemed depressed after tire plant closings and layoffs of rubber jobs. Muse noticed that "rubber and polymer science" was a niche area of excellence where the University could shine nationally and internationally. He decided that Akron needed to raise from ground a towering symbolic phoenix in the form of a shining building dedicated to do research in rubber and polymer Science. The US$ 17 million, 146,000 square-feet Goodyear Polymer Science Building was completed in 1991. It brought back the lost glory of the Rubber Capital years (The University of Akron archives). The 12-story twin-tower has an unusual structure and a reflecting façade, making it one of the most recognizable landmarks of the Rubber Capital region in the Northeast Ohio.

The College of Polymer Science and Polymer Engineering has grown into the largest and most comprehensive program in the United States, feeding most number of professionally qualified researchers into the world rubber industry. According to the last survey done in 1997 by the *U.S. News and World Report*, Akron's polymer program was ranked close second to the University of Massachusetts's program at Amherst. Akron was well ahead of some of the highly endowed private universities.

A lot of emerging polymer science is rooted in the principles of rubber science predecessor. Goodrich and GenCorp, the successor of General Tires are not active in rubber, but very deeply involved in polymers. Goodyear Tire & Rubber Company chairman Samir Gibara, pointed out that the Akron region draws more competitive advantage with the Polymer Science and Engineering Institute at the University of Akron than it would by having another two tire plants. He shared that, "It (the Polymer program) provides the intellectual legacy of the tire industry to the city" (Love and Giffels, 1999). Goodyear and Bridgestone/Firestone have maintained their research and technology development centers in Akron, because the University of Akron provides their researchers "a window to the world of polymers."

Since its start, the University of Akron has produced hundreds of Master's and Doctorate graduates in rubber science for the rubber industries everywhere around the world. A number of these highly skilled scientists have joined, and they often run a wide variety of value-adding rubber polymer companies in and around Akron. Akron University graduates lead Advanced Elastomer Systems, GenCorp, A. Schulman, Americhem, and many more leading rubber companies. Many of the international students graduating from the Polymer Science and Polymer Engineering program of the University of Akron have gone back to develop and grow rubber- and polymer-based companies in their home countries.

In 1997, this author in collaboration with a partnership with Dean Kelley of the College of Polymer Science and Polymer Engineering, innovated award-winning inter-disciplinary programs in Technology Management and Innovation. In a jointly taught course named Polymer Management Decisions, Dean Kelley and this author developed seamless cases and course materials for the Master's and Ph.D. students in Polymer Science and Polymer Engineering. Many of these students, who completed a Graduate Certificate in Technology Management and Innovation, significantly enhanced their marketability and earning potential in polymer and rubber industries.

The University of Akron also supports a number of area high schools with their focus on polymers. In 1994, an associate degree program in polymer testing and processing was started to supply highly skilled workforce for the rubber and polymer industries. The University also created in 1994 the Akron Polymer Training Center, offering testing and training in rubber processing to the people already working in the rubber and polymer industries.

In the Northeast Ohio, within 60 miles from Akron, there are more than 400 polymer and rubber-related companies drawing technological guidance from the University of Akron. This is one of the world's highest concentrations of polymer and rubber companies in a region. Some people have renamed the region from the Rubber Capital of the World to the Polymer Valley.

3. RISK-TAKING INNOVATIVE ENTERPRISES

Synthetic rubber is produced in the United States by 25 large capital intensive vertically-integrated plants, though synthetic rubber is sometimes one of the many bulk chemicals produced in these petrochemical complexes.

Many of these are petrochemical complexes with synthetic rubber production as the forward vertical integration. Some major tire manufacturers, produce synthetic rubber for their backward vertical integration. The styrene-butadiene synthetic rubber (SBR) plant of Goodyear Tire and Rubber Company in Houston, Texas, with 500 workers produced as much rubber as 180,000 rubber plantation farmers in South India (Barlow et al., 1994).

Like plastics, synthetic rubber comes in a variety of chemical compositions with different levels of performance characteristics. Emulsion styrene-butadiene rubber (E-SBR), butadiene rubber (BR), and cis-polyisoprene rubber (IR) are used in large tonnage quantities (million tons) and are sometimes referred as commodity elastomers. The medium-tonnage SRs including ethylene-propylene (EPDM), solution styrene-butadiene (S-SBR), butyl rubber (IIR), nitrile (NBR) and chloroprene (CR) are produced in 0.5 to 1 million tonne range. Highly specialized elastomers such as thermoplastic elastomers (TPE) and others are produced in smaller quantities.

Most of the consumption of rubber is in the industrial North America, Western Europe, and the north-east Asia – far away from the tropical regions where natural rubber is grown. The synthetic rubber plants are located near the heavy consumers of rubber.

EMERGENCE OF A REGIONAL INNOVATION CLUSTER FOR RUBBER TECHNOLOGY BARONS

Akron, Ohio, at the junction of 41.04 N and 81.31W, was born in 1825 when the Ohio and Erie Canal was being planned from Erie Lake moving down south. About 500 miles away from Akron, an ex Civil war surgeon, Dr. Benjamin Franklin Goodrich (1841-1888), switched from practicing medicine to oil-drilling, and then to rubber processing (Love and Giffels, 1999). With a partner he started Hudson Rubber Company in Melrose, New York near Albany. The company needed more investment but the partner refused to contribute more capital unless they moved to the west of the Allegheny mountains running through Pennsylvania, with no competition for rubber goods. Goodrich visited Cleveland in search of new investments, but most investors in Cleveland were interested in investing in shining steel mills or drilling “Black Gold” oil in the neighboring Pennsylvania (Love and Giffels, 1999).

On his visit, Goodrich saw a one-page flyer of the Akron Board of Trade’s 1870 report. He presented his business plan to the Board of Trade members who invested in his rubber venture, which led to the birth of rubber and tire industry in Akron, Ohio (Love and Giffels, 1999). (This will be elaborated in greater detail in the next section).

In 1898, Frank A. Seiberling followed the footsteps of Dr. Benjamin Franklin, and founded the Goodyear Tire and Rubber Company to honor Charles Goodyear who died penniless in 1860 stabilizing rubber. Goodyear Tire and Rubber Company started selling rubber sundries on December 1, 1898 (Rodengen, 1997). At first it primarily focused on high-volume pneumatic bicycle tires and solid carriage tires. Bicycle tire business was highly fragmented with six companies, including Dunlop, Hartford Rubber of Connecticut, and others from Chicago (Rodengen, 1997).

In 1900, Paul W. Litchfield, Goodyear’s first technically trained tire executive took over as factory superintendent at the young age of 25. As a senior at the Massachusetts Institute of Technology, Litchfield got involved into emerging rubber technology innovations and visited a number of rubber factories in New England (O’Reilly 1983). After graduation, he first joined one bicycle tire maker, and then moved to a belting company in New England. He then moved to International Automobile and Vehicle Tire Company where he designed automotive tires, before moving to Goodyear in Akron. Under his guidance as a tire designer, rubber compounder, and a factory supervisor managing personnel, Goodyear Company innovated its first automobile tire in 1901. By then, Goodyear was producing 400,000 bicycle tires per year. Litchfield steadily built Goodyear as a global rubber giant enterprise.

On August 3, 1900, Harvey S. Firestone contributed $10,000, half of the total investment used to charter the Firestone Tire & Rubber Company of Akron, Ohio, under the laws of West Virginia (Lief, 1951). At that time, Ohio’s laws imposed double liability on stockholders. Harvey Firestone had moved to Akron to work for Whitman & Barnes, a manufacturer of carriage tires, rubber horseshoe pads, and twist drills. Harvey contributed his patent for applying tires to carriage wheel channels, and his associates assigned their side wire patent to the new corporation. The early challenge for the tire industry was how to keep the tires from slipping off the wheel.

The popularity of bicycles with salesmen, engineers, and doctors and other in the 1890s had boosted the demand and production of tires. Next came the surge in demand for solid rubber tires for smoother ride on carriages. In Akron, entrepreneurs engaged in farm equipment, building construction, railways and other businesses, rapidly switched to rubber.

In January 1901, Texas Oil Industry was discovered with a big oil find. Then came the amazing rise of the automobile industry in Detroit. In 1907, Goodyear and other rubber companies established their offices in Detroit.

Cooper Tire Company also started in Akron in 1914 as a maker of tire repair kits (Love and Giffels, 1999). In 1915, it acquired Akron Giant Tire and Rubber

Company. In 1917, Cooper moved to Findlay, Ohio, about 120 miles west of Akron.

4. CATALYTIC REGIONAL INNOVATION INSTITUTION

The Akron Board of Trade, through its 1870 flyer attracted potential innovative entrepreneurs to Akron's low 18.7 mil tax rate, rich coal mines, and flour mills (Love and Giffels, 1999). The Akron Board was willing to nurture innovative new enterprises.

Dr. Benjamin Goodrich visited Akron and saw large quantities of coal being dug and transported by new railway lines transporting cereal oat products, sewer pipes, and farm machines. The fast-growing city was the home of leading enterprises like American Tin Plate, American Sewer Plate, Diamond Match, International Harvester, Quaker Oats, and others. Ten new churches were springing up near the downtown (Love and Giffels, 1999). Paved South Howard Street had fashionable shops, and Victorian mansions spread along the East Market and Fir-Hill area.

Dr. Goodrich was impressed. He met and explained his business plan for a rubber factory to the Akron Board of Trade. He was going to invest US$ 20,000, and he wanted the Board members to invest US$ 15,000 in his rubber factory which threatened none of their existing businesses. A number of board members, including president John F. Seiberling, a farm equipment manufacturer and the father of Goodyear founder, with the grandson of Akron founder Simon Perkins, each invested US$ 1,000 or less, for a total of US$13,600 (equivalent to over US$ 400,000 in 2007 dollars). Goodrich raised the other $20,000 and had enough financial capital to re-establish his rubber factory in Akron, Ohio.

Goodrich and his brother-in-law Harvey W. Tew of Jamestown, New York, opened Goodrich, Tew & Co. on Main Street Akron, south of Exchange and near Lock One of the Ohio Canal. The company's major product was fire hose, but it also produced other rubber goods such as belts, bottle stoppers, rings for fruit jars, valves, tips for billiard cues and more.

The first five years were financially rough for Goodrich. The investors wanted their money out. Dr. Goodrich bought them out for US$ 12,500 with help from Colonel Perkins. The company's stock at US$ 50,000 was raised in 1880 to US$ 100,000 and the company was incorporated as BF Goodrich. The company's financial performance improved with the bicycle boom of the 1880s, continuing until the late 1890s.

In the 1880s, John Boyd Dunlap of Belfast, Ireland obtained in England fairly broad bicycle tire patents. He then also captured other key patents for fastening the pneumatic tires to a flat-base flange. This helped Dunlap gain a substantial market share in the global pneumatic tire industry. BF Goodrich produced the first pneumatic tires in the United States in 1896 for the Cleveland-based Winton automobile (O'Reilley, 1983).

The Panic of 1893 and the subsequent economic depression shrank 2,000 jobs in Akron with 40,000 residents, and made it easier for companies to hire skilled unemployed. America's first gasoline-powered Duryea automobile was introduced in 1892. Soon thereafter a number of automobiles, including Autocar, Ford, Stanley-Steamer, Hertel, Haynes-Apperson, Oldsmobile, and others were introduced (O'Reilley, 1983). Michelin of France was the first to install pneumatic tires on automobiles. By 1908, the horse-drawn carriages were being replaced by 65,000 automobiles produced in the U.S.

With 40 of the 134 U.S. tire companies located in Akron by 1920, Akron became well known around the world as the Rubber Capital of the World (O'Reilly, 1983). There was a rubber company on every other city block. Between 1910 and 1920, Akron was one of the fastest growing cities in the United States. During this period, its population tripled from 69,087 to 208,435 with the rapid expansion of rubber-related enterprises. Here the rubber barons blended their entrepreneurial ambitions with emerging technological innovations and their capital to multiply their wealth to dizzying levels.

Workers from nearby steel mills and coal mines of West Virgina and Pennsylvania, and the poor hopefuls from the Southern states of Kentucky and Tennessee, migrated in large numbers to Akron looking for the well-paying rubber jobs. So did hundreds of workers from distant Hungary, Russia, Italy, and Austria rushing in seeking "the Black Rubber Gold." Housing shortage was so severe in this boomtown that workers rented beds by 8-hour shifts. Some workers' families were willing to live in chicken coops. By 1930, more than 40 percent of the tires made in the United States were made in Akron's rubber enterprises (O'Reilly, 1983). The Great Depression in the 1930s slashed the demand for automobiles and rubber tires and Akron's population declined by 4 percent.

As mentioned before, the rubber enterprises in Akron, however, rebounded during the World War II. Rubber industry became part of America's winning giant industrial-military complex. The Goodyear Aircraft Company employed 32,000 workers at its peak. After the end of war, the rubber industry in Akron shrank a little. But, it had a healthy growth for the next 20 years – until the twin shocks from the disruptive radial tire innovation and the sky-rocketing oil-prices.

5. DISRUPTING RIVAL RADIAL TIRE INNOVATORS

A national innovation policy may encourage an enterprise to become more innovative, but the enterprise must still compete in the dynamic marketplace with its rivals. Alternate technological innovations continually compete to emerge as the dominant design and the preferred technology standard in an industry (Gehani, 1998). Utterback and Abernathy (1975) examined the dynamic pattern of product and process innovations, and defined dominant design as the product innovation when a number of product innovations converge to a commonly accepted product design.

Foster (1986) suggested that often incumbent technological leaders get complacent, and new-generation innovators gain "attacker's advantage." Bower and Christensen (1995) noted that as markets shift, the industry leaders with large investments sunk in their existing technologies (who were once disruptive innovators themselves); fail to see the emerging disruptive innovations coming from the potential or new challengers. The incumbents resist making large investments in new technological innovations to reach out to the emerging new customers. Bower and Christensen (1995) postulated that the new disruptive technologies demand a portfolio of competencies that are different from those of the incumbent technological innovations and the existing customers (Gehani, 1998).

Christensen (1997) also pointed out that prudent business strategies, such as investing in the most profitable products currently in high demand by the best customers, can weaken an industry leader. Based on his studies of a number of industries, Christensen noted that breakthrough technologies and disruptive innovations may be overlooked because many existing customers may be lukewarm at first to such radical discontinuous innovations. Customer driven incumbents may choose to overlook such strategically significant innovations. This allows more nimble entrepreneurial innovators "to catch the next great wave of industry growth" (Christensen, 1997). This phenomenon is vividly illustrated by the evolution of rubber and tire industry.

In 1946, Pierre Boudon, related to the Michelin founding family, was granted a patent for a new radial type of tire construction (Love and Giffels, 1999). The reinforcement in radial tires is aligned along the tire cross-section instead of being in biased cross plies as in the conventional tires. The radial tires had approximately 7% higher fuel economy and almost twice the durability of a bias-ply tire. But these tires had a less smooth and harder ride (Rodengen, 1997). The radial tires also had the propensity to delaminate. They required new tire-building equipment, and they were lot more costly to produce. Radial tires sold for 65% more than the bias-ply tires.

In the mid-sixties, Michelin received a large order to sell radial tires in the U.S. through Sears and Roebuck, and the fear of radial tire innovation spread through the U.S. automotive and tire industries. The radial tires required expensive retooling for the auto industry as well as the tire industry. Some of the senior tire executives, who held previous assignments in Europe, feared that sooner or later the radial tires would be adopted by a large number of American consumers.

In 1970 and 1971, only 1% of replacement tires were radial tires (Rodengen, 1997). As the gas prices soared higher and higher in the 1970s, increasing number of consumers adopted the radial tire innovation for its higher fuel efficiency and durability. Diffusion of adoption of radials for replacement tires increased rapidly to more than 14% in 1973, and almost to 25% by 1975.

Michelin management was fully committed to spread the radial revolution. Between 1971 and 1975, it invested over US$1 billion globally to convert and modernize a majority of their 45 plants around the world, and emerged as the third-largest tire maker in the world and the largest tire-maker in Europe, edging past Dunlap (Rodengen, 1997). Ford started fitting radial tires on its Continental cars, and new models (Rodengen, 1997; Financial World, 1974). In 1975, Michelin opened its first North American tire making plant in South Carolina, making 80 million radial tires a year.

Goodyear, Firestone, Goodrich, Uniroyal, General and others first resisted the disruptive innovation of radial tire technology innovated by Michelin. But, Goodrich first saw the significance of the radial tire innovation, and stopped making passenger tires in Akron in 1975. In 1978, Goodyear Tire and Rubber Company shut down its rubber tire factory in Akron. Firestone rushed to launch its 500 Radial tire truck in the market. But the tread peeled off, and Firestone was forced to have one of the U.S. rubber industry's largest tire recalls (Love and Giffels, 1999). Firestone shutdown its rubber tire plants in Akron in 1981. Between 1975 and early 1982, more than 6,100 rubber tire jobs were lost. The rubber workers had played a key collaborative role in the rise of the rubber industry in the Rubber Capital Akron. They were also going to play an equally significant role in its demise in Akron by deepening the cracks caused by Michelin's radial revolution.

6. COLLABORATIVE INNOVATIVE SUPPLIERS

Finally, under a National Innovation System, enterprises do not operate or compete in isolation by themselves. They compete based on the help and support they receive from their collaborative suppliers. They innovate by partnering with their collaborative suppliers. Suppliers who collaborate and help their buyers innovate provide a strategic source of competitive advantage. Wal-Mart and Microsoft dominate their respective industrial sectors, not only because of the innovations of their founders, their competitive strategies, but also because of the powerful supplier ecosystems they have developed (Lansiti and Levien. 2004). Their supplier ecosystems include their worldwide suppliers, outsourcing partners, distributors, and producers of supporting technologies. Together these network relationships boost the health and vigor of their ecosystems by creating and sharing platforms of products, services, tools, and technological innovations to gain their competitive advantages.

For the rubber tire manufacturers, the labor-intensive tire building is a key capability that drives their competitive advantage. Supply of skilled, affordable, and willing rubber workers can make or break an innovative rubber and tire enterprise. Workers' unions govern the supply of a steady stream of able and willing workers needed to run tire building equipment. Akron emerged as a regional cluster and the Rubber Capital of the World in 1920 because of the steady stream of skilled immigrants and migrant workers from the neighboring West Virginia, Pennsylvania, Kentucky and Tennessee. Deteriorating relationship of management with United Rubber workers' union also led to the downfall of the Rubber Capital in the 1960s.

The robust growth of the rubber factories in the 1920s was firmly founded on the backs of poor Appalachian whites from the East, and the poor African-Americans from down South. As the rubber industry grew, more African-Americans migrated from the South. In 1910, there were only 657 African-Americans living in Akron. Their number increased to 5,580 in 1920, and it exceeded more than 10,000 by 1930 (Dyer, 2003). The World War II expanded the need for workers in rubber and allied industries, and in the 1940s more than 12,000 African-Americans migrated to the Rubber Capital in Akron. Let us examine how the role of rubber workers' union pulled the final curtain down for the rubber industry in the Rubber Capital of the World.

In April 1979, M. G. "Jerry" O'Neil, the Chairman of General Tire, was heading the only rubber company in the region still running a full-scale truck-tire building with 1,265 workers (Dyer, 2003). It's Plant I was a relic built in 1915 with a multi-story design and wooden floors. The more modern tire plants used a single-storey design with a more efficient production flow. O'Neill addressed workers and requested them for a pay cut to pay for building a more modern single-story tire building plant.

Akron, with a strong rubber workers' union had negotiated higher wages, and therefore a higher cost of doing business compared to the Southern parts of the United States with unorganized labor and lower wages. Larger land needed for a single-story tire plant was cheaper in the South.

The Local 9 Union bent its rules and agreed to take a 36 cents an hour pay cut – to pay for building the new single-story plant (Love and Giffels, 1999). The new plant was proposed to be built near Akron Municipal Airport, or in the nearby Northfield. The money was promised to be returned to workers if the plans to build the new plant were to be canceled. The rubber workers agreed to work on Sundays and that they would run the proposed plant unprecedented 7 days a week. Managers were granted the discretion to assign workers their jobs irrespective of their seniority. The rubber workers agreed to compromise because they recognized and accepted the new threat of global radial tire competition in rubber industry.

O'Neil carefully considered the union workers' concessions, but re-examined the bottom line, and proposed to shut down Plant-1 in Akron in February 1982 (Dyer, 2003). Investment in the new single-story plant in and around Akron did not seem financially attractive enough for the General Tire management.

Five years later, in 1987, General's Tire plants were sold to German Continental AG. Other parts were retained as Gen Corp. O'Neil retired as the chief executive of Gen Corp in 1993 (Dyer, 2003).

Between 1960 and 1979, at least 24 of the 31 tire plants built in the United States were built in the South with no organized unions. The union of rubber workers could not demand increase in salaries in the South to match the inflation in cost of living. Most of the rubber plants in Akron were not modernized or re-equipped with the radial tire technology innovation (Dyer, 2003).

Prior to these plant closings, Akron already had a high 15% unemployment. Tire building workers, who were used to earning a high $13/hour wage, were willing to take any work at a fraction of their former wages after these plant closings. When a nearby Land 'O Lakes dairy factory announced the opening of 74 minimum wage jobs, more than 7,000 applications flooded in (Love and Giffels, 1999).

By 1983, Akron was left with very few tire building rubber jobs. Rubber plants and head-offices were shut down and moved to the South. Ironically, the South was the place from where legions of workers had earlier migrated to make Akron the Rubber Capital of the world. Between 1970 and 1990, more than 50,000 people, and about a fifth of Akron's population went away. Housing units in Akron declined in the 1980s (Dyer, 2003).

To survive the downfall, Goodrich and Uniroyal first merged their tire operations in 1986. But, their corporate cultures were too rigid to blend. Three years later, the combined company was sold to Michelin Tire company of France. In 1994, Michelin moved its tire production facilities in Akron to Greenville, South Carolina (Dyer, 2003).

Goodrich, turned into primarily a chemical and aerospace company, and moved out of Akron to Bath township in 1986. It then shifted to Richfield in 1996. Goodrich's former multi-storey tire plant on Main Street in Akron was remodeled to house Akron Global Accelerator with multiple start-up companies. Its former factories were transformed into offices occupied by Advanced Elastomer Systems, a joint-venture between Exxon and Monsanto, developing thermoplastic elastomers (TPEs) – the next-generation of specialty synthetic rubbers (Dyer, 2003).

MANAGERIAL IMPLICATIONS AND FUTURE RESEARCH

This empirical study of innovations in rubber and tire technology has illustrated that a tri-helical National Innovation System can kick start innovations in an emerging risky technology. The synergistic interactions between government, university, and industry can also give birth to innovative new high-growth regions. However, as illustrated by the evolution and innovations in rubber industry, in the long run the innovative enterprises must withstand the dynamic external challenges posed by their disruptive rival innovators and other geo-political environmental forces. In such difficult times, the support of collaborative innovative suppliers of key resources, either raw materials or human capital, must not be underestimated.

Our future studies would focus on the financial analyses of leading innovators in a National Innovation System. These new investigations would help us validate the reasons for, and results from, the key strategic decisions regarding relocating production plants away from a regional innovation cluster while incurring enormous financial and human expenses.

In the case of rubber and tire technology, the innovative enterprises such as Goodrich, Firestone, General Tires, and Goodyear, bore the full impact of the tsunamis from their key stakeholders, while their national government stood on the sidelines. In the free-market capitalist economy, the national U.S. government did little as tens of thousands of rubber workers were laid off with grave consequences for their family members and their communities. In emerging economies like Brazil, India, or Thailand, can their national governments afford to standby as their large enterprises are forced to adapt to the tectonic shifts in their global market forces?

It is, therefore, proposed that corporate strategic leaders and national policy makers carefully assess and integrate the impact of disruptive innovations by the key rivals and consider the full potential contributions from their collaborative suppliers. These must be integrated in an inter-dependent manner with the national innovation policy, regional innovation accelerator institutions, and the key regional universities and institutions of higher education most relevant to the firms' technologies.

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