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Technological innovations and industry clustering in the bicycle industry in Taiwan

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A B S T R A C T

This study explores technological innovations and industry clustering in the bicycle industry in Taiwan. It shows that clustering in the bicycle industry not only decreases transaction costs among the firms in the cluster but also increases cooperation and efficiency between the bicycle manufacturers and their partners as a result of standardization and modularization of bicycle components. Following a patent analysis, the study finds that two systems—the wheel system and the bicycle frame system—are the strengths of Taiwanese bicycle and component manufacturers; conversely, the transmission (i.e., gears) and brake systems are their weaknesses. Moreover, industry clustering increases the efficiency of information exchange such that the spillover effect of technological innovation is significant.

1. Introduction

Until China's recent emergence as an economic power, Taiwan was the world's leading bicycle manufacturing country. Most people assumed that large orders by original equipment manufacturers (OEMs) helped Taiwan attain this position, but they did not realize that considerable technological innovation has enabled Taiwan to attract foreign customers who place orders with Taiwanese bicycle companies. Ongoing technological innovations by those bicycle manufacturers and component manufacturers have never stopped, and R&D expenditures have remained constant at about 2% to 5% of sales.

While most OEM orders were transferred to bicycle manufacturers in China, Taiwan's bicycle manufacturers and bicycle component manufacturers took advantage of their technical expertise and manufacturing technology to build their own brands. For example, Maxxis is the largest bicycle tire manufacturer in the world; the roller chain made by KMC accounts for 70% of world market share; bicycles made by FSA are highly favored in Europe; and the bicycle brakes made by PROMAX, particularly its mechanical disc brakes, account for 90% of world market share.

Moreover, GIANT and Merida, two well-known bicycle brands, already enjoy a strong reputation worldwide. It is apparent that technological innovation is the foundation of the progress enjoyed by the Taiwanese bicycle industry to date. Although the industry is about 50 years old, it made little progress until the 1970s when Taiwan's bicycle manufacturers went to Japan to learn about standardization of bicycle components, which in turn helped them understand bicycle specifications. This contributed to the development of new technologies and products for Taiwan's bicycle industry.

In the 1970s, critical technological innovations for bicycles, such as welding technologies and carbon–fiber manufacturing technologies, laid the foundation for the today's bicycle industry in Taiwan. Now the industry has formed an industrial cluster, and many technological innovations and business operations in one bicycle company often influences another.

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We explore technological innovations in Taiwan's bicycle industry from the perspective of industrial clustering, then how to obtain competitive advantages as a result of clustering. Finally, we discuss the relationships between technological innovations and industrial clustering.

2. Overview of Taiwan's bicycle industry

Table 1 illustrates the major bicycle manufacturing countries in the major world markets. It shows that Taiwan is second only to China in terms of market share in the U.S. and Japanese markets, but first in the EU market [1].

The development of Taiwan's bicycle industry can be divided into six stages:

2.1. Assembly stage (1946–1951)

Bicycles were the major form of transportation in Taiwan during the Japanese occupation following World War II, even though that most bicycles and related components were imported from Japan. When the war broke out, Taiwan's bicycle industry experienced sharp growth because Japanese imports were unable to reach Taiwan, thus giving small and medium-size bicycle manufacturers an opportunity to grow with much less competition. Nevertheless, most Taiwanese manufacturers imitated Japanese bicycle components.

2.2. Import replacement and stagnation stage (1952–1968)

In 1952, the Taiwanese government adopted policies that limited imports in order to save foreign reserves. For the bicycle industry, this meant only twelve bicycle components could be imported, including the frame, chain, brake, gear, etc. On the other hand, the government encouraged local bicycle manufacturers to increase their manufacturing capabilities. This gave the manufacturers greater confidence to expand their businesses and lay a foundation for future growth. Bicycles became the major means of transportation during this period, and domestic demand was high. However, about this time counterfeits of Taiwan bicycles began to appear in the market, which resulted in a price war. As a result, the motorcycle industry increased in strength. All these factors contributed to a dark era for the bicycle industry in Taiwan.

2.3. Export-oriented production (1969–1974)

The energy crisis of the early 1970s resulted in a major uptick in the use of bicycles in the U.S. Add to that heightened interest in exercise and health care, with both factors promoting greater demand for bicycles. This contributed to a greatly flourishing bicycle industry in Taiwan. As a result, the Taiwanese bicycle industry began to export its products to the U.S. This decision was helped considerably by a large OEM order from Schwinn, the largest bicycle manufacturer in the U.S. Consequently, the number of exported Taiwanese bicycles from 100,000 in 1970 to one million in 1972. Growth might have been even greater except that a large quantity of low-quality bicycles were also shipped, which greatly undermined the image of Taiwanese bicycles.

2.4. Growth stage (1975–1986)

The Taiwanese bicycle industry experienced significant and continuous growth from 1975 to 1986, as Taiwan's bicycle companies strived to improve their quality and reputation, and the bicycle and components manufacturers cooperated to increase production quality and quantity. With a large order from BMX (Bicycle Motocross), Taiwan surpassed Japan in 1985

Table 1
Market share of major bicycle manufacturing countries (2006).

Major bicycle markets of the world					
U.S.		Japan		EU	
Manufacturing Country	Market Share	Manufacturing Country	Market Share	Manufacturing Country	Market Share
China	74%	China	79%	Taiwan	39%
Taiwan	18%	Taiwan	17%	Vietnam	13%
Italy	4%	Vietnam	2%	Poland	12%
Hong Kong	3%	Others	2%	Philippines	9%
Canada	1%			Lithuania	6%
				China	5%
				Czech	5%
				India	5%
				Bangladesh	4%
				Tunisia	2%
Total	100%	Total	100%	Total	100%

Source: [1].

to become the second-largest bicycle manufacturing country. By 1986, Taiwan's bicycle industry had the ability to make 10 million bicycles per year, although most were low-quality bicycles with correspondingly low prices.

In 1984, the government helped bicycle manufacturers establish an integrated supply chain system to control the quality of bicycle manufacturing. This gave manufacturers an opportunity to develop advanced technologies and manufacturing skills, and to share their know-how and experience with their partners, and eventually they received OEM orders form large foreign bicycle companies. With efficient coordination, industrial clustering, and the integrated supply chain systems, the bicycle industry greatly increased its competitive advantage globally.

2.5. Upgraded manufacturing (1987–1991)

Due to rising costs and competition from China and other southeast Asian countries, Taiwan's bicycle manufacturers moved their lower-quality bicycle production assembly lines to countries with lower manufacturing costs. At the same time, and with help from the government, Taiwanese bicycle companies began to upgrade their manufacturing capabilities using the latest materials and manufacturing processes.

2.6. Globalization stage (1992 to present)

In response to the changing global business environment, to maintain competitive advantage, and to pursue sustainable development, most Taiwanese bicycle manufacturers have now moved their factories to China. They receive orders in Taiwan, but take advantage of cheaper labor and do most of the manufacturing in China. Taiwanese bicycle manufacturers are good at innovation, and their bicycles now have a high reputation worldwide. Today they develop their own brands, including GIANT, and now occupy a strong position in the competitive business environment.

3. Exports

Table 2 shows the growth of exports in Taiwan's bicycle industry from 1993 to 2006. In 1996, exports reached a peak of some 9.5 million bicycles, but by 2006 this number had decreased to 4.31 million. The average price per exported bicycle rose from $103 in 1993 to $200 in 2006, owing to the fact that Taiwanese bicycle manufacturers changed their business models to fit today's dynamic environment, and are now exporting their high-price and high-quality bicycles to the market [2]. The result is that Taiwanese bicycle companies have moved to the top position. Moreover, they have moved away from the role of OEMs, instead becoming original design manufacturers (ODM) or original brand manufacturers (OBM), thereby striving to be specialized value-added bicycle manufacturers.

Taiwan's bicycle manufacturers generally export 80% of their products, which implies that the industry is influenced by the global business climate. In Taiwan's bicycle industry, the main upstream bicycle components include rolled steel, aluminum alloy, rubber and paint; midstream components include the bicycle frame, chain, hub axle, brake set, gear, handlebars, and wheels. Although the country's bicycle manufacturers are quite capable of producing an entire bicycle themselves, foreign buyers of Taiwanese bicycles often insist that certain components be made by a specific foreign brand, such as gears by Shimano. In addition, the patents on these critical bicycle components constitute a major barrier that hampers technological innovation in Taiwan's bicycle industry. Therefore, it is crucial that Taiwanese bicycle manufacturers break through these bottlenecks so they can support local bicycle component manufacturers.

Table 2
Taiwanese bicycle industry exports.

Year	Quantity of bicycles	Growth rate (%)	Export amount (million $)	Average unit price ($)
1993	8,621,237	2.30	888.7	103.09
1994	8,751,660	1.51	842.3	96.24
1995	9,064,129	3.57	907.3	100.10
1996	9,503,365	4.85	836.1	87.98
1997	8,826,513	−6.93	758.7	85.95
1998	9,388,311	7.64	925.9	98.62
1999	7,908,532	−15.76	916.6	115.90
2000	8,877,738	12.26	876.4	98.71
2001	5,595,865	−36.97	622.4	111.23
2002	4,760,447	−14.93	613.1	128.80
2003	4,562,892	−4.15	668.9	147.79
2004	4,957,822	8.66	805.1	162.39
2005	4,746,735	−4.25	891.6	187.83
2006	4,316,417	−9.07	865.3	200.47

Source: [2].

4. Four major crises demonstrate industry flexibility

The period between 1970 and 2000 was a time of great change in Taiwan's bicycle industry. Four major incidents caused setbacks, but manufacturers were always able to turn these crises into opportunities. During these three decades, the technological capabilities and manufacturing capacities of Taiwan's bicycle manufacturers grew substantially. Table 3 lists the four crises, and how manufacturers broke through the bottlenecks to bring substantial change to the industry.

Taiwanese bicycle manufacturers beat American manufacturers with lightweight bicycles; they beat the Japanese with BMX (Bicycle Motocross); they landed in the European market with MTB (Mountain Bikes); and they swept across the world with high-quality shock absorber and aluminum alloy bikes [3]. This shows the capability and flexibility of Taiwanese bicycle manufacturers.

Table 3 also shows that during each crisis, Taiwanese bicycle manufacturers responded by developing a new type of bicycle, brought it to market, and saw it become a popular new model. One of the strengths of Taiwanese bicycle manufacturers is their flexibility—in this case the ability to respond to these crises rapidly. But innovation is equally critical, and Taiwanese bicycle manufacturers focused their R&D efforts on developing new materials for bicycle frames.

4.1. R&D breakthroughs

In trying to develop new materials, Taiwanese bicycle manufacturers always look for which new materials that can be applied to the bicycle frame, because it is the main structure of the bicycle and creates two-thirds of its weight. Table 4 shows the development stages of various bicycle frame materials and manufacturing technologies. Each new technology represents a technical breakthrough, which enabled Taiwanese bicycle manufacturers to gain competitive advantages.

Taiwanese bicycle manufacturers had experienced a number of breakthroughs in bicycle technology. For example, finding and successfully adopting carbon–fiber materials was an important and successful innovation paradigm for Taiwanese bicycle manufacturers. The characteristics of carbon fiber are extreme hardness, anti-corrosion, and low weight. Bicycle riders feel the flexibility, low weight, and high quality of the bike when the frame is made from carbon fiber [4]. Prior to its application to bicycle manufacturing, carbon fiber was widely used in products such as tennis rackets, golf clubs, and aviation materials. Now it is also used in response to customer demands for lightweight bicycles.

Beginning in late 1984, the Industrial Technology Research Institute of Taiwan (ITRIT) was charged with implementing the Carbon–Fiber Bicycle Development Project, funded by the Taiwanese government. Initially, many Taiwanese bicycle companies participated in this R&D project but they later withdrew for financial reasons. However, GIANT continued to participate, thus reaping substantial benefits. It was a great opportunity for GIANT to upgrade its technological capabilities, but it was not easy to manufacture the carbon–fiber bicycle frame. Although GIANT continued to lead the Taiwanese bicycle industry, any failure that might result in a loss of its huge R&D investment would be devastating. However, in 1988 the first carbon–fiber bicycle was successfully developed, manufactured, and sold by GIANT, and by 1993 its annual production capacity had reached 100,000 bicycles. Later, the Materials Research Laboratories (MRL) and ITRIT transferred the technology for manufacturing carbon–fiber bicycle frames to other Taiwanese bicycle manufacturers. It is clear that the Taiwanese bicycle manufacturers relied on the Taiwanese government and semiofficial institutions before they accumulated enough resources to engage in R&D projects on their own [5].

As GIANT began to mass-produce carbon–fiber bicycles (before that, only some Italian and French bicycle manufacturers produced handmade carbon–fiber bicycles), Merida took the lead in developing the first aluminum alloy sport bicycle in 1993. Moreover, in 2002 Taiwan Hodaka applied a new magnesium alloy (also used in missiles) to develop advanced bicycle frames. Taiwanese bicycle manufacturers went to great effort to upgrade their capabilities, but that investment enabled them to obtain international competitive advantage and to succeed in the world markets.

5. Bicycle industry clustering

The concept of industrial clustering has attracted much attention during the past decade, both as an increasingly important phenomenon and as a basis for networking players within the same region [6]. Beaudry [7] found that industrial clustering influences industry entry, growth, and patenting. Other recent studies address the effects of spatial proximity among firms and show that industrial clustering can lead to innovative activities [8]. Thus, technological capability can be

Table 3
Four major crises faced by Taiwanese bicycle manufacturers.

Year	Background	Popular bicycle types	Technological development and breakthrough
1973	The first energy crisis	BMX (Bicycle Motocross)	Electric welding technology
1979	The second energy crisis	MTB (Mountain Bike)	Gas welding, Lightweight bicycles
1991	The Gulf War	High quality shock absorber and its components	Lightweight bicycles, Aluminum alloy manufacturing process
2001	Globalization economy recession	Compound materials were widely applied to the bicycle manufacturing	R&D capabilities upgrading for satisfying the market need

Table 4
New materials and technologies in Taiwanese bicycle manufacturing.

	Bicycle Manufacturing Technology	Material
Before 1983	Copper welding	Steel tube
1983–1987	MIG (metal inert gas) welding or TIG (tungsten inert gas) welding	Alloy steel
1988-1993	TIG welding	Aluminum alloy
	Agglutination	Carbon fiber
1994–1999	TIG welding	Titanium alloy
	One-piece forming	Carbon fiber
After 2000	Die-casting	Magnesium alloy

fostered through geographical clustering [9]. Based on previous studies, this study explored how interaction between technological R&D and industrial clustering influence technological innovations in the bicycle industry in Taiwan, as well as how to obtain competitive advantages from clustering.

Geographic, cultural, and institutional proximity offers companies numerous advantages, including special access, closer relationships, and better information communication [10]. Clusters reveal important insights about the role of geographic proximity in competitive advantage, but they also necessitate new roles for companies, government, and other institutions seeking to enhance competitiveness [11]. Clusters influence competition in three ways: (a) by increasing the productivity of companies within the cluster; (b) by driving the pace and direction of innovation; and (c) by stimulating entrepreneurship within the cluster [12]. In general, firms cluster in a particular location to take advantage of strong local demand and to reduce consumer search costs [13]. A variety of intermediate inputs at a cheaper price can be obtained by companies that are part of an industrial cluster that also includes specialized local suppliers.

An industrial cluster typically attracts many skilled workers [14]. In addition, infrastructure benefits, such as access to major highways, railways, and airports, is another advantage. Information communication can create knowledge spillovers, which are in turn facilitated because tacit knowledge flows more easily within a cluster [15]. While knowledge is more vague and difficult to codify, it is better transmitted through repeated face-to-face interactions, which are better managed in close proximity [16]. Therefore, industrial clusters often are localized to facilitate knowledge flows and general communication among the various parties [17]. This implies that firms will be more innovative when located in an industrial cluster than when isolated from others [18].

Previous studies found that industrial clustering encourages increased technological innovations, while decreasing transportation time and cost between related upstream and downstream companies, owing to the shortened geographical distance [19,20]. In addition, communication efficiency is high, and the cost of communication is lower within the same industrial cluster, making communication more convenient [21,22]. Industrial clustering enables frequent and efficient information exchanges [8], which makes it not merely beneficial to technological innovations but also helpful to formal or informal communications [23,24]. Another benefit of industrial clustering is sharing the cost of infrastructure and resources, which gives an industry cluster the advantage of increased synergies [25,26].

5.1. Positive effects of bicycle industry clusters in Taiwan

Our study identified a number of beneficial effects growing from the decision to create industry clusters within Taiwan's bicycle industry. A few are discussed below.

5.1.1. Decreasing transaction costs

Oriental societies emphasize interpersonal relationships, so interpersonal networking is a catalyst for forming industrial clusters. The formation of a Taiwanese bicycle industrial cluster is based on a spontaneous social network created amongst relatives, partners, friends, and/or ex-colleagues, for example [27].

Transaction costs fall into two types: *ex ante* transaction costs (i.e., costs of searching for information, negotiations, decision making, and contract evaluation), and *ex post* transaction costs (i.e., costs of monitoring, implementation of agreements, and goods examination) [28]. Many factors determine transaction cost, such as bounded rationality, opportunism, uncertainty, and complexity of environments, small size of transaction, and asymmetric information, among others, and these may result in further consequences such as moral hazard and adverse selection [29].

Communication among Taiwanese bicycle manufacturers and bicycle component manufacturers within the same industrial cluster is quick. Taiwanese bicycle and bicycle component manufacturers have close interpersonal networking relationships, so communication efficiency is high and the cost of communication is low, thus decreasing the cost of information searching and reducing the possibility of asymmetric information [30]. Although close communication within the Taiwanese bicycle industry may bring with it the risk of imitation, the positive benefits of industrial clustering are useful for expanding mutual trust between the bicycle manufacturers and bicycle component manufacturers, which in turn is beneficial to developing new products and standardizing products and components.

On the other hand, industrial clustering can also have the effect of binding up closer reciprocal linkages to further coordinate and integrate their respective movements, and speed up information exchange [31]. Therefore, the industrial clustering is beneficial to the bicycle manufacturers and bicycle component manufacturers and is a catalyst for technological development [32].

5.1.2. Standardization and modularization of bicycle components

Nowadays, most bicycle components and their connecting interfaces have become standardized within the Taiwanese bicycle industry, so they can be supplied to most Taiwanese bicycle manufacturers. Moreover, there are a number of bicycle components that require a strong interface to ensure that the components can perform the required function.

Among the key success factors in Taiwan's bicycle industry is setting up appropriate interface compatibilities among the bicycle components and establishing common standards or specifications through close linkage and integration from upstream to downstream. Standardization of bicycle components means that during the early R&D stage the interface compatibility and common specification of each bicycle component must be taken into consideration. By 1996, Taiwanese bicycle and components manufacturers realized the benefits of standardizing bicycle components, thus establishing interface compatibilities of major components during their respective R&D stages.

Taiwanese bicycle and bicycle components manufacturers modularize their bicycle components to improve quality control of their products. Modularization means integrating several related components into one unit or system. The best example is the integrated bicycle hub created by the R&D Center of Taiwan's bicycle industry—a front fork, disc brake, and V-brake as one oil pressure disc brake—creating the world's first modular bicycle unit. In today's uncertain and complex business environment, modularization of components is essential for managing the growing complexities associated with product varieties, costs, time, and quality.

In many respects, the development of component modules is a good strategy. Bicycle manufacturers found ways to increase manufacturing efficiencies by using common components, procedures, and designs while still offering a wide range of products. Standardization and modularization of bicycle components offers several key advantages, as follows:

- Less manufacturing complexity, optimal efficiencies of scale, and greater manufacturability.
- Reduces the costs of manufacturing and purchasing by enabling procurement in volume.
- Provides a wide variety of products that use common components, common procedures, and common designs.
- Improves product quality because tested and qualified components make bicycles and components more reliable.

In the past, Taiwanese bicycle and bicycle component manufacturers did not utilize the concept of integration and coordination, but by accepting standardization and modularization, Taiwanese R&D authorities and institutions invited various bicycle manufacturers or bicycle component manufacturers to jointly participate in the early stages of R&D activities. As a result, standard bicycle components and modules can be used throughout the whole bicycle industry. This in turn enhanced their manufacturing and R&D competitiveness, giving them a sustainable competitive advantage.

Table 5
R&D events by major semi-official R&D institutions, on behalf of the Taiwanese bicycle industry.

Semi-official R&D Institutions	Significant R&D Event
Metal Industrial Research & Development Center of Taiwan	• July 1989: assisted Taiwanese bicycle manufacturers by implementing "The Development Project of Bicycle Components" • February 1990: successfully developed aluminum alloy forging and welding processes. • August 1990: successfully developed an electric-arc welding technology used on aluminum alloy components using funds provided by the Ministry of Economic Affairs.
Materials Research Laboratories (MRL), Mechanical Industry Research Laboratories (MIRL), and Union Chemical Laboratories (UCL) of Industrial Technology Research Institute of Taiwan	• May 1987: successfully developed a carbon–fiber bicycle frame. • March 1988: Industrial Technology Research Institute of Taiwan transferred five technologies to assist Taiwanese bicycle manufacturers in upgrading their R&D capabilities. • August 1990: MRL of Industrial Technology Research Institute of Taiwan jointly developed a corrosion-resisting aluminum material with Taiwanese bicycle manufacturers. • September 1990: MRL and Taiwanese bicycle manufacturers jointly developed compound material for use on one-piece bicycle frames. • July 1991: MRL successfully researched one-piece technology for carbon–fiber bicycle and transferred this technology to bicycle manufacturers in July 1992.
R&D Center of Taiwan Bicycle Industry	• July 1990: provided technical support and jointly developed modular units of bicycle components. • July 1991: executed the R&D project of the bicycle transmission components

Table 6
Patent held by Taiwanese bicycle or bicycle component manufacturers (1987 to 2006).

Item	Wheel system	Bicycle frame system	Transmission system	Brake system	Bicycle components	Total
Year						
1987	65	33	11	4	19	132
1988	42	9	5	5	5	66
1989	37	25	4	6	23	95
1990	87	21	14	3	19	144
1991	110	41	17	6	29	203
1992	95	39	19	3	32	188
1993	81	45	13	15	30	184
1994	79	51	18	20	31	199
1995	104	76	23	33	67	303
1996	52	51	25	31	50	209
1997	46	50	26	45	53	220
1998	25	46	20	21	38	150
1999	41	72	16	25	29	183
2000	87	88	49	25	58	307
2001	96	142	40	24	63	365
2002	58	88	40	22	44	252
2003	64	91	43	25	57	280
2004	70	93	45	27	61	296
2005	76	98	51	30	64	319
2006	77	99	54	35	66	331

Source: [2].

Although industrial clustering in the Taiwanese bicycle industry increases competition, it also encourages innovation, enables frequent and fast information exchanges among companies, and optimizes the spillover effect of technological innovations [33].

6. Innovations in Taiwan's bicycle industry

Innovation is the key driver of competitiveness and productivity [34]. Achieving technological innovation depends on the attainment, accumulation, and application of knowledge and information [35]. These processes rely heavily on the involvement of human resources that have technological knowledge and technical skills [8]. Innovation is an internationally distributed system of activities and therefore geographically localized and clustered firms are likely to form only a limited set of the total actors engaged in such a system [36].

A majority of enterprises in Taiwan are small and medium enterprises (SMEs) that lack capabilities and resources, and they account for about 98% of the total number of manufacturing enterprises. To increase the competitive advantage of Taiwanese SMEs and upgrade their R&D capabilities, the Center-Satellite Plant System Promotion Committee (CSPSPC) was established in July 1984 by the Industrial Development Bureau, Ministry of Economic Affairs of Taiwan. The goal was to assist Taiwanese industries in establishing their center-satellite plant systems, consolidate their supply chain management, and encourage complementarities, coexistence, and prosperity within them. In 1990, CSPSPC was reorganized into the Corporate Synergy Development Center (CSDC). CSDC promoted the Project of Center-Satellite Plant System to help Taiwanese bicycle manufacturers obtain OEM orders from foreign bicycle manufacturers, to learn advanced technologies and then transfer them to their partners in the supply chain. By joining the Project of Center-Satellite Plant System. Taiwanese bicycle manufacturers were able to gain competitive advantages. Some large manufacturers, such as GIANT, dominated the development of the center-satellite plant system because they had enormous bargaining power with the bicycle component manufacturers because they purchase a great quantity of bicycle components each year. Therefore, the large bicycle manufacturers have considerable influence on subsequent R&D development of bicycle components.

The center-satellite plant systems are located primarily in the middle part of Taiwan, including GIANT (mainly in Taichung County) and Merida (mainly in Changhwa County). These manufacturers integrated the needed component manufacturers to form their own center-satellite plant systems. For example, GIANT put together the largest center-satellite plant system by combining a total of 21 component manufacturers. With such close integration of center factories and satellite factories, these manufacturers are able to shorten their operations processes, decrease transaction costs, increase competitive advantage, and upgrade the R&D capabilities of the entire Taiwanese bicycle industry [37].

The development of the center-satellite plant system eventually contributed to industrial clustering by forming a complete supply chain for Taiwan's bicycle industry. Within the center-satellite plant systems, bicycle and bicycle component manufacturers can increase their interactions, thus significantly increasing the development of technological innovations. Another determinant is foreign OEM clients, who have considerable influence on innovations developed by Taiwanese bicycle manufacturers or bicycle component manufacturers, because they have enormous bargaining power and frequently insist that Taiwanese bicycle manufacturers must meet specific bicycle specifications.

Table 7
Patent held by Taiwanese bicycle or bicycle component manufacturers (2006)

Bicycle sub-system	Patent counts	Number of companies	Average number of patents per company
Wheel system	77	37	2.08
Bicycle frame system	99	64	1.55
Transmission system	54	28	1.93
Brake system	35	13	2.69
Other bicycle components	66	31	2.13
Total	331	173	1.91

Source: [40].

Taiwanese bicycle manufacturers today do not always produce their own bicycle components. Taiwanese bicycle manufacturers are willing to manage the production network, from upstream suppliers to downstream manufacturers, in order to achieve greater efficiency through supply chain management. Therefore, bicycle and bicycle component manufacturers developed industrial bicycle networks based on competition/cooperation relationships, and eventually they formed industrial clusters in the middle part of Taiwan where there were so many supportive mechanical companies and excellent technical personnel.

Formal communication channels within the industrial clusters of Taiwan's bicycle industry include announcing a firm's future products, disclosing patent rights, and participating in worldwide bicycle exhibitions, such as the International Bike Exhibition in Germany, Italian Bicycle and Motorcycle Exhibition, and the International Bicycle Exhibition in the U.S. Starting in 1996, the International Bicycle Design Competition of Taiwan has been held annually by the Industrial Development Bureau, Ministry of Economic Affairs of Taiwan, and supported by the Taiwan Bicycle Industry R&D Center. The purposes of this competition are to allow Taiwanese bicycle manufacturers to compete with one another and to attract international bicycle manufacturers to participate in this competition. Another purpose is to provide opportunities for Taiwanese bicycle manufacturers to learn the technologies of other bicycle manufacturers and to evaluate and compare their R&D capabilities.

Taiwanese bicycle manufacturers or bicycle component manufacturers have invested a great deal of effort and resources in participating in international bicycle fairs. Most Taiwanese bicycle manufacturers participate in two or three international bicycle fairs each year in order to obtain foreign OEM orders and learn technologies from others. These fairs enable Taiwanese manufacturers to understand the R&D capabilities of their competitors, and to stimulate their own innovation aspirations. The R&D and manufacturing capabilities of bicycle manufacturers determines whether they will obtain further OEM orders. Hence, international bicycle fairs or design competitions provide opportunities for the manufacturers to promote and display their R&D capabilities.

Forming an industrial cluster for the bicycle industry in Taiwan is an innovation with far-reaching effects. It facilitates quick communication; R&D activities are usually project-based and involve much coalition-building and face-to-face contact, which is facilitated when players co-locate [38]. In addition, the concentration of bicycle manufacturers and their manufacturing partners in the middle part of Taiwan increases the possibility of meeting people in other software firms and gathering information. If a bicycle manufacturer develops a new technology, many bicycle manufacturers within the Taiwanese industry will soon learn that technology. Another reason for forming an industrial cluster is risk sharing, which generates a co-existence relationship between the bicycle manufacturers and bicycle component manufacturers. Most SMEs lack economies of scale; therefore combining the production capacities and inventories of these SMEs in order to support one another is a wise strategy.

6.1. Organizations that support the development of Taiwan's bicycle industry

The bicycle industry in Taiwan has established a complete supply chain that cooperates with the bicycle manufacturers and bicycle component manufacturers. Moreover, the well-known organization of Taiwanese SMEs produces flexible production and quick response; therefore interactions and information exchange have the advantages of rapid coordination and close integration, and eventually result in competitive advantage.

The organizations that have made substantial contributions to the development of the bicycle industry in Taiwan are official R&D authorities (i.e., Small and Medium Enterprise Administration, Ministry of Economic Affairs of Taiwan), and semi-official R&D institutions (i.e., Industrial Technology Research Institute of Taiwan, Taiwan Bicycle Industry R&D Center, and Metal Industrial Research & Development Center of Taiwan). Because the support of official and semi-official R&D institutions increases the intellectual capital of the bicycle and bicycle component manufacturers, their new product development is enhanced [39]. The two kinds of organizations are discussed below.

6.1.1. Official R&D authorities

Official R&D authorities played an important role in the development of the Taiwanese bicycle industry by providing funding and R&D planning. To support the R&D activities of Taiwanese SMEs, a project named "Encouraging SMEs Innovation

Project," organized by the Small and Medium Enterprise Administration, and the Ministry of Economic Affairs of Taiwan, aims to encourage Taiwanese SMEs to reinforce their R&D and new product development. Moreover, the Project assists Taiwanese SMEs with innovations and R&D activities and encourages strategic alliances and R&D consortiums of SMEs. For its part, the Ministry of Economic Affairs of Taiwan provides funding to support the bicycle manufacturers.

6.1.2. Semi-official R&D institutions

Semi-official R&D institutions also played an important role in developing the Taiwanese bicycle industry. For example, the purpose of establishing the R&D Center of Taiwan Bicycle Industry (the R&D Center) was to help the industry develop relevant bicycle products in joint cooperation with bicycle manufacturers and bicycle component manufacturers. In 1996, the R&D Center undertook several R&D projects related to bicycle products that had originally been funded by the Ministry of Economic Affairs. The R&D Center established a materials analysis lab, a vibration analysis lab, and a motor-driven analysis lab to develop electric bicycles, body building equipment, treadmills, and electric wheelchairs. In addition, the R&D Center gradually expanded its services to provide related examination and testing for bicycles, bicycle components, and other relevant bicycle products.

Table 5 shows major R&D events that involved major semi-official R&D institutions. Clearly, semi-official R&D institutions played an important role during the development of the Taiwanese bicycle industry, because Taiwanese SMEs lacked resources. Therefore, the funding support from semi-official R&D institutions was vital to ongoing R&D in the bicycle industry. Nevertheless, not all bicycle manufacturers sought the support of governmental funds because sometimes that support did not meet their needs.

7. Patent analysis of Taiwan's bicycle industry

Table 6 shows the patent count for Taiwanese bicycle and bicycle components manufacturers from 1987 to 2006, showing that between them the manufacturers hold 331 patents as of 2006.

Table 7 shows that Taiwanese bicycle and bicycle component manufacturers hold at least 30 patents in every bicycle subsystem, with an average patent count of more than 1.5 per company.

8. Conclusion

Industrial clustering in the Taiwanese bicycle industry is beneficial for obtaining competitive advantage and for stimulating technological innovations among Taiwanese bicycle manufacturers and bicycle component manufacturers. In addition, industrial clustering enables frequent and efficient information exchanges, which makes the spillover effect of technological innovations especially apparent and further upgrades the innovation capabilities of the entire Taiwanese bicycle industry. Moreover, industrial clustering brings about information sharing, technology diffusion, and standardization and modularization of bicycle components, which increases the competitive advantages of Taiwan's bicycle industry.

This study found that industrial clustering benefits the technological innovations of the entire bicycle industry in Taiwan, providing many opportunities for mutual cooperation between Taiwanese bicycle manufacturers and bicycle component manufacturers. Another obvious benefit of industrial clustering is to decrease transportation time and cost between related upstream and downstream companies, owing to the shortened geographical distance and implementation of just-in-time supply chain management. In addition, communication between the bicycle manufacturers and bicycle component manufacturers in the same industrial cluster is convenient.

Firms in the Taiwanese bicycle industry value interpersonal relationships, which is useful for reducing the risk of asymmetric information, and enhances mutual trust between the bicycle and components manufacturers. Because communication efficiency is high and the cost of communication is low, it decreases the information search cost such that industrial clustering helps to decrease transaction cost.

Another benefit of industrial clustering in Taiwan's bicycle industry is sharing the cost of infrastructure and necessary resources such that with greater synergy in the industrial cluster, the closer are the cooperative relationships between the bicycle manufacturers and bicycle component manufacturers. If enterprises within the same industrial cluster have common collective interests, their overall bargaining power will increase, and their relationships will be stronger.

Thus, we found that clustering in Taiwan's bicycle industry is not merely beneficial to technological innovation, but is also helpful to the formal and informal communications and cooperation of Taiwanese bicycle manufacturers and bicycle component manufacturers.

We offer the following conclusions:

- The interpersonal relationships or networks, such as relatives, partners, friends or ex-colleagues within the Taiwanese bicycle industry are a catalyst for forming industry clusters within the bicycle industry in Taiwan. This industrial clustering produces more frequent information exchanges so that knowledge or technology is quickly shared within the industry. Interpersonal relationships or networks facilitate more efficient cooperation and better communication between bicycle manufacturers and bicycle component manufacturers.

- Industrial clustering in Taiwan's bicycle industry contributes to decreasing the transaction cost of businesses within the cluster, which increases mutual communication and enhances mutual trust. Therefore, industrial clustering has a positive effect on technological innovations of the Taiwanese bicycle industry.
- Standardization and modularization of bicycle components provides the advantages of decreasing manufacturing complexity and increasing manufacturability, reducing the costs of manufacturing and purchasing, providing wide varieties of products, and improving product quality. A key success factors in Taiwan's bicycle industry is establishing compatibilities among bicycle components and setting up an industry cluster in the bicycle industry in Taiwan, tightly combining both upstream and downstream operations.
- The Project of Center-Satellite Plant System is beneficial to Taiwan's bicycle industry clustering. Participating in this project, bicycle manufacturers and bicycle component manufacturers had opportunities to enhance their mutual cooperation, and eventually shared their technological innovations while continuing to seek further opportunities for cooperation.
- Official R&D authorities and semi-official R&D institutions in Taiwan have a positive influence on the technological innovations coming out of the Taiwanese bicycle industry by providing the R&D and funding supports for bicycle and components manufacturers. In addition, the official R&D authorities and semi-official R&D institutions help Taiwanese bicycle manufacturers and bicycle component manufacturers to further innovate, and encourage them to form strategic alliances or R&D consortiums.
- Based on our patent analysis, we found that Taiwanese bicycle manufacturers and bicycle component manufacturers own at least 30 patents in every sub-system of the bicycle. We also determined that the wheel system and bicycle frame system are their strengths, while the transmission system (i.e., gears) and brake system are their weaknesses.

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