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Emergent Process of a Dominant Design: A Revisit of the Bicycle Industry

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Abstract
The notion of dominant design has received much attention in technology and strategic management. Despite abundant research into dominant design, little is known about the emergent process of dominant design. To fill this gap, this study explores how a dominant design emerges in an industry and which factors affect it. Based on analysis of the case of bicycle industry from the early to the late 19th century, this study clarifies the concept of the "value standard," which plays a critical role building a dominant design. The findings reveal how the value standard is affected by technological innovation and socio-political factors and how the design that exceeds the threshold of the value standard becomes the dominant design. The findings also indicate how both component and architectural innovation generate various designs that may become the dominant design and how alternative designs converge with the dominant design under selection pressure.

Keywords
Value standard, Dominant design, technological innovation, socio-political factors, safety bicycle.

JEL classification: M10

1. Introduction

The notion of dominant design has received much attention in technology and strategic management. Many scholars interested in dominant design have investigated the influence of patterns on competition (Abernathy and Utterback, 1978; Anderson and Tushman, 1990), strategy for building dominant design (Khazam and Mowery, 1994; Cusumano *et al*., 1996), and firm survival (Khazam and Mowery, 1994; Baum *et al*., 1995; Tegarden *et al*., 1999). Despite the wealth of dominant design research, little is known about the emergent process of dominant design. To fill this research gap, we explore how a dominant design emerges in an industry and which factors affect its emergence.

Two perspectives can be applied when analyzing the process of technology evolution: the technological approach and socio-political approach. The technological approach, focusing on the technology itself, analyzes how product architecture and components change over time (Clark, 1985; Abernathy and Clark, 1985). Meanwhile, the socio-political approach, based on the notion that society builds technology, focuses on the social context (Pinch and Bijker, 1987; Bijker, 1995). These approaches are not conflicting but rather complementary. Indeed, most scholars have pointed out importance of considering both technological and socio-political factors when analyzing the diffusion of technology and systems (Hughes, 1983; Tushman and Rosenkopf, 1992).

In accord with this background, we analyze the emergent process of dominant design from both the technological and socio-political perspectives. To link these two approaches, we focus on the "value standard," a key concept meaning uniform view of the evaluation criteria regarding technology and products shared by various firms and users in an industry (Miyazaki, 2006). Focusing on the case of the bicycle industry, we suggest that technological innovation and socio-political factors build a value standard, and a product that exceeds the threshold of this value standard becomes a dominant design.

Studying the case of the bicycle industry is appropriate for two reasons. First, the process of emergence of a dominant design is clear in this industry. The Safety bicycle clearly became the dominant design when it emerged in 1885, and the basic architecture of the bicycle has not changed for more than 100 years. In contrast, a dominant design has not emerged in all product categories (Srinivasan *et al*., 2006). In addition, as investigating the emergence of a dominant design requires consideration of cognitive factors, it is only by looking back into history that we can recognize a specific design as a dominant design. Second, because of the abundant research into the history of bicycle, we can precisely describe the details regarding the emergence of a dominant design. Many scholars have studied bicycle design from a business management perspective (Roy, 1986; Pinch and Bijker, 1987; Nierop *et al*., 1997; Galvin, 1999; Galvin and Morkel, 2001). To analyze the process correctly, drawing on a multitude of references is important.

The construction of this paper is as follows. Section 2 surveys the literature regarding dominant design, technological innovation, and the socio-political approach. Section 3 describes the evolution of bicycle design from the early to the late 1880s. In Section 4, we develop some propositions with the aim of generalizing the process of the emergence of dominant design. Finally, in Section 5, we conclude our discussion by describing the study limitations and providing recommendations for future research.

2. Literature Review

2.1 Theory of Dominant Design

The concept of dominant design has attracted many researchers, who have described it in various ways. Several scholars have described dominant design as the architecture that establishes the dominant status in a product category (Abernathy and Utterback, 1978; Anderson and Tushman, 1990). Utterback (1995) defined dominant design as the design that wins market dominance and embodies the demand of the majority of customers. This design need not be of the best quality. Henderson and Clark (1990) suggested that a dominant design is characterized by both a set of core design concepts that correspond to the major functions performed by the product and are embodied in its components and a product architecture that defines the ways in which these components are integrated.

In this paper, we define the dominant design as the design that wins the market battle against rival designs and satisfies a certain level of customer demand. This definition leads to consideration of two aspects. First, although product innovation frequently occurs and many alternative designs emerge in the fluid phase of industry, the dominant design survives this competitive situation. Second, although a dominant design need not provide the best performance among all designs, it must satisfy a certain level of customer needs. We can recognize the dominant design in various industry and product categories. In their study of dominant design in several industries, Suarez and Utterback (1995) described Underwood's Model 5 in the typewriter industry, the all-steel and closed-body car in the automobile industry, and the all-glass and 21-inch-tube in the picture tube industry. VHS in the VCR industry (Cusumano *et al*., 1992) and the IBM PC in the PC industry (Tegarden *et al*., 1999) have also been identified as dominant designs. The important consideration in the discussion of dominant design is how its emergence affects patterns of industry evolution. Emergence of a dominant design changes the nature of competition and decreases uncertainty in an industry. In an industry that does not have a dominant design, the focal point is competition regarding product innovation. Once a dominant design emerges, competition changes from a focus on product innovation to one of process innovation (Abernathy and Utterback, 1978).

Although a dominant design needs to be based on a "better" technology, a dominant design need not be the "best" technology compared with other designs. If a certain design is inferior to other designs, it may still become the dominant design. In their study of the VCR industry, Rosenbloom and Cusmano (1987) found that despite being inferior to Sony's Betamax in terms of technology, VHS became the dominant design. The crucial point in this battle was not the technology of the tape recorder, such as the quality of pictures and length of recording, but whether that company can cooperate with their rivals through opening its technology.

As discussed above, the emergence of a dominant design has a major impact. However, it is not until a dominant design emerges that its domination of a market can be recognized. Thus, the concept of a dominant design can be considered a more cognitive concept than a physical concept.

2.2 Technological Approach

In the early studies into the process of emergence of dominant design, the focal point was the technology itself. These studies recognized the relationship between technology and society, based on the understanding that "technology constructs a society." Once an important technology is created, technology evolves by its interaction with markets and firms through the selection process. Clark (1985) described the process of technological evolution as the result of a problem-solving process in which a core concept is first created, and problem-solving activities proceed to a low level of hierarchy.

Once the problem is resolved, this activity ceases. Repeating this process, design hierarchies are established based on not only product concepts but also customer concepts.

The concept of "hierarchy of design" is succeeded by that of product architecture, the scheme by which the function of a product is allocated to physical components (Ulrich, 1995; Schilling, 2000). Product architecture is divided into two types: integral architecture and modular architecture. Integral architecture, a representative example of which is the automobile, refers to a complex mapping from functional elements to physical components and/or coupled interfaces between components. On the other hand, modular architecture, a representative example of which is the PC, refers to a one-to-one mapping from functional elements in the functional structure to the physical components of the product and specifies de-coupled interfaces between components (Ulrich, 1995).

The notions of architectural and modular innovation critically affect the competitive position of firms. According to Henderson and Clark (1990), who introduced the concept, architectural innovation is the reconfiguration of an established system to link together existing components in a new way. In contrast, modular innovation is innovation that changes only the core design concepts of a technology. When architectural innovation occurs, established firms tend to fail because the architectural innovation destroys the usefulness of the architectural knowledge that they have established.

As discussed above, the technological approach focuses on the technology used in the process of technological evolution. In this approach, the aims of research are problem solving and determining the relationship between components and product architecture. In particular, the research into product architecture focuses on the importance of distinguishing between changes in product architecture and changes in components.

2.3 Socio-political Approach

To gain an understanding of the diffusion of technology and systems, many researchers have insisted on analyzing not only the technology itself but also its context (Tushman and Rosenkopf, 1992; Miller *et al*., 1995; Rosenkopf and Nerkar, 1999; Jenkins and Floyd, 2001). Expanding the notion of technology and society to the paradigm of a research stream that they termed the "social construction of technology" (SCOT), Pinch and Biker (1987) and Biker (1995) suggested that the interaction between technology and society leads an artifact to assume dominant status. On the basis of this concept, they attempted to explain the evolution of products by including social groups in the analysis and interpreting their findings from a variety of perspectives. This approach thus emphasizes three concepts: relevant social groups, defined as groups whose members share the meanings of an artifact; interpretative flexibility, defined as consideration of the different interpretations held among people and the need for flexibility in how artifacts are designed; and closure and stabilization, defined as the process of stabilization of an artifact and the resolution of problems. Pinch and Biker (1987) suggested that the key point of closure is whether the relevant social groups see a problem as being solved.

The actions of the groups considered to have sociological legitimacy may affect the emergence of a dominant design. In their analysis of the process by which the standard for cochlear implants emerged, Garud and Rappa (1994) explained why the multimodel channel model became the standard instead of the single channel model. After the University of Iowa conducted comparable tests and declared that the results supported the multichannel model, other research institutes supported the multichannel model, too. In consequence, the Food and Drug Administration and the National Institutes of Health ultimately supported the multichannel model, which became the industry standard. As observed in this case, gaining legitimacy from external institutions leads a product to assume standard dominance within a market.

We have seen the two approaches toward examining technology evolution, the technological approach cannot be used without consideration of socio-political factors, as both these approaches are closely related. To understand the process of evolution of technology, it must be analyzed from both perspectives. The following section describes the method of analysis employed for conducting a case study of the bicycle industry using both the technological and socio-political approaches.

3. Method

The analytical method used in this paper is that of a case study. The aim of this paper is to provide new insights into the process underlying the emergence of dominant design. Use of a case study design rather than a quantitative design helps in the following ways: enables analysis of a longitudinal process in detail (Glaser and Strauss, 1967), enables analysis of how and why many bicycles with distinct designs have been created by great designers since the 19th century and identification of the functions of these bicycles in each period, and enables analysis of the factors that generate events and determine the causal relationship in detail. This capacity was an important consideration, as a combination of technological and socio-political factors affected the emergence of new bicycle designs, including the emergence of the women’s movement, enthusiasm for bicycle races, and the provision of infrastructure. This case study was conducted mainly using archival data collected by prior research into the history of the bicycle industry on the basis that analysis of rich historical data was vital to present the facts precisely. The following section analyzes the emergence process of dominant design in the bicycle industry.

4. Case Analysis: Evolution of the Bicycle Design

4.1 The ancestor of the Bicycle: The Draisine

People today have an image of what a bicycle is—a machine with pedals, cranks, wheels of the same size, a pneumatic tire, and a diamond frame. However, the design of the Draisine (Figure 1), the bicycle’s ancestor, invented by Karl Drais in 1817, is far from that of a modern bicycle. The Draisine had no pedals or crank, and the rider had to kick the ground to propel the bicycle forward. Although these mechanisms made the machine simpler, considerable time passed before the modern bicycle was invented. The reason was that then people thought if riders took their foot off the ground, they may fall off the bicycle (Penn, 2010). Although the Draisine had no pedals, riders could travel at about 15 kilometers per hour. The Draisine had an armrest between the handle and saddle on which riders could support their elbow.

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4.2 From “Kicking” to “Pedaling”: The Boneshaker

In the history of bicycle, the most important innovation was the pedal. With its invention, which was not the result of a technological change but rather a cognitive change, people could travel without kicking the ground. Between 1861 and 1863, Pierre Michaux invented an innovative bicycle with two wheels propelled by pedals and cranks attached directly to the front hub. The Michaux bicycle (Figure 1) was widely accepted in the U.K., where it was called the “Boneshaker” because of the strong vibration that riders felt in their backbone while riding it. As the wooden tires of the early Boneshaker were covered by iron to prevent abrasion, they could not absorb ground vibration. Another problem with this bicycle was the noise caused by riding it, which also caused many accidents by making cows and horses run wild (Kobayashi, 2009).

The reason Michaux attached the pedal to the front hub was not to propel riders forward but to provide them a place to keep their feet while traveling downhill (Kobayashi, 2009). While traveling downhill, riders did not need to pedal, and thus their feet remained up in the air. To solve this problem, Michaux placed the pedal instead of the footrest near the front hub. Many engineers improved the Boneshaker after Michaux invented the prototype of this bicycle. A more sophisticated model of the Boneshaker emerged around 1870, in which the position of the saddle was closer to the front wheel to increase rider power for increased pedaling power and stability. With this change, riders could more powerfully propel themselves forward using their weight during pedaling. Moreover, various components of the Boneshaker were improved: a spring was placed on the saddle and brake, a rump was provided for night riding, and an ornament was added to the frame. With these changes, the Boneshaker became widely accepted worldwide by the 1880s (Sano, 1985).

4.3 The High Wheel Bicycle: The Ordinary

Although the Michaux bicycle was more comfortable and faster than the Draisine, it could not go fast enough to satisfy riders. To overcome this, the bicycle design was changed further, resulting in the invention of the “Ordinary” bicycle (Figure 2). The “Phantom,” the first Ordinary bicycle, was made by Reynolds and Mays in 1869 in the U.K. Designed with wooden wheels on a double-tension spoke made from one long wire onto which both ends were attached to the hub double spoke, a triangular frame, and lightweight iron bars, the Phantom weighed about 24 kilograms, and was lighter than the Boneshaker (Counter, 1955).

The turning point in the design of the Ordinary bicycle was the emergence of the “Ariel.” Produced in Coventry by Jams Starley and William Hillman, the Ariel featured a tubular steel backbone and a solid fork, a shorter and stiffer seat spring, slotted cranks, a rear brake, wire wheels, solid rubber tires, and cylindrically or cone-shaped plane bearings on the wheel axis (Sano, 1985; Herlihy, 2004). The innovation of the ball bearing in the U.K. in the late 1870s, which became widely used in the bicycle axle, also greatly impacted the bicycle industry. The accuracy of the ball itself was very important in the functioning of the bicycle components. As early models of the ball bearing were handmade, they were easily misshapen by strong pressure. As technology progressed, improved ball bearings made with metallic spheres were created that dramatically decreased the friction among the rotating parts, allowing riders to travel more speedily and comfortably (Herlihy, 2004).

The most distinctive feature of the Ordinary bicycle was its large front wheel. In the case of a bicycle with pedals directly attached to the front wheel, the distance of one pedal was equal to the circumference of the wheel. As the easiest means of increasing the distance traveled with the turn of one pedal was increasing the diameter of the front wheel, the diameter of the front wheel was increased to 1.5 meters, allowing riders to travel up to 30 kilometers per hour (Penn, 2010). Although the Ordinary was superior to other models in terms of speed, it was inferior in terms of safety. Because of the large front wheel, riders experienced difficulty mounting and dismounting. Owing to the position of the saddle, they also experienced difficulty balancing on the bicycle, leading many to fall off and hit the ground headfirst (Herlihy, 2004).

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4.4 The Pursuit of Safety: The Improved Ordinary and the Tricycle

Although the characteristic style of the Ordinary appealed to many, the Ordinary did not become the standard model. To meet the demand for a safe and comfortable bicycle, engineers developed two models: the "Extraordinary," invented by Singer in 1878, and the "Kangaroo," invented by Hillman, Herbert, and Cooper of Coventry in 1884. The main features of the Extraordinary were the moving of the position of the saddle back from the front wheel. These features helped riders to travel more safely and comfortably compared with with the existing Ordinary (Counter, 1955). The Kangaroo (Figure 3), which incorporated a key technical invention—the chain drive—had a 36-inch front wheel geared up to the equivalent of 60 inches by means of two independent chain drives, one connecting each crank to its side of the front wheel. Moreover, by decreasing the diameter of the front wheel to about 92 centimeter, which was less than the largest Ordinary wheel by 50 centimeter, the inventors of the Kangaroo increased the ease by which the rider could mount and dismount (Herlihy, 2004).

Other attempts at improvement led to the invention of the tricycle (Figure 4). The first successful tricycle was the Coventry tricycle, the first model of which was propelled by the lever moving the legs up and down and the second model by a driving chain system. The improved Coventry was the first machine in history to adopt the rack and pinion system. The Coventry tricycle became known as a good bicycle and remained popular for more than 10 years. By 1884, over 200 models of the tricycle had been created in the U. K. other than the Coventry tricycle. In the late 1880s, demand for the tricycle emerged in the U.S.A. as well, especially among society women. Since two people could ride the tricycle together, husbands and wives often went cycling for both health and pleasure (Herlihy, 2004). Although the tricycle had the advantage of safety, it had the problems of lack of speed and, being much larger than a two-wheeled bicycle, difficulty in storage. These disadvantages prevented the tricycle from becoming the dominant design.

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4.5 Emergence of the Dominant Design: The Safety Bicycle

Although the Ordinary was the first commercially successful bicycle (Hounsell, 1984), it did not diffuse throughout the world because of a fatal deficit: the lack of safety and fixed gear ratio (Caunter, 1955). To overcome this deficit, English engineer Henry Lawson invented the first model of the "Safety" bicycle with a chain drive in 1879. Although Lawson's model had a large front wheel and a small rear wheel, as did the Ordinary bicycle, it was the prototype of the Safety bicycle (Sano, 1985).

In 1885, John Kemp Starley created the first true Safety bicycle. Called the "Rover" (Figure 6), this bicycle had the same function and features as the modern bicycle: same-size wheels, a chain drive system, and rear-wheel drive (Herlihy, 2004). The next model of the Safety bicycle contained a very important component in the history of the bicycle, the pneumatic tire. Before John Boyd Dunlop, a Scottish veterinary surgeon, invented the pneumatic tire in 1888, bicycles had solid tires that provided for an uncomfortable ride at a slow speed. Dunlop invented the pneumatic tire in response to his son's request to invent a device that would allow his solid-tired tricycle to ride more smoothly and rapidly on granite streets. Use of the pneumatic tire dramatically improved the comfort and speed of bicycles, as witnessed when the tires were first used in a bicycle race in Belfast in 1889, where the pneumatic-tired bicycle won all four races (Lay, 1992). Talk of this racing success spread the news that a new type of tire with striking new properties was available for the bicycle (Tompkins, 1981). Despite having great advantages, the pneumatic tire also had several setbacks. One setback was the difficulty of fixing the tire if it went flat. Each time the tire was punctured, the casing had to be soaked apart with naphtha to reach the tube inside. After performing the necessary patch repair, the tube had to be replaced and the casing built up again with solution before the repaired part was reattached to the wheel. Since this process was difficult, riders were not always capable of making satisfactory repairs themselves (Tompkins, 1981).

Another model termed the "Whippet" bicycle (figure 6) was invented in London in 1885. The most interesting feature of this bicycle was the attachment of a variety of springs on the frame to decrease ground vibration, a problem that engineers had been struggling to resolve. While the attempt to resolve this problem by attaching springs to the frame was revolutionary, the arrival of the pneumatic tire, another means of decreasing ground vibration, shortly after the invention of the Whippet bicycle led to the Whippet's disappearance (Herlihy, 2004).

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5. Discussion

The previous section described the evolutionary process of bicycle design. This section develops several propositions with the aim of generalizing the process underlying the emergence of dominant design. Although a product concept tends to be created inside a firm (Brown and Eisenhardt, 1995; Krishnan and Ulrich, 2001), a value standard is shared by the firm and users of its products. A value standard is defined as a uniform view of the evaluation criteria used to judge technology and products shared by various firms and users within an industry. Although a product tends to take one form, many diverse interpretations of the product and judgments regarding its performance may emerge among users (Pinch and Bijker, 1987; Christensen, 1997). With repeated interaction between a firm and users and with user learning, the concept generated inside a firm may change over time (Clark and Fujimoto, 1991).

5.1 Value standard and dominant design

Within the bicycle industry, three dimensions comprise the value standard of the bicycle: speed, safety, and comfort. Regarding speed, Karl Drais created the Draisine, the prototype of the bicycle, to allow riders to arrive at a destination in less time than if they had walked. Whereas the Draisine could travel at 15 kilometers per hour, the Ordinary could travel at 30 kilometers per hour. The invention of the bicycle race, in which speed is the most important factor other than safety and comfort, increased the importance of speed. To increase speed, engineers improved bicycle components and architecture, ultimately resulting in the invention of the Ordinary, the fastest bicycle. Though the Ordinary could travel faster than the Boneshaker because of its extremely large front wheel, many of its riders experienced injury because its design downplayed safety. As a result, demand for a safe yet fast bicycle emerged. This characteristic of the Ordinary defined the reference of the value standard.

As for the second value standard of safety, riding a bicycle was dangerous because the two wheels were in a straight line, posing the risk that riders would fall off the bicycle and run over the obstacles if they made a mistake while steering. The Draisine, Boneshaker, and Ordinary were not designed to be safe at a level that met rider’s demand, especially the Ordinary, which downplayed the significance of safety. As riders of the Ordinary could not set their feet on the ground because of the large wheel, they would often fall off the saddle when they slammed on the brakes. Therefore, a demand for a bicycle that was both safe and fast emerged, creating the value standard of safety. In response to this demand, Starley invented the Safety bicycle in 1885 to increase the safety of the bicycle and allow riders to ride easily without constraints, regardless of gender differences.

Regarding the third value standard of comfort, high performance is necessary when riding a bicycle for a long duration. The means used to suppress ground vibration, as well as noise from the saddle and handles significantly affects the degree of comfort. As reflected in the name of the Boneshaker, riders of this early model would feel a strong jolt in their backbone while riding on stone-paved streets. Tires also play an important role in improving comfort. The Boneshaker had a crude tire, specifically an iron-coated wooden wheel, which led riders to experience strong ground impact. Although engineers introduced the solid (non-pneumatic) tire to increase comfort, it did not increase comfort to a level sufficient to satisfy user needs. It was only with the development of the pneumatic tire by Dunlop in 1888 that the bicycle provided for a comfort level that met user demand. Indeed, the comfort level provided by the Safety bicycle with pneumatic tires exceeded the value standard level.

In this discussion of the emergence of a value standard, it is important to stress that a value standard did not exist until the first bicycle had been created. In the fluid phase of an industry, the image and concept of a product are ambiguous in the interaction between firms and users (Abernathy and Utterback, 1978). It is only with the advancement of time that the value standard of a product is gradually generated. Although the value standard is composed of several functions, those functions that are highlighted depend on the era. For example, while the invention of the bicycle race highlighted the value of speed, women's increased participation in society and the diffusion of the bicycle among the masses highlighted the value of safety and comfort. With repeated societal changes that highlight the significance of the value standard, a common understanding of the value standard is generated within an industry. In the case of the bicycle industry, the Safety bicycle sufficiently satisfied the demand for speed, safety, and comfort, and thus became the dominant design. Based on this analysis, the following propositions are developed:

Proposition 1: Technological innovation and socio-political factors generate the value standard within an industry.

Proposition 2: The dominant design is the design that exceeds threshold of the value standard.

5.2. Evolution of components and architecture

In the process of emergence of dominant design, product innovation rather than process innovation is likely to occur (Abernathy and Utterback, 1978). A product is nested within a hierarchy system in which many components are intricately combined and evolves in each level of component, subsystem, and system (Murmann and Frenken, 2006). A product is likely to become a dominant design during architectural innovation (Henderson and Clark, 1990), which changes the combination of components. Here, we describe how the relationship between product components and architecture has changed over time within the bicycle industry.

The first innovation within the bicycle industry was the invention of the Draisine, which, as there had been no bicycle or bicycle industry before it, was a radical innovation. The second innovation was the invention of the Boneshaker, which was a modular innovation. Although the Boneshaker had the same product architecture as the Draisine, the pedals were attached to the front wheel and it contained new components. While these changes had little impact on the appearance of the bicycle, they generated a large change in its use, as they allowed riders to travel without kicking the ground. Propelling the bicycle by pedals allowed riders to travel much faster than before with much less effort, thereby not only increasing speed but also decreasing fatigue. The third innovation was the invention of the Ordinary, which was an incremental innovation. The Ordinary had the same architecture as the Boneshaker and its pedals, saddle, crank, and frame were similar in appearance, but it had a much larger front wheel, of a maximum diameter of about 170 centimeter. Owing to this innovation, the Ordinary allowed riders to travel much faster than the older model bicycles.

The fourth innovation was the invention of the Safety bicycle. As the Safety bicycle differed widely from the Ordinary in terms of its components and architecture, its invention was a radical innovation. Specifically, its chain and gear were assembled within the frame, and its architecture altered to allow for rear wheel rather than front wheel drive. Furthermore, the position of the saddle, which was located between the front and rear wheel, affected the shape of the frame. Of all the changes and innovations in this era, the most important was the invention of the pneumatic tire, which greatly reduced ground vibration and determined the shape of the frame.

As shown in the case of bicycle, the components themselves evolved dramatically until the dominant design, that of the Safety bicycle, ultimately emerged. This component evolution generated architectural evolution, particularly in the transition from the Ordinary to the Safety bicycle, in which both components and architecture can be clearly seen to have evolved. The following proposition is developed on this basis:

Proposition 3: Dominant design emerges via evolution of both components and architecture.

5.3. Path of Design Evolution

Product design evolves along an industry's design hierarchy and between competing design paths (Suarez and Utterback, 1995). Although a variety of designs are created to embody a product concept, most are eliminated during the process of natural selection. Simultaneously, product design outside the mainstream may have a significant impact on the emergence of a dominant design. In the case of the bicycle industry, several important product designs did not become dominant, among which three were particularly notable. The first was the Kangaroo, which was invented as an evolution of the Ordinary with a gear and chain drive system. While the Ordinary, thanks to its large front wheel, was superior in terms of speed relative to previous models, it lacked safety. To resolve this problem, the designer of the Kangaroo made the front wheel smaller and used a chain drive system that enabled changing the gear ratio. Despite its partial success in decreasing the number of complaints compared with former models, the Kangaroo disappeared after a decade because it did not sufficiently satisfy the value standard of speed, safety, and comfort.

The second model was the Whippet bicycle, which used an exceptionally unique design, namely seven pivot points in its suspension design, to decrease ground vibration. Although the Whippet bicycle was popular for about five years, it suddenly became obsolete with the invention of the pneumatic tire, whose use in later models better absorbed ground vibration compared with the use of the spring frame in the Whippet bicycle. The third model was the tricycle, created in the era of the Ordinary by the addition of a wheel to a normal bicycle. Although the addition of a third wheel increased safety, it increased the weight, thus compromising speed, as well as size, creating difficulty in its easy storage in a typical rider's garage. Due to these problems, the tricycle did not become the dominant design.

As revealed in the discussion above, before a dominant design emerges, many product designs are created to embody a product concept. However, almost all these product designs are rendered obsolete because they do not exceed the threshold of the value standard. On the basis of this observation, we developed the following proposition:

Proposition 4: In the emergent process of dominant design, many designs outside the mainstream are generated and selected. The evolution of design is thus more of double linear process rather than a singular linear process.

6. Conclusion

In summary, we analyzed the emergent process of dominant design using the case of the bicycle industry and developed several propositions based on the findings. Perhaps our most important contribution is clarification of the value standard as a concept that plays a critical role in the building of a dominant design and that it is affected by both technological innovation and socio-political factors. We also clarified how a design that exceeds the threshold of the value standard becomes the dominant design; how both component innovation and architectural innovation generate various designs, among which one may emerge as the dominant design; and how alternative designs converge with the dominant design under selection pressure.

This study faced several limitations that present opportunities for further research. To address the focus on dominant design within a single industry, future research should consider the applicability of the findings to other industries. Srinivasan, Lilien, and Rangaswamt (2006) pointed out that the emergence of a dominant design is not common across all industries. Another intriguing research direction is investigation of how the value standard is created or how technological innovation and socio-political factors affect the value standard in an industry that does not have a dominant design.

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Figure 1. Six early models of the bicycle in the 19th century. The Draisine is shown in the middle figures and the Michaux bicycle in the bottom right figure. Reprinted with permission of Science and Society Picture Library.

Figure 2. The "Rudge" Ordinary bicycle, 1884. Reprinted with permission of Science and Society Picture Library.

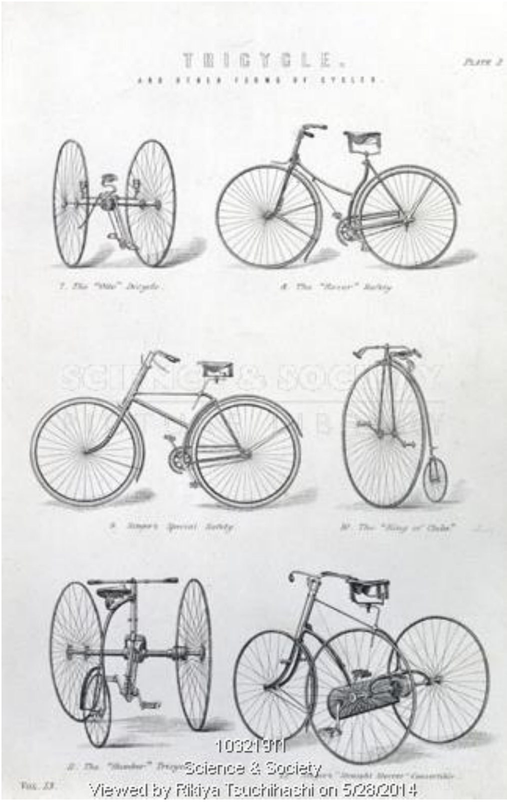

Figure 3. Early models of the bicycle in the late 19th century. The tricycle is shown in the bottom figures. Reprinted with permission of Science and Society Picture Library.

Figure 4. The “Kangaroo” bicycle, 1878. Reprinted with permission of Science and Society Picture Library.

Figure 5. The “Rover” Safety bicycle, 1885. Reprinted with permission of Science and Society Picture Library.

Figure 6. The “Whippet” spring frame Safety bicycle, 1885. Reprinted with permission of Science and Society Picture Library.