Ex-ante project management for disruptive product innovation: A review

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CHRONICLE	ABSTRACT
	Disruptive innovation has attracted much interest, discussion and argument in academia and industry since it was defined. Based on a review of the related research publications, this paper aims to clarify the concept of disruptive innovation on controversies, summarize ex-ante studies on project management for disruptive product innovation, and propose potential research areas of the disruptive product innovation. The ex-ante studies are classified into three aspects: timing and conditions of disruptive innovation, factors for the implementation of disruptive innovation, forecasting and implementation of disruptive innovation. After a review of the existing methods of disruptive innovation, the potential research of disruptive innovation is presented.

1. Introduction

Since the term "disruptive innovation" was proposed by Christensen (1997) based on disruptive technologies introduced by Bower and Christensen (1995), it has attracted much interest in the academic field. After reviewing papers with keywords of disruptive innovation, disruptive technologies, or disruption, it is found that Christensen's concept of disruptive innovation has been strengthened and broadened either in the same or different perspectives. Moreover, research on applications and forecasts of disruptive innovation has been conducted in different organizations of industries, manufacturing (Christensen, 1997; Christensen & Raynor, 2003), services (Guttentag & Smith, 2017), healthcare (Vrolijk, 2010; Tsai et al., 2009; Ahn et al., 2018), and education (Robinson et al., 2016), which can be summarized into two areas: ex-ante analysis and ex-post analysis, as follows.

The ex-post analysis mainly focuses on the summary of common features of disruptive innovation based on the analysis of successful disruptive innovative cases (Charitou & Markides, 2003; Markides, 2006), effects of disruptive innovation on firms, Industries or the market (Danneels, 2006; Gilbert, 2003), ways to defend against disruptive innovation (Bergek et al., 2013; Cubero et al., 2021; Kilkki et al., 2018), or response to disruptive innovation for incumbents (Gilbert & Bower, 2002; Sandström et al., 2009). Compared to the ex-post analysis, the ex-ante analysis provides guidance for firms to implement disruptive innovation. It is classified into three aspects in this paper for the disruptive innovation implementation: timing and conditions

for disruptive innovation, factors for the implementation of disruptive innovation, methods of generating disruptive technologies or realizing disruptive innovation.

According to questions proposed for the review of the development history of disruptive innovation theory, this paper aims to (1) discuss controversial points of the concept of disruptive innovation and clarify some common misunderstandings; (2) classify the ex-ante analysis or forecasting methods in order to find ways to implement disruptive innovation; (3) propose some potential research directions of disruptive product innovation. They will be presented in the following Sections.

2. Review and discussion of disruptive innovation's concept

The concept of disruptive innovation was proposed based on "disruptive technologies" introduced by Bower and Christensen (1995) from the view of technical innovation (Christensen, 1997). Disruptive technologies are not the mainstream technologies on performance dimensions valued by customers. In the early development phase of a product, the product based on disruptive technologies just serves a niche market for non-mainstream performance attributes. With the performance valued by mainstream customers to be improved to meet their demands, the new product gradually replaces mainstream products, then disruptive innovation happens. Since Christensen's view of disruptive innovation was proposed, it has attracted many discussions among scholars from different research backgrounds. Some scholars misunderstood disruptive innovation as equivalent to discontinuous innovation or radical innovation (Abernathy & Clark, 1985; Kostoff et al., 2004; Shahady et al., 2008). Kassicieh et al. (2002) and Kostoff et al. (2004) held similar opinions that disruptive innovation or disruptive technology is scientific discoveries that broke through the usual product/technology capabilities to provide a basis for a new competitive paradigm. Markides (2006) conceived that Christensen's proposal mixed definitions of disruptive technological innovation and disruptive business model innovation or disruptive product Innovation. He conceived that DI includes business model innovation and radical product innovation, and explained that the two different types would pose different challenges or implications for incumbents. In fact, discontinuous innovations include not only disruptive innovation, but also radical innovation. Disruptive technologies are not related to a dramatic technology change. Govindarajan and Govindarajan and Kopalle (2006a) mentioned that the radicalness is a technology-based dimension of innovations, and the disruptiveness is a market-based dimension. However, disruptive innovation generally does not involve particularly complex technological changes, and its main manifestation is to assemble finished components together, and the product structure is simpler than previous products (Christensen, 1997). Some authors conceived that "disruption" in disruptive innovation had disruptive effects on incumbents (Kassicieh et al., 2002). For example, Guttentag and Smith (2017) presented that Airbnb is a disruptive innovation compared to upscale hotels, and it is not really a disruptive innovation relative to budget hotels/motels. The reason is that attributes valued by customers of Airbnb are not the same, but same as budget hotels/motels' customers. In fact, "Disruption" in disruptive innovation is a relative term to the market (Govindarajan & Kopalle, 2006b).

Some scholars strengthened disruptive innovation' s proposition on some points or broadened its viewpoint. Rafii and Kampas (2002) reinforced that disruptive innovation is a technology, product, or process that typically offers lower performance and less functionality at a lower price than the existing products. Thomond (2003) conceived that disruptive innovation is a process, technology, product, service or business model that is successfully utilized, enabling organizations to significantly change traditional competition rules and thereby change needs of the existing market. Thomond et al. (2002) summarized characteristics of disruptive innovation from the perspective of the market level, product performance, effect of disruptive innovation on the mainstream market and customer value. Keller and Hüsig (2009) believed that disruptive innovation has the similar characteristics with the one proposed by Christensen as follows : (1) disruptive innovation allows products to have a new set of attributes; (2) disruptive innovative products do not meet expectations of mainstream customers in one or several existing attributes, therefore disruptive innovation only focuses on a niche market; (3) incumbents neglect the niche market due to the contrary innovation process or value with entrants; (4) the entrants further enhance innovation and improve attributes valued by mainstream customers; (5) incumbents lack the necessary competitiveness in innovation and they cannot provide new attributes, therefore they fail. Summerer (2012) mentioned that disruptive innovation often changes products or services in a way that the market does not expect, typically in a lower-price way or personalized customization for a group of customers, which usually has features that mainstream customers do not want initially, but these features were valued by marginal or new customers. Klenner et al. (2013) mentioned that disruptive innovation brings a different combination of performances to the market. While disruptive innovations do not perform well in the performance dimensions that are most valued by mainstream customers. They provide a better value in one or more performance dimensions that are orthogonal to current products, therefore disruptive innovation is expected by some niche customers, including new customers of the current product or low-end market customers. Wan et al. (2015) pointed out that disruptive innovation includes technology innovation and process change, which can bring a novel value to consumers. From the perspective of product design, Guo et al. (2016) proposed that disruptive innovative design is an innovative design process of products realized through a different package of function and performance features from the existing product, and it is implemented initially for attracting low-end customers or new customers.

In addition, some scholars proposed arguments by taking counter examples. Christensen has further elaborated the theory of disruptive innovation in the later publications (Christensen et al., 2004; Christensen, 2006; Christensen et al., 2018; Christensen et al., 2015). Controversies mainly include the following three areas.

2.1 Is the performance of product or service offered by disruptive innovation necessarily lower than the mainstream product or service?

Bower and Christensen (1995) proposed that disruptive technologies introduced a set of attributes that are different from the one that has long been valued by mainstream customers. This set of attributes usually perform significantly worse in one or two performance dimensions that mainstream customers particularly value, but it creates other important attributes for customers in the low-end market or new market. For example, Sony's early transistor radios sacrificed the fidelity of sound, but created a market for portable radios by providing a new set of features, including small size, light weight, and portability.

Compared to the mainstream 14-inch hard drive with no less than 200MB at the time, although the capacity provided by the 8-inch, 5.25-inch, 3.5-inch hard drives (an attribute that was important to major computer users at the time) was small, they created other important attributes. The power supply of the 8-inch hard drive was improved, and its size is smaller. The stepper motor in the 5.25-inch hard drive has features of small size and low cost. The 3.5-inch hard drive provides features of durability, light weight and low power consumption (Christensen, 1997). Danneels (2004) pointed out that the core concept of disruptive technology is to change the competition base of performance which is not necessarily worse than the existing technical performance. New products based on a disruptive technology initially have worse performance on some compared to the mainstream market product but have better performance on dimensions valued by emerging market segments. For example, Digital Video Disk (DVD) has higher image quality than tape. Rao et al. conceived that disruptive innovation includes not only bottom-up type, but also top-down type for high-end customers. These customers are least sensitive to product price (Rao et al., 2006). The product quality provided by the top-down type disruptive innovation is superior to existing products and the price is high. They argued that not all disruptive innovation is necessarily inferior in quality.

Technologies provided by disruptive innovation allow performance to degrade in dimensions valued by mainstream customers, but usually offer novel features that attract new customers or low-end customers. These novel features include an increase in non-mainstream performance. Although disruptive innovative products are generally not as good as mainstream products in overall performance, some non-mainstream performances may outperform the performance offered by mainstream technologies. In a word, the technical performance provided by disruptive innovations may be not all worse than the mainstream technical performance.

2.2 Will incumbents necessarily fall or be replaced by new entrants?

Christensen (1997) stated that disruptive innovation was mostly successfully applied by entrants. As disruptive innovative products were put into the market and their quality was improved to meet demands of mainstream customers, disruptive innovative products will replace mainstream products, and entrants will gradually devour the market share of incumbents, thus completing the disruption. Many scholars have discussed this problem in their publications. In other words, should the success of a disruptive innovation be characterized by incumbents' failure?

King and Tucci took disk drives as an example to illustrate that firms with experience in serving prior market segments were more likely to enter new market niches (King & Tucci, 1999, 2002). According to some cases of disruptive strategic innovations, such as low-cost airlines, online banking, Charitou (2003) pointed out that entrants and incumbents can coexist. Although new ways of entrants in disruptive strategic innovations attract a respectable size, they never really replace the incumbents. From the perspective of management, Gilbert (2006) pointed out that it is unverified that the success of disruptive innovation will cause incumbents to lose their dominant market position. Schmidt and Druehl (2008) argued that disruptive innovations may have a major impact on the existing market but will not completely replace it. Moreover, they took an example of Intel's Celeron that did not encroach to fully displace the Pentium line of processors. Yu and Hang (2011) discussed that disruptive innovation is not only successfully applied by entrants, but incumbents can also still maintain a market segment even though entrants have occupied some market segments. Digital cameras were compared to analog cameras as a disruptive innovative example (Yu & Hang, 2011). By using an empirical research method, King and Baatartogtokh (2015) pointed out that approximately one-third of incumbents in 77 disruptive innovative cases were not displaced by disruptive technologies. Annerstedt (2003), and King and Tucci (2002) also proposed similar arguments that entrants are not necessarily to replace the incumbents though a disruptive innovation succeeds.

Roy (2018) argued that incumbents do not compromise with disruptive technologies and jump from old technologies to a new technology. Based on an analysis of the speech recognition industry, Marx et al. (2014) examined that incumbents are not necessarily destroyed by disruptive technologies, their relationship also converted from competition to cooperation. Faced with disruptive innovation, incumbents develop new technologies (Adner & Snow, 2010) or invest to extend the technical trajectory and make it be interrupted as late as possible (Adner & Kapoor, 2016; Chen et al., 2010).

After a review and analysis of propositions on this problem, it shows that disruptive innovation can seize some existing market segments with its development, but it does not necessarily replace incumbents. Existing products, services or business models can coexist. For example, portable scanners are successful products with disruptive technology. Although portable scanners work less well than traditional desktop scanners, they operate at a high speed with the small size, lightweight, and portable. The portable scanners attract new customers who work outside or are on a business trip. The portable scanners and traditional desktop scanners satisfy different market segments, they can coexist.

2.3 Is product's price offered by DI necessarily lower than products in the mainstream market?

Christensen (1997) mentioned that although initially the unit capacity cost of 3.5-inch and 8-inch hard drives is higher than that of the 14-inch hard drive, the new customers are willing to pay a higher price for attributes, especially smaller sizes. Christensen (1997) also stated that the price of disruptive innovative products is easily accepted and they have lower profit margins per unit. It seems contradictory for understanding correctly. Danneels (2004) pointed out that the price of disruptive innovative products is not necessarily lower than the price of mainstream products. He cited digital cameras as an example and mentioned that even if the digital camera is more expensive than the traditional film camera, the price is not high for new customers (Danneels, 2004). Hogan (2005) took medical devices as an example to show that disruptive product innovations are more profitable for companies than incremental ones. Govindarajan and Kopalle (2006a, 2006b) discussed that disruptive innovation introduces a different set of attributes, features, performance and price from existing products, although a new group of customers will value this set of attributes, in the early period of the product's appearance, the price of the product is high. Rao et al. (2006) said that disruptive innovation includes not only bottom-up type, but also top-down type for high-end customers who are least sensitive to price. Products provided by the top-down type are superior to existing products and can be sold at high prices. For types of disruptive innovation, Christensen (2003) proposed a similar classification, low-end disruption and new market disruption, to target customers valued price and price insensitive, respectively.

The price of disruptive innovative products is not necessarily lower than that of mainstream products, but they are within an acceptable range for the target customers. For example, the digital photography technique emerged in the early 1990s was a disruptive technology relative to film photography in the market at that time. One of the new features of this example was the quick access to photographs without chemical interactions. The price of a digital camera is about $995, while the price of a traditional film camera is $135. After a comprehensive analysis of relevant scientific literature and examples of disruptive innovation, it is found that disruptive innovation is a process in which a different product, service or business model from the mainstream ones is introduced to attract low-end or new market customers. A three-dimensional model of disruptive technology innovation, disruptive product innovation, disruptive business innovation is shown in Fig. 1.
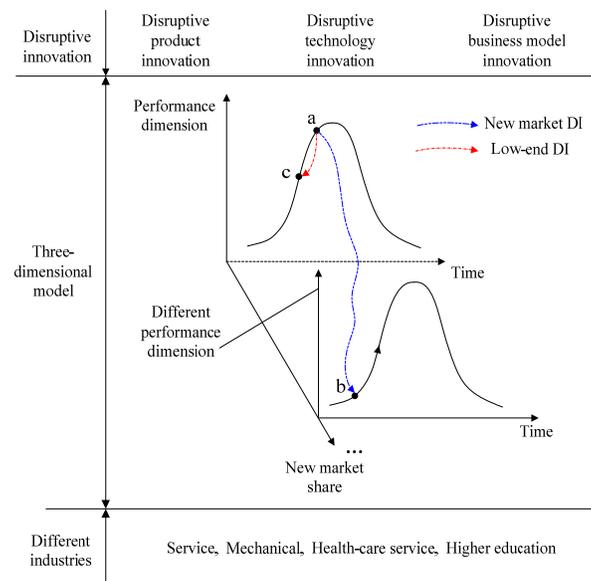

Fig. 1. Three-dimensional model of disruptive innovation

The "disruption" or "disruptiveness" in disruptive innovation is a relative term that threatens the market (Guttentag & Smith, 2017), and it is an explanation of the disruptive innovation perspective (Sandberg, 2002; Trott, 2001; Christensen et al., 2000). This paper mainly focuses on the related research on disruptive product innovation. The product provided by disruptive innovation usually transmits high value to customers. Compared to the existing products, disruptive innovative products have following characteristics (Christensen et al., 2018; Christensen et al., 2015; Adner, 2010; Hüsig, 2005; Li et al., 2018):

(1) They are mainly designed for low-end customers or new market customers. After the products are launched into the market, they may attract some mainstream customers.

(2) They have the characteristics of simplified functions or reduced performances on one or several performance dimensions, while allowing products to improve on one or more other non-mainstream performance dimensions, including portability, easy operation, energy saving and some other performances.

(3) They are customer-oriented and can deliver a high value to non-mainstream customers. Although the price of disruptive innovative products are not necessarily lower than prices of mainstream products, they are with the low profit and in an acceptable price range to low-end or new market customers.

3. Ex-ante studies on driving disruptive innovation

For the disruptive product innovation, the related ex-ante studies on driving disruptive innovation can be classified into following three aspects.

3.1 Timing and conditions for disruptive innovation

Christensen (1997) used the trajectory of demand and supply relationships to describe the development of products and market access for disruptive innovation and proposed that the time when the performance demand trajectory intersects with the supply trajectory is the timing of disruptive innovation. Adner (2010) described the generation of disruptive innovation by using "demand heterogeneity" and proposed that when the preference overlap in market segments is asymmetric, companies with small occupational demand choose to look for opportunities in non-competitive market segment instead of falling into the price competition with other rivals. Keller and Hüsig (2009) measured the disruptive potential of an innovation by the threat that it posed on incumbents to fail. Sun et al. (2011) used "disruptive innovation window" to describe that timing for disruptive innovation's implementation is at the maturity of the product life cycle.

3.2. Factors that affect the implementation of disruptive innovation

Christensen (1997) found that the internal resource allocation process leads to a systematic insufficient of disruptive technologies, thus putting incumbents in the "innovator's dilemma". Cubero et al. (2021) discussed the factors of influencing commercialization of disruptive innovations. Walsh et al. (2004) conceived that the mechanism for overcoming customers' resistance to disruptive technologies is to demonstrate that such technologies can provide significant cost reductions and/or performance improvements of products. Thomond et al. (2003) took Vodafone as an example to illustrate that a company should overcome obstacles for implementing disruptive innovation from following four aspects: (1) to strengthen strategic awareness, (2) to promote the generation of creative ideas, (3) to fund the initiation of potentially disruptive ideas, and (4) not to ignore the potentially disruptive concepts. After an analysis of the entry behavior of a US startup firm and a Japanese incumbent firm to a new sub-market, Chesbrough (2003) found that firms' entry decisions were not only related to the located region of the firm, but also configuration choices of required resources and available configuration choices vary with different organizational settings. Markides (2006) proposed that the way in which incumbents prevent themselves from being disrupted by entrants was to accept disruptive innovation and to find methods to develop it.

Hang et al. (2011) pointed out the overall successful factors of disruptive innovation are market positioning, technology and other favorable drivers, such as favorable lifestyle changes and useful policies. Li et al. (2010) examined influence factors of disruptive innovation in China's high-tech SMEs that are government support, external knowledge resources, strategy orientation and research work. By analyzing the disruptive innovation process of the e-bike industry in China, Ruan et al. (2012) found that government policies or interventions play a positive role in the extension of disruptive innovation. After applying their proposed framework in the German amateur photo camera market and German electric car market, Klenner et al. (2013) found that the disruptive susceptibility of established value networks was closely related to the market and organizational maturity. Ansari et al. (2016) mentioned that the challenge for some entrants was the gained support of incumbents that they disrupt. Guo et al. (2015) proposed a method of quantitatively evaluating disruptive innovative product's design schemes. Based on an analysis of the speech recognition industry, Marx et al. (2014) examined factors affecting the implementation of disruptive innovation, one is that incumbents may be reluctant to develop or acquire potential disruptive technologies, and the other one is related to the business environment where the firm exists.

3.3 Way to generate disruptive technologies or to implement disruptive innovation

Christensen and Raynor (2003) suggested that incumbents develop disruptive innovation by creating independent units. Thomond et al. (2003) constructed a conceptual framework for implementing the disruptive innovation strategy by considering enterprise innovation strategies and human resources' support with the following four steps: opportunity identification, opportunity development, solution development, and sales process. Kostoff et al. (2004) proposed a two-step method to create

disruptive technologies: creating appropriate ideas based on text mining of literature and specialized seminars and roadmap training. Bao et al. (2020) proposed path selection method for disruptive innovation by using extension models, which can solve incompatible problems hierarchically and in stages. Govindarajan and Kopalle (2006) examined that ex-post measures of disruptiveness can help firms to make forecasting of DI. Measurements include firms' organizational abilities, technology sensing and technology responding ability. Rao et al. (2006) took Skype as an example to examine that a combination of two or more disruptive technologies can result in a new discontinuous innovation with new market value. Sun et al. (2014) explored potential disruptive technologies based on technical evolution laws in TRIZ (a Russian abbreviation of "theory of Invention problem solving"). Based on a case study of Sony's creation of transistor radio, Yu and Hang (2008) summarized that creating technologies for disruptive innovation is positively related to diversified customer orientation, a compelling vision to encourage emotional commitment, initial market application prospects, and a good development team. Considering a product as a technology system, Sun et al. (2012) proposed a disruptive innovation process model based on analysis of the evolutionary state of technology systems. Tan and Sun (2014) proposed an ex-ante analysis method of disruptive innovation based on the conflict resolution theory in TRIZ. Based on patent development paths, k-core analysis, and topical modeling of past and current technology trends, Momeni and Rost (2016) proposed a method to identify potential disruptive technologies. Nagy et al. (2016) determined that an innovation could be disruptive to an organization by identifying where the innovation exists in the value chain of the organization. By adding weight constraints in the data envelopment analysis model to deal with the relationship among product technical attributes, Lim and Anderson (2016) forecast disruptive technologies in the flat panel industry. Guo et al. (2016) proposed a systematic approach to generate disruptive innovative products' design schemes, including three steps of function differentiation design, components' design, and optimization design. The existing ex-ante studies mainly focus on solving problems from the firm level. They provide some guidance for firms to forecast disruptive innovation or disruptive technologies. Since most of them are limited to the macro angle, they lack guidance at the specific operational level.

4. Potential research areas of disruptive product innovation

Disruptive innovation provides opportunities for firms to seize market share, regardless of incumbents or entrants. The firms can choose disruptive product innovation, disruptive technology innovation, or disruptive business model innovation. This section discusses disruptive product innovation and related potential research directions. The product innovation process includes Fuzzy Front End (FFE), New Product Development (NPD), and Commercialization (COM). As shown in Fig.2, in order to attract low-end customers or new customers, it is important for disruptive product innovation to generate ideas for demands of new customers or low-end customers. The process details are the development of disruptive technologies, conversion from disruptive technologies to products, and successful commercialization of new market disruptive innovative products and low-end disruptive innovative products.
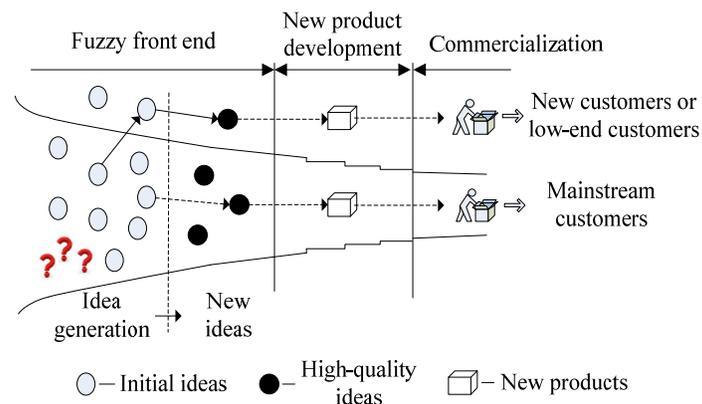

Fig. 2. Disruptive product innovation process model

4.1 Generation of disruptive innovative ideas

The generation of innovative ideas is the initial step in product innovation. The output of high-quality ideas provides an important foundation for new product development (Chou, 2014; Tan, 2013). The generation of disruptive innovative ideas is the premise to develop disruptive innovative products. Therefore, some methods should be developed to stimulate the generation of new ideas for low-end customers or new customers.

With the development of innovation ecosystem and innovation network (Nylund et al., 2019; Yu et al., 2020), innovation subjects cooperate to carry out open innovation, or cross-border disruptive innovation, they provide more possibilities for the generation of new ideas. In the future, innovative ideas based on the flow and application of interdisciplinary knowledge and information may subvert the whole industry. Therefore, the method of generating ideas based on cross-border technology

transplantation or bionic technology (Xu et al., 2020) should be paid enough attention. From another point of view, the demand forecast methods for new markets should also be studied.

4.2 Conversion process from disruptive technologies to products

Technology is the means to realize product functions. Complex products usually include more than one function. Therefore, how to use disruptive technology to develop new products is very important. There has been much research focusing on conceptual design (Saravi et al., 2018), however, it is difficult from conceptual design to detailed design. Therefore, research on the conversion process of disruptive technologies to the detailed design of products is required. A detailed process is necessary for the disruptive product design.

4.3 Assessment of disruptiveness in new products

Despite their having been a large amount of research on new product success (Ho & Tsai, 2011) or sales forecasting of new products (Lou et al., 2020), NPD still faces high risk, and the risk probability has not been significantly reduced. Moreover, there is little research on assessment of disruptiveness in new products, so it is necessary to conduct the related research on assessment of the disruptiveness in new products.

The disruptiveness of a product is its disruption to the market. In the product design process, it can be considered as the disruption of the new product to the existing products under the premise that the product attracts new users or low-end users. Therefore, key features of products that are valued by new customers or low-end customers should be recognized, and some quantitative analysis methods are advised to be introduced to analyze weights of factors. In addition, the factors affecting the disruptiveness potential of a new product also include some other factors, such as product performance, organizational factors, market positioning, managers' keen sight and decision, incumbents' counterattack, etc. Therefore the recognition of key factors, and the classification of them is the base of assessment of disruptiveness in new products.

5. Conclusion

After a review of the evolution history of the disruptive innovation concept, this paper discussed the concept of disruptive innovation and clarified some controversies on its concept. Moreover, the ex-ante studies on driving disruptive innovation were summarized into three aspects, timing and conditions for disruptive innovation, factors that affect the implementation of disruptive innovation, forecasting or implementation of disruptive technologies or disruptive innovation.

Based on the review of the methods of driving disruptive innovation, it is found that the existing methods are limited to the macro level. There is a lack of guidance for firms to implement disruptive innovation. It shows that some detailed methods of forecasting disruptive innovation or implementing disruptive innovation are required. Especially for disruptive product innovation, this paper proposes three potential research directions based on the new product development process, they are generation of disruptive innovative ideas, conversion process from disruptive technologies to products, and assessment of disruptiveness in new products, respectively. More detailed methods are required to promote the occurrence of disruptive innovation.

Besides the disruptive product innovation, disruptive technology innovation and disruptive business innovation are also important. The related research methods are also required, which is our further research topic.

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