A market-based perspective on technological development: disruption as an appropriate recourse to keep innovating in saturated markets?

Antoine Debaty

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Supervised by :

Juan Carlos Salazar Elena

juancarlos.salazar@uam.es

Antoine Debaty

i6226743

antoine.debaty@gmail.com

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Abstract

The concept of disruptive innovation, i.e. an innovation that displaces existing competitors despite lower performance, has become extremely popular over the last decades. Since the seminal contribution of Clayton Christensen, *The Innovator's Dilemma* (1997), different frameworks have been proposed to analyse specific cases of disruptive innovation, such as hard disk drives, cell phones, digital camera, etc. However, much work remains to be done concerning the ex-ante modelling of disruption, in particular by applying one of these models to assess which innovations are most likely to become disruptive. This thesis attempts to advance in this direction with a particular focus on the market-based drivers leading to disruption. Through a calibration process using previously analysed cases, a modified framework is elaborated for forecasting purposes. This reformulated model is then applied to the Light-Fidelity communication technology for an ex-ante assessment of its likelihood to disrupt the WiFi standard. Findings are promising and indicate that LiFi is a perfectly suited candidate to solve the situation of saturation currently faced by the wireless communication market.

Keywords: disruptive innovation, prediction, market saturation, disruptive susceptibility, Light-Fidelity.

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1. Introduction

1.1. Background and presentation of the field of research

The need to innovate is inherent in human nature. Each generation has faced its own troubles and has attempted to solve them with the introduction of new techniques. Throughout history, the first men tamed fire, Johann Gutenberg invented modern book printing and Thomas Edison introduced the first models of light bulbs. Such a commitment to innovation has gathered pace over the past decades, and technological change has become a key component of modern society. Whether in medicine, transport or communication, unprecedented breakthroughs are nowadays performed at increasingly regular intervals, which makes analysts such as Gary et al. (2020) claim that the 21st century will see the emergence of a new Industrial Revolution.

In capitalist societies, this growing propensity to innovate is principally driven by economic considerations. Technological change is indeed portrayed as the principal engine of growth (Sood & Tellis, 2011) and business enterprises are the largest financial contributors to research efforts (Eurostat, 2020). Due to their corporate nature, the investments they realise make undeniably call for corresponding profits. One of the most striking examples of this can be found in the pharmaceutical sector where, for instance, market size assessments are necessarily carried out before investing billions of dollars in the development of new vaccines (Verma, 2019).

This being said, these profits largely depend on the demand these innovations are able to generate. As will be shown in this work, pushing the resolution of cameras or the storage capacity of hard drives beyond their limits can paradoxically be counterproductive since it exceeds the level of performance sought by a vast majority of their users (Christensen, 1993; 1997; Christensen & Bower, 1995; Lucas & Goh, 2009). Indeed, most of them do not perceive the benefits of improving a device which already performs well enough. In this context, the market is said to be saturated[1] by too large a technological offer. As a result, firms find themselves in a very uncomfortable situation as they are facing two opposing alternatives: either restricting the technological development of their offer, or continuing with it and exceeding what most of their customers are asking for.

[1] A market is "saturated" when "no more of a product or a service can be sold because there are no more possible customers" (Cambridge Dictionary, 2020). In the context of this work, the absence of customers for new technologies is due to the high level of performance of older ones that already satisfy them.

1.2. Relevance of the concept of disruption and research question

This thesis made the choice of employing the widely discussed theory of *disruption* to study the above-mentioned dilemma. Depicting how firms proposing underperforming products take advantage of this situation to displace established competitors (Christensen & Bower, 1995), this concept is described as a "powerful means of broadening and developing new markets" (Yu & Hang, 2010, p. 435), allowing firms to keep innovating despite performance saturation.

The objective of this work will therefore consist of identifying the market conditions favouring the emergence of disruptive innovation and to what extent taking the disruptive path can help to solve the above-mentioned issues of market congestion.

1.3. Relevance of such research

Having gained growing interest among academicians since the seminal contribution of Clayton Christensen in the 1990s (Christensen, 1993; 1997; Christensen & Bower, 1995)(see Figure 1.1), the theory of disruption has simultaneously faced heavy criticism because of its low capacity to accurately predict the emergence of innovations. Different isolated frameworks based on markets such as hard disk drives, cell phones or word processors have been well elaborated (Govindarajan & Kopalle, 2006; Guo, Pan, Guo, & Gu, 2018; Hüsig, Hipp, & Dowling, 2005), but none of them have confronted their findings with empirical evidence. It even recently led Christensen (2018), the spiritual father of this concept, to call for more research on determining the various circumstances conducive to disruption.

The present work attempts to deal with this objective by adopting an uncommon lens. Whereas most predictive analyses have been centred on the technological drivers of disruption, i.e. by comparing the level of performance achievable with various technologies (Adner & Snow, 2009; Adner & Zemsky, 2005; Govindarajan & Kopalle, 2006; O'Reilly & Tushman, 2011), this thesis rather bases its approach on identifying the market dynamics behind it. Referring to the field of STS[2], this perspective is better able to capture the social roots behind every innovation. As

[2] Science and Technology Studies (STS) is the field of study investigating the interactions between science, technology and the society surrounding them. To do so, it notably examines how humans simultaneously assume the roles of producers and users of technologies, in particular through innovation (Harvard University, 2020). For more information, consult Bijker, Hugues and Pinch (1987), Jasanoff, Markle, Petersen and Pinch (1995) and Sismondo (Sismondo, 2003)

stated by various scholars (Christensen & Bower, 1995; Prahalad & Ramaswamy, 2004; Roy, 2018), disruption must therefore rather be conceived as the outcome of the association of several societal factors (e.g. changing customer preferences, customer loyalty, density of firm competition, …) than the result of isolated firms blindly flooding the market with technological progress in the hope of overtaking the market..

In terms of impact, the findings of this work are far from just theoretical. Predicting the emergence of a disruptive innovation certainly carries some practical implications. First, it enables the managers of large companies to detect the threat posed by disruptive competitors before they get too big. Moreover, this concept gives the practitioners an extra lens so they can forecast tomorrow's technological state and already prepare for it. Both implications will be highlighted by the ex-ante assessment[3] of the disruptive susceptibility of the wireless communication market.

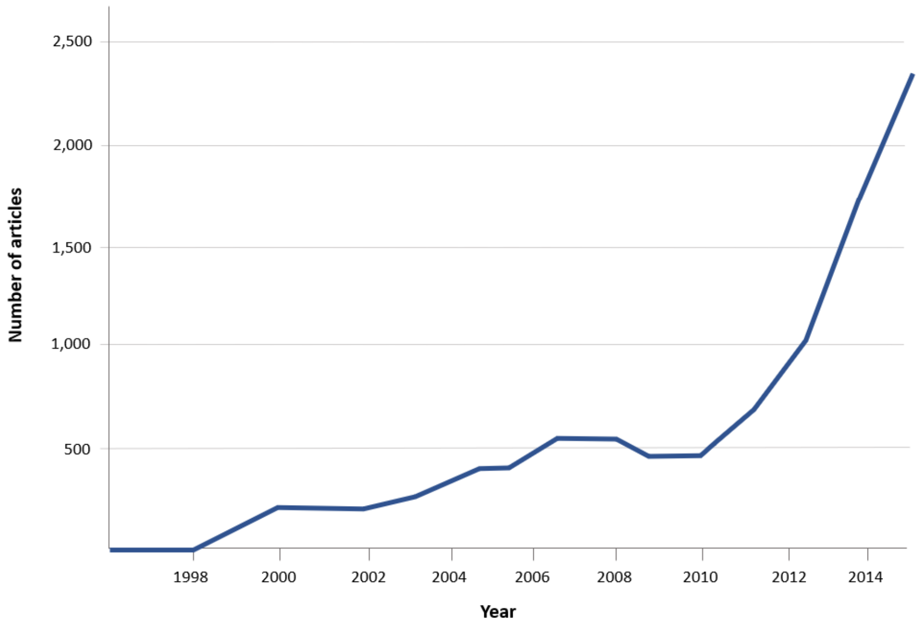

Figure 1.1 - Number of articles mentioning "disruptive innovation" or "disruptive technology" from 1998 to 2014 (own illustration inspired from Christensen et al. (2015))

[3]Ex-ante assessments attempt to predict in advance the events that will take place in the future. They oppose ex-post analyses that are those conducted after the event they describe (Pettinger, 2016).

1.4. Content of the thesis

The rest of the paper is presented as follows. First, the literature review provided in section 2 gathers the bulk of the debates that have surrounded the theory of disruption over the past decades. It notably focuses on the factors distinguishing disruption from other kinds of innovation (Adner, 2002; Christensen & Raynor, 2003; Markides, 2006), as well as the prerequisites for its emergence (Danneels, 2004; Druehl & Schmidt, 2009; Hardman, Steinberger-Wilckens, & van der Horst, 2013). It is also in this section that the urgency of defining a model enabling the prediction of a disruptive innovation that would be based on market situation is stressed.

Presented in the methodology part in section 3, the path taken to fill the above-mentioned literature gap mainly encompasses the study of several cases through the particular lens of the *disruptive susceptibility framework*. Coined by Philippe Klenner, Stefan Hüsig and Michael Dowling in 2013, this model is indeed perfectly adapted to answer the research question of this thesis. Moreover, relying on an acknowledged theory developed by real experts gives additional consistency to the results obtained in the analysis part. This section will also outline the reasons behind the choice of a case study approach, as well as the set of criteria used in the case selection process.

The core objective of this work, i.e. the application of the disruptive susceptibility framework to three concrete examples is presented in section 4. While the two first cases concern past episodes of disruption (i.e. the hard disk drive and the flash memory industry) investigated to challenge the eleven theoretical assumptions of the model, the analysis culminates with the evaluation of the constantly evolving market of wireless communication through the reformulated disruptive susceptibility. A particular emphasis is put on the development of the highly popular Light-Fidelity technology (LiFi).

This case study constitutes the final step of the reflection presented in this work and is discussed in section 5. Having started with the observation of a regular pattern, i.e. market saturation, the present piece of research has relied on the strong theoretical concept of disruptive innovation to generalize its purpose. The findings resulting from the LiFi analysis and their implications are discussed in the ultimate part of this work which also presents their limitations and the opportunity for future research.

2. Literature Review

2.1. Context

The concept of disruption has become extremely popular over the last decades. It is now a frequent subject of study in business schools and numerous entrepreneurs set up new businesses with the avowed desire to disrupt established markets. The craze surrounding this concept goes so far that some authors consider disruption to be one of the most affluent academic management theories (King & Baatartogtokh, 2015). However, this concept is a victim of its success and gradually loses its substance as the way it is employed deviates from its original meaning (Christensen, McDonald, Atman, & Palmer, 2018). The objective of this literature review will be to confront the various opinions held on this topic and to illustrate how this work may contribute to the whole debate.

2.2. Early trajectory of the concept

Back in 1942, the well-known economist Joseph Schumpeter laid the foundations of what would become the theory of disruption by coining the concept of *creative destruction*. With this formulation, the Austrian expert wanted to shed light on how frequently new production units are replacing outdated ones. As frustrating as it may sound, this process was considered as an "essential fact about capitalism" (1942, p. 73). Indeed, given the restricted pool of actors able to conjointly evolve on a market, the arrival of a dynamic entrant firm coming up with ground-breaking products necessarily involves the fall of a weakened competitor.

In 1995, Clayton Christensen, by far the most affluent contributor to the theory of disruption, published an article conjointly with Joseph Bower in which they detailed for the first time the broad outlines of his landmark concept (Christensen & Bower, 1995). Starting from the simple observation of several market developments (mechanical excavators, hard disk drives, steel minimills, printers, telephony), the two authors highlighted how frequently large firms dominating their markets were replaced by small, entrant firms.

What made this correlation peculiar is the recurring pattern in which this shake-up was occurring. In each case, the new challengers were offering products which were underperforming compared with the competition in terms of the attributes considered to be critical (i.e. the primary dimensions of this product performance). Instead, they were proposing a novel package of attributes (i.e. its secondary dimensions) absent from the market until then. For this reason, small-sized challengers were disregarded by incumbent[4] firms considering these new competitors as insufficiently performant, and consequently not designed to pose a threat to their activity.

One of the most iconic cases of disruption, which illustrates just how this process takes place, is the fall of Kodak at the turn of the last century. The American company used to be one of the largest firms in the photography market, designing cameras of excellent quality and constantly improving resolution and ease of use. The organisation failed, however, to respond rapidly to the arrival of digital cameras, assuming that these new products were unable to achieve the same levels of performance as the established ones. Although digital cameras were providing new possibilities such as the ability to display, delete, and transfer photos directly from the device, other indicators of the quality of a camera, such as the resolution of its pictures, were indeed very poor. For this reason, sales were initially limited to restricted segments, essentially comprising a small number of professionals in the field, while the vast majority of customers continued to purchase Kodak's cameras (Lucas & Goh, 2009). However, as repeatedly observed in other industries, disruptors such as Fujifilm rapidly improved the performance of their products, at some point reaching a sufficient level to satisfy the demand of the main segment of amateur photographers. As a result of the established companies' negligence, new entrants gradually seized most of their market share by attracting individuals fully convinced of the superiority of their new technology. According to Christensen and Bower (1995), this process is the final stage of the camera market disruption, which saw incumbents such as Kodak observe their customer base melt away.

A complementary perspective describes disruption as accomplished as soon as the set of criteria chosen by consumers in their purchasing decisions changes (Danneels, 2004). This trend took place in the photography market as the picture resolution achievable with digital cameras reached acceptable thresholds. Indeed, it quickly became unthinkable for consumers, even the most casual ones, to buy analogue cameras. They were gradually seen as a technology of the past, regardless of their performance.

Christensen soon realised that many examples, such as the emergence of low-cost airlines, highlighted the possibility for disruption to emerge in different ways than just technological improvement (cost-reducing business models, standardisation of processes, …). He therefore decided to enhance the applicability of his theory by calling his

[4] One of the key aspects of the theory of disruption is the distinction made between incumbent and entrant firms. The belonging of a company to one of these categories depends on its existence, or not, prior to the introduction of the disruptive innovation (Christensen, 1997).

concept, disruptive innovation, instead of disruptive technology (Christensen & Raynor, 2003). Nowadays, this term has been adopted by the entire scientific community. However, researchers such as Constantinos & Markides (2006) are contesting its relevance due to the homogeneous way in which it deals with different phenomena, each posing their own specific challenges.

2.3. Performance overshoot as the triggering factor

2.3.1. The basics of the concept

Two years after having laid the foundations of the concept that would establish his fame, Clayton Christensen came back with his bestseller, "The Innovator's Dilemma" (1997). This title directly refers to the dilemma faced by company managers who cannot avoid the disruption of their business, even when making supposedly good decisions.

This book was also the occasion for Christensen to introduce the cornerstone of his theory, i.e. the *performance overshoot* (or *performance oversupply*). As shown in figure 2.1, such a situation occurs as soon as the level of performance of a technology for a given attribute (e.g. screen resolution, battery autonomy, …) exceeds the one that market demand can absorb (Christensen, 1997) and causes a performance overshoot. Although complex to estimate, this absorptive capacity is usually approximated by the average user's willingness to pay for technological improvement. It must be emphasised that this demand does not follow the level of performance in a linear fashion and rather tends to decrease as the latter improves[5] (Adner, 2002; Adner & Zemsky, 2005). Indeed, someone ready to spend 150€ on a 24-megapixel camera might not want to pay 1500€ for a 240-megapixel model.

[5] That explains why the slope of demand curve is declining as the level of performance increases.

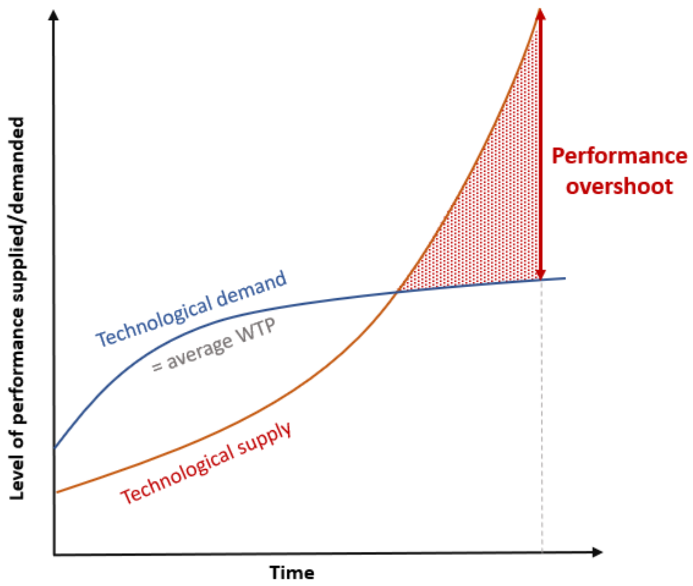

Figure 2.1.1 - Dynamics behind performance overshoot (own illustration based on Christensen (1997, p. 12))

This phenomenon of performance overshoot occurs because technical improvement is no longer sufficiently valued beyond a certain threshold at which the basis for competition is expected to change. For example, the first users of digital cameras were those who stopped valuing improvements made in the quality of the pictures. Instead, they were looking for alternatives allowing them to filter these pictures before printing them. (Lucas & Goh, 2009).

2.3.2. The breach opened by performance overshoot

In each case, new disruptive options offer an unprecedented set of attributes to oversupplied customers which are particularly valued by some of them. According to Christensen, these attributes are - in order of importance - functionality, reliability, convenience and price. Although the entire expert's community does not necessarily agree on this hierarchy, price is often conceived as the ultimate driver of disruption (Sood & Tellis, 2006; 2011). Once a product presents a level of performance considered to be sufficient by a majority of the market, its demand becomes entirely price-driven. For instance, while most camera buyers expect their device to have decent photo quality, this property has become so common nowadays that they will eventually base their decision on its price or its supposed durability.

This reflection led Christensen to describe innovations as being most likely to enter the breach created by performance overshoot when they are "*simpler, cheaper, and more reliable and convenient than established products*" (Christensen, 1997, p. 149). In his review from 2002, Ron Adner even went one step further by stating that, while disruption is enabled by the acceptable performance of the innovation, it will eventually be *enacted* by its price (p. 686). As shown later, considering disruptions as only coming from cheap alternatives is misleading, since it does not account for a vast array of innovations having succeeded in disrupting a market by proposing higher selling prices.

2.3.3. Contrary views

Even if portrayed as a *sine qua non* condition for market disruption, the presence of established firms overshooting customers with excessive performance has regularly been contested by scholars such as Ron Adner and Peter Zemsky (2005). In the same way, Andrew King and Baljir Baatartogtokh (2015) illustrated this contrary view by taking examples of disrupted markets such as postal services in which the main performance criterion, i.e. speed of delivery, was not even judged to be sufficiently met before the emergence of disruptive entrants.

2.4. Shape of disruption

2.4.1. Presentation of the S-curve model

A vast majority of scholars agree on coining disruption as a process rather than an isolated event (Christensen, Raynor, & McDonald, 2015; Kumaraswamy, Garud, & Ansari, 2018; Markides, 2006). It implies that a start and an end can be identified, and that the market overhaul happens in between. For instance, the very popular streaming website Netflix started its activity in 1997 and took a long time before displacing DVD rentals and pay-per-view content providers (Christensen et al., 2015).

This being said, opinions differ when it comes to delineating the path taken by innovations on their way to disrupt the market. Inspired by the previous work done on the technology life cycle by William Abernathy and Kim Clark (1985) as well as Richard Foster (1986), Clayton Christensen and other researchers portrayed the performance of disruptive innovations as following an *S-curve*[6] (Hüsig & Keller, 2009; Markides, 2006; Reiner, 2013; Roy, 2018).

[6] This model is close to the S-curve representation of the "diffusion of innovation" developed by Everett Rogers in 1995. The main divergence between both patterns is the value assigned to the vertical axis: while Rogers' graph analyses the market penetration of an innovation, the model presented here rather focuses on pure technological improvement. As shown in the subsection 2.4.2, attempts have already been made to connect both concepts. For more information, consult Rogers (1995)

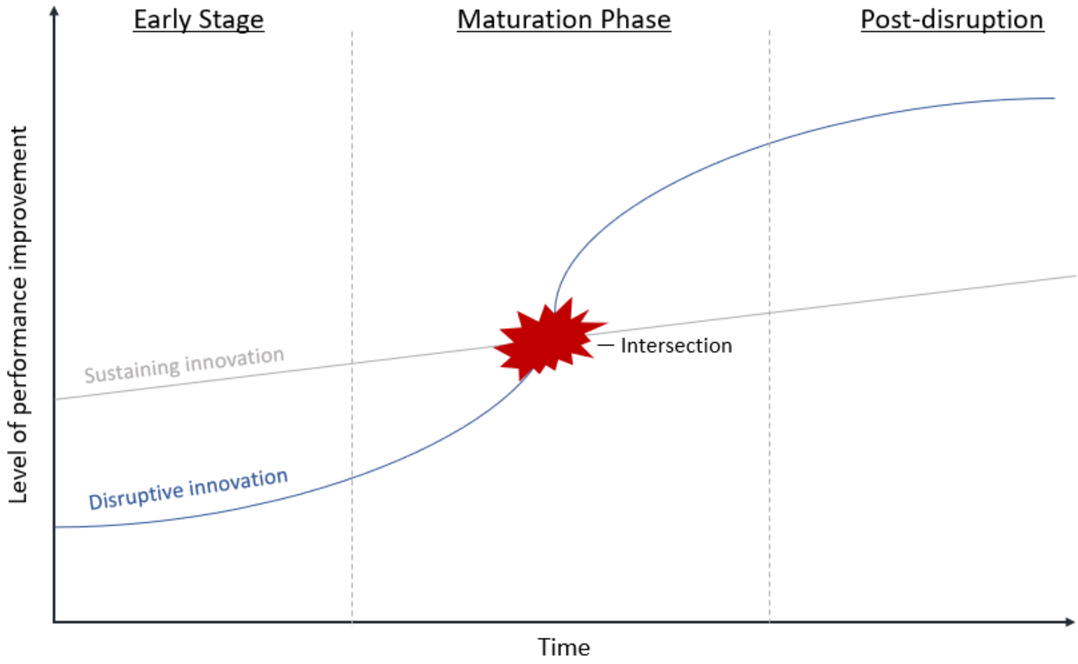

Figure 2.2 – The S-curve model (own illustration based on Sood and Tellis (2006, p. 153))

As illustrated in figure 2.2, the S-curve model is a three-stage process including an early stage, a maturation, and a post-disruption phases.

In the beginning, disruptive innovations tend to propose their own package of attributes. In what is considered as the early phase, the level of technological progress is low among entrant firms. They propose cheap, underperforming products which are solely designed for the most price-sensitive user segments. It was the case with Netflix who was proposing limited catalogue of films displayed in a poor quality (Christensen et al., 2015). Therefore, disruptors tend to focus on small niche markets where actors are inclined to trade some of these mainstream sorts of performance for the novel ones, most of the time including cheaper prices. This notably happened during the introduction phase of LED technology, whose initial performance was extremely poor compared to incandescent light bulbs. But the cost savings they provided through lower power consumption and longer durability convinced the low-end segments[7] (Moore, 2019).

Then occurs what is presented by Erwin Danneels (2004) as a *maturation phase*. At this stage, the innovation has the opportunity to grow and to become adequately performing in a sufficient set of attributes to challenge established

[7] Low-end disruption represents the type of disruptions entering the market by selling to its low-end segments, i.e. the most price-sensitive customers.

companies and capture their market segments. The performance of both firms is said to intersect. Here, the slope of the S-curve, i.e. the pace at which this intersection occurs, largely varies depending on the sector (Christensen et al., 2015).

The last part of this three-step pattern takes place when the market is fully disrupted. Room for performance improvement has narrowed and the competition is now supposed to be fully price-driven (Adner, 2002). Disrupted firms have generally moved upmarket, providing their highest-end customers with sustaining improvements justifying high premiums, while disruptors are profiting from the large market segments they have acquired (Adner, 2002). Logically, another entrant candidate should start contesting its domination afterwards by initiating a new S-curved disruption process.

2.4.2. Critiques regarding the S-curve model

The main criticism of the S-curve model has been formulated by Clayton Christensen himself (1997). The point he is making concerns the imprecision with which this pattern portrays the overtaking of the mainframe market by the entrant firm. Disruption is not purely a matter of a product's performance, but rather of the market segments it is able to attract thanks to it. Coming back to the light bulb industry as an example, LEDs did not replace a large proportion of the incandescent lamps because they offered equal or higher lighting performance. They did it rather because the lighting level they reach was now considered sufficient for a large proportion of users who decided to adopt it for its additional characteristics (lower power consumption and longer durability). Hence, the vertical axis of the figure should be reconsidered to present the *customers' utility* resulting from the level of performance offered to them.

On a broader perspective, the mid-stage of the S-shaped model has generated the bulk of the debates over the two last decades. Ashish Sood and Gerard Tellis (2006; 2011) have indeed argued that the performance curves of competing firms rarely intersect once, as portrayed here. While several disruptive entrants never reach the level of performance imposed by the market, it also happens that those achieving this intersection are subsequently overtaken again by vengeful incumbents counter-attacking through massive investments in R&D (Adner & Snow, 2009). This situation, represented in figure 2.3, gives a better account of what happened with a technology such as radiation imaging, whose performance improvement somehow managed to relegate the potentially disruptive ultrasound alternative to a marginal one (King & Baatartogtokh, 2015). Moreover, Sood and Tellis disproved the alleged smoothness of performance improvement that they rather depict as following a step curve, occasionally improving during phases of technological breakthrough.

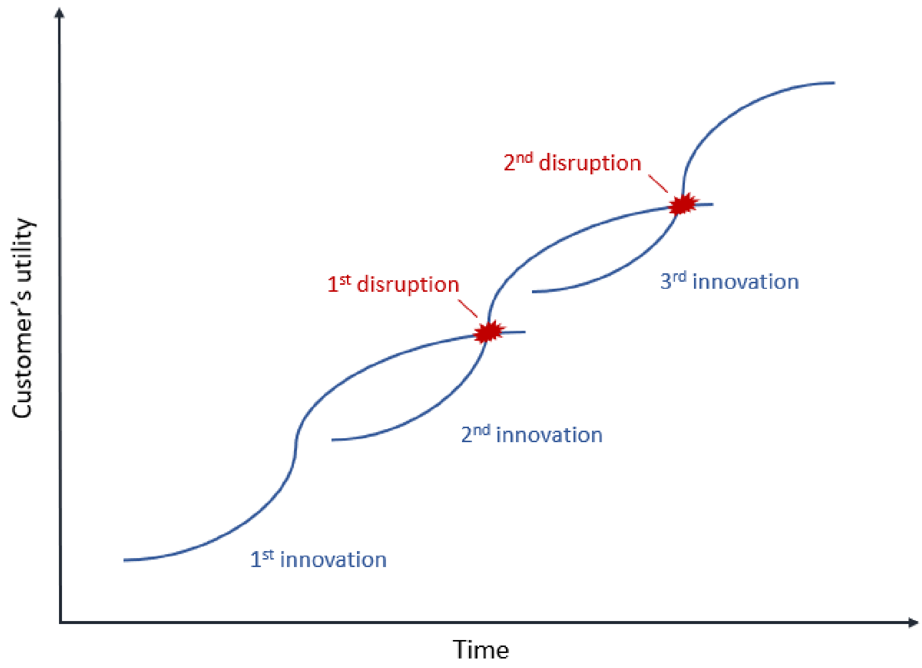

Figure 2.3 – Reconsidered version of the S-curve model (own illustration based on Christensen (1997, p. 46) and Sood and Tellis (2006, p. 153))

2.5. Additional entry door for disruption

Although the S-curve pattern is well suited to determine the development of some cases of *low-end disruption*, it does not give a fair picture of how some innovations disrupt a market through the creation of a novel one. With regard to this, an additional perspective on the conditions necessary for disruption to occur has emerged over the last twenty years. Whereas early scholars were considering it as only appearing at the low-end of the market, through cheap and underperforming alternatives that needed to mature in price-sensitive niches before entering main markets (Christensen & Bower, 1995; Govindarajan & Kopalle, 2005), the idea of *blue-ocean* disruption strategy[8] has attracted rising attention over the last decade (Charitou & Markides, 2003; Christensen & Raynor, 2003; Danneels, 2004; Druehl & Schmidt, 2009; Hardman, Steinberger-Wilckens, & van der Horst, 2013). To back their argument, the adepts of this complementary theory found empirical evidence highlighting that some firms are causing

[8] In their book, Chan Kim and Renée Mauborgne define blue ocean strategy as the willingness for companies to explore "uncontested market spaces" where non-consumption is prevailing (Kim & Mauborgne, 2005, p. 4).

disruption through the introduction of products (mass produced automobiles, iPods, …) that cannot be linked to any pre-existing market. Hence, this new offer manages to attract customer's attention with new arguments that are not based on cost reduction (Druehl & Schmidt, 2009).

The existence of an additional entry door for innovations to disrupt a market has a two-fold implication. Given how different are the attributes they offer to customers when compared to the low-end case, it firstly makes it difficult to compare new and previous offers according to a price/performance ratio. It is also inconceivable to draw S-curve in order to compare both trajectories. Moreover, it is worth emphasising that this disruption creates an opportunity for companies to engage with individuals or firms that had so far not been attracted by the previous product. Compared to the low-end disruption model whereby customers simply switch from one offer to another depending on their related utility (largely basing their decision on the price-performance ratio of the innovation), here emerges a new group of users who would otherwise not have consumed. This consequently results in an increase in the level of consumption of the concerned products. As shown later, this was the case for flash memory, which through its commercialisation has created a whole new market of companies requiring it in the manufacture of their devices (electronic clipboards, cash registers, …) (Christensen, 1997).

Some cases of *high-end disruption* such as the emergence of cell phones sold at higher prices than the pre-existing landline have also been reported by Vijay Govindarajan and Praveen Kopalle (2005). For them, this category is well embedded in the disruption framework since developers of cell phones were initially targeting small, unsatisfied niche markets, i.e. corporate executives looking for more portability and convenience at any cost, and not mainstream predictable customer segments.

While scholars such as Sood and Tellis (2011) are refuting these additional perspectives on disruption that would not be based on a low-priced approach from entrant firms, others appreciate the higher practicability that these complementary views grant to the overall theory (Christensen et al., 2015).

2.6. The sustaining versus disruptive debate

Since the identification of disruptive innovations can no longer exclusively rest on the pricing strategy of their promoters, another set of criteria must be defined.

As a reminder, disruption theory sprouted in Christensen's mind after multiple observations following the same pattern: the repeated fall of large, market-leading companies in favour of new entrants. According to him, the reason for this phenomenon lies in the opposing corporate priorities of both structures. An overwhelming majority of incumbent firms actually consider innovation as an opportunity to *sustain* their current customer base. Whether by adding a minor functionality to an existing technological product or by completely reshaping its design, long-established companies excel at satisfying the demand of well-identified customers. It is also worth noting that taking the path of sustaining innovation also allows these firms to bolster both their sales volume and margins while satisfying their most demanding customer segments (Christensen & Raynor, 2003).

What conversely defines disruptive innovation for Christensen is that it is targeting the potential of non-existent or unpromising markets, regardless of the inherent degree of technological radicalness associated to the breakthrough (Yu & Hang, 2010). Very often, this situation puts the managers of incumbent firms in a complex dilemma. The immediate interest of its various stakeholders leads them to continue with "business-as-usual" practices while the threat of potentially disruptive entrants should prompt them to investigate the less promising markets as well. By taking up the S-curve concept, this situation can be represented by either advancing along the same curve (i.e. through sustaining innovations), or by the creation of a novel one, as it is portrayed in figure 2.3 with the apparition of a new trajectory at the bottom right of the previous one. Later, analysts such as Constantinos Markides (2006) portrayed the distinction sustaining versus disruptive to be oversimplified.

2.7. Perspectives around the nature of the firm and its influence on the disruption process

2.7.1. Two opposing visions

Another debate that has attracted particular attention over the last decades concerns the characteristics generally observed among disrupting and disrupted companies. While Christensen and his colleagues maintain that small entrant firms are those most adapted to follow the disruption pattern in their desire to challenge large established companies (Ansari & Krop, 2012; Christensen & Bower, 1996; Christensen & Raynor, 2003; Christensen, Raynor, & McDonald, 2015), empirical evidence has occasionally indicated opposite results (Adner, 2002; Chesbrough, 1999; King & Baatartogtokh, 2015; Sood & Tellis, 2011).

2.7.2. Mainstream perspective

A majority of the theoreticians are actually endorsing the former traditional perspective. To this end, authors such as Erwin Danneels developed the idea that while large incumbents should normally outperform competitors at developing products embedding disruptive technology because of their large investments in R&D, their lack of *customer competence* (2004, p. 254) prevents them from taking advantage of it. In their research, scholars have found various factors to explain this weakness. In addition to the reasons traditionally mentioned, such as excessive bureaucracy or arrogance from large business owners who consider themselves too big to fail (Christensen et al., 2018), another part of the literature is shedding light on the relationship these companies have built with their customers to explain their apathy in the face of disruption. Whilst some of them are highlighting the management myopia of executives, who prefer to stay close to their safe and profitable customer base (Christensen & Bower, 1995; Leonard, 1992; Reiner, 2013; Vecchiato, 2017), others portray this trend as resulting from a poor resource allocation leading incumbents to become financially dependent on their external resources, i.e. their customers (Bower, 1970; Christensen, 2005; Gans, 2016; Gilbert, 2005; Hüsig, Hipp, & Dowling, 2005). It has also been shown that disruption of incumbents is not always the ultimate consequence of a series of wrong decisions but that it could also result from structural barriers inherent to their activity and limiting their room for manoeuvre. That is, for instance, why established wood product manufacturers simply could not counter the intrusion of potentially disruptive plastic producers, in which case it would have meant a complete overhaul of their business model (King & Baatartogtokh, 2015). Moreover, any strategic change is more time-consuming in large structures and their decision to finally compete with disruptors often comes too late. Added to the fear of long-established firms of cannibalising their current sales by the introduction of better-performing innovations (Druehl & Schmidt, 2009; Govindarajan & Kopalle, 2005), this perspective underpins the dilemma experienced by managers of incumbent structures. It also explains why flexible small-sized enterprises with no pre-existing customer base are better able to engage in unstable and financially unattractive markets.

2.7.3. Controversies

As mentioned above, other scholars consider the inertia of incumbents as overstated and advance additional drivers for disruption which are not based on the companies lifespan (Adner, 2002). Such explanatory factors can particularly be found in the socio-economic context of a given region, or in its regulatory landscape. This complementary approach can be employed, for instance, to understand why the disruption of the hard disk drive industry happened in the United States and not in Japan (Chesbrough, 1999; Yu & Hang, 2010). Additionally, it is also challenging the mainstream perspective, judged as too focused on the issues related to incumbents. Thinley Tharchen and Raghu Garud (2017) have indeed emphasised the numerous challenges faced by entrant firms in building a new viable ecosystem around disruptive innovation.

Researchers such as Danneels (2004) and Sood and Tellis (2006; 2011) went one step further by empirically refuting the idea that the size of a firm would be negatively correlated with its chances for being disrupted (Christensen & Raynor, 2003). To do so, they demonstrated that a major part of innovations traditionally considered as disruptive were rather *sustaining breakthrough* designed by incumbents themselves. A conclusive example may be found in Danneels' assessment of the car industry, where fossil-free alternatives are usually commercialised by dominant companies, and not by small-sized challengers.

2.7.4. Potential coexistence of both types of innovation

Even when incumbents are actually disrupted by small entrants, additional research has somewhat contradicted Christensen's prediction of the systematic fall it is supposed to trigger. It has indeed been shown that a third of these incumbents were actually coexisting with their disruptors (Gans, 2016; Sood & Tellis, 2011). This is, for example, the case in the education sector, where online courses represent an outstanding extension of traditional options without being a substitute for them (King & Baatartogtokh, 2015).

In the same vein, critics of Christensen's theory even challenge his most famous case studies, including the hard disk drive industry, to underline the long-term survival of some incumbents in the face of emerging firms (Lepore, 2014). Unlike the original theory presenting retrenchment in the highest-tier niches as the unique means for incumbents to temporarily survive disruption, these authors conversely propose the *status quo* to be a rational option (Adner & Snow, 2009). It is worth mentioning here that this latter option does not suggest the absence of technological improvement from the attacked firm, but rather the concentration of its efforts to fight back and retain its customer base (Hardman et al., 2013).

2.8. A model not beyond reproach

Voices have gradually been raised against Christensen's theory, judging it to be insufficiently rigorous (Danneels, 2004; Sood & Tellis, 2011), too qualitatively-based or lacking in nuance (Klenner et al., 2013; Markides, 2006). Experts such as Yu and Hang (2010), Govindarajan and Kopalle (2005), as well as King and Baatartogtokh (2015), particularly deplore the lack of academic literature testing the validity and generalisability of such a concept through quantitative methods. Above all, Jill Lepore (2014) highlights how arbitrary the criterion for determining a firm's success is, Christensen basing his distinction solely on the revenues it generates.

In addition to these concerns, one of the most recurring criticisms of current disruption theory is its lack of predictive ability. The major body of existing case studies is indeed restricted to the description of markets that have already been disrupted, successfully or not (Christensen, 1997; Lucas & Goh, 2009). But this type of ex-post analysis is severely limited. Indeed, it does not enable managers of established firms to predict the potential disruption of the market they are presently dominating. Above all, what is presented as a one-way theory by Danneels (2004) et Sood and Tellis (2006; 2011) suffers from a severe lack of interest and consistency if it is unable to identify a disruptive innovation before it has completely taken over the market.

2.9. Towards ex-ante modelling of disruption

To fill this gap, many researchers sharing the same concern have attempted to shape accurate ex-ante models (Dijk, Wells, & Kemp, 2016; Hardman, Steinberger-Wilckens, & van der Horst, 2013; Hüsig, Hipp, & Dowling, 2005; Hüsig & Keller, 2009; Guo, Pan, Guo, & Gu, 2018; Hahn, Jensen, & Tanev, 2014; Yu & Hang, 2010). In his writings, Joseph Schumpeter (1947) was already stressing the complexities involved in the ex-ante forecasting of innovations. Such a task is getting even more complex in the case of disruption in view of the unpredictability of market evolution. It goes to such an extent that opposing views (Adner, 2002; Kumaraswamy, Garud, & Ansari, 2018; Lepore, 2014; Sainio & Puumalainen, 2007) are doubting the feasibility of any ex-ante prediction of market disruption given the unforeseeable actions and reactions of its components (e.g. stakeholders, policymakers …).

As noted by Govindarajan and Kopalle (2005), experts did not imagine that the cell phone market could exceed 900,000 users before its introduction. It was indeed supposed to remain a niche device used by wealthy professionals only. Thus, using old-fashioned techniques based on the measurement of the economic potential of a customer segment at a fixed moment has proven to be inefficient. A comprehensive, long-term approach basing itself on both quantitative and qualitative reasoning is therefore preferable to a rigid and incomplete quantitative analysis.

To this end, researchers generally proceed through a two-step approach. They first create a model based on an in-depth analysis of ex-post observations, and then apply it to real case analyses of current innovations in order to predict their possible disruption (Govindarajan & Kopalle, 2005; Klenner, Hüsig, & Dowling, 2013; Vecchiato, 2017). Very consistent, the same method will be employed in the core section of this work.

2.10. A market-based perspective and the social construction of innovation

The various predictive models can be divided into three main categories depending on the lens they adopt to anticipate the emergence of disruption. The one that has received the most attention so far includes technology-related drivers of such changes (Adner & Snow, 2009; Adner & Zemsky, 2005; Govindarajan & Kopalle, 2006; O'Reilly & Tushman, 2011). This work will instead focus on the last two categories, related respectively to the market and the environment in which disruptive innovation is most likely to emerge. With a particular focus on the former, predictions realised through this perspective are better-suited to capture the socially constructed nature of disruptive innovation, conversely to the analyses centred on technological advancements (Govindarajan & Kopalle, 2006). This phenomenon is indeed more a question of market dynamics, with flows of customers switching from one technology to another, than of the absolute level of performance they are able to offer (Christensen & Bower, 1995; Prahalad & Ramaswamy, 2004; Roy, 2018).

In the same vein, Yu and Hang (2010) depict disruption as a relative phenomenon. This means that innovation will never be inherently disruptive but that it rather causes disruption through the way it is framed (Kaplan & Tripsas, 2008). Being the first proponent of a multidimensional analysis as mentioned above, Christensen (2005) uses this key distinction to explain why the emergence of the same technology, for instance the internet network, led to widely varying results depending on the sector in which it was implemented. As an example, it caused the fall of the DVD-renting sector, whereas it was adopted by clothing-retail companies. Experts such as Gurses and Ozcan (2015), Mahto et al. (2017) and Orlikowski and Gash (1994) join themselves to this analysis, emphasising the crucial role played by the market environment on technological development.

Thus, Fan and Suh (Fan & Suh, 2014), Oliveira et al. (2016) and Schimdthuber et al. (2018) advocate that the models that attempt to predict disruption should first integrate customers, whether current or potential, in their analysis. Understanding what is driving their current and future attitude is undeniably critical to determine whether the situation as it is now will last in time, or if, on the contrary, the incumbents should worry about non-consumption from which disruption could emerge (Danneels, 2004; Yu & Hang, 2010). Predictive models should also integrate the heterogeneity of these customers into their forecast. Adner (2002) breaks down this diversity into the disparities between individuals in terms of budget, skills, benefits they derive from the use of the innovation, and potential substitutes for it. This heterogeneity may even be extended to the entire *value network*[9], every stakeholder understanding the innovation in different ways and shaping it accordingly (Bijker, 1995; Leonardi, 2011; Kumaraswamy, Garud, & Ansari, 2018).

2.11. Contribution to the literature

This literature review has shed light on the state of advancement of the theory of disruptive innovation. Starting with a description of the pioneering work made by Clayton Christensen at the end of the twentieth century, it has subsequently pointed out the various debates that have arisen since then.

In spite of already extensive literature written on the topic, this review has also shown that much work remains to be done concerning the ex-ante modelling of disruption. In their most recent piece of work summarising the state of research on this subject, Christensen has indeed stressed the need for further research on the "circumstances in which disruption is most and least likely to occur, and at what pace" (Christensen et al., 2018, p. 1067). In this perspective, a large set of isolated case studies have already been conducted by researchers to create their models but hardly any work to date has assessed the validity of their conclusions by applying them to novel innovations. This thesis will attempt to fulfil such an objective with the reconsideration of Klenner, Hüsig and Downling (2013) framework of *disruptive susceptibility*.

[9] A value network can be defined as a "set of connections between organizations and/or individuals interacting with each other to benefit the entire group" (Investopedia, 2019). Because of its similarity to the concept of "market", these two terms will be used interchangeably in this work

By employing this model, this work also contributes to filling the void in the existing literature by using a framework that enables the anticipation of disruption through an uncommon lens. Whereas a substantial volume of research has been carried out on the analysis of disruption from a technological point of view, the disruptive susceptibility framework indeed addresses this concept by adopting a market-based perspective.

Finally, the application of this framework to the wireless communication market, and more precisely to the emerging LiFi technology, as part of a case study is also an unprecedented contribution to the literature. Moreover, it amplifies the existing theory on the ex-ante prediction of disruptive innovation through a market-based perspective. This approach is particularly valuable for disruptive susceptibility, a theory suffering from a concrete lack of real case applications.

3. Theoretical framework and research methodology

3.1. Theoretical framework

3.1.1. Introduction

While the previous section has highlighted the contribution brought by a market-oriented prediction of disruptive innovation, the present one will consist of defining how such a task can be achieved. Nevertheless, an explanation of the two principal pieces of theoretical concepts used in the course of this work, i.e. the performance trajectories and the disruptive susceptibility framework, is required before exploring methodological considerations. First of all, a summary of the former in the way it has been coined by Clayton Christensen in his early writings (Christensen & Bower, 1995; Christensen, 1997) will be presented.

3.1.2. Performance trajectories

3.1.2.1. Taking back the concept of performance overshoot

Everyone knows Moor's law, the concept introduced by Gordon Moor in the late twentieth century portraying technological development as embracing a remarkably regular exponential growth. Basing his view on the surging market of microprocessors, the American businessman portrayed a quite dehumanised image of innovation whose large-scale evolution would be only a matter of mathematical inevitability.

However, adopting this stance without further reflection would involve the oversight of one of the most elementary economic concepts which states that supply must always be supported by a corresponding demand if a market wants to reach an equilibrium. In case of mismatch, the market is considered to be either in shortage (when the demand is higher than supply) or in surplus (the opposite case) (BC Campus, n.d.). The latter situation has progressively attracted the interest of scholars working on disruption phenomena, and has been conceptualised by Clayton Christensen by the term overshoot. Supported by a vast majority of the researchers' community, this concept has even become the cornerstone of his theory of disruptive innovation.

3.1.2.2. Distinction between principal and secondary attributes

One of the core components of supply overshoot theory lies in the dynamics of *performance trajectories*, which refers to the rate at which an innovation improves its level of performance along a given dimension (Christensen, 1997).

Whether it is in the sector of light bulbs, or display monitors, lots of comparisons are made between competing technologies depending on the level of performance they provide to their users. However, given their heterogeneous desirability, an infinite list of attributes could be employed to distinguish them. While some individuals particularly value the tone of the light emitted by a bulb, others base their purchasing decision on its lifespan. In any case, the objective here is not to assess which type of technology is the best in general (e.g. incandescent versus LED bulbs), but rather to rank these innovations according to objective criteria gauging the benefits they bring to their users.

Thus, the decision is often taken to focus on the trajectory of their most popular feature, a critical attribute that Christensen and Bower (1995) present to be identifiable in every industry. In the case of light bulbs again, the comparison is often based on their power consumption, whereas the choice for a certain type of display monitor is usually influenced by its screen resolution (Sood & Tellis, 2006). All the other attributes must be considered as secondary.

3.1.2.3. Representation of the trajectory taken by disruption

Displayed in blue in figure 3.1, the demand trajectory presents the willingness of customers to pay for a product providing a certain level of performance along the main attribute. The heterogeneity in how much these customers are ready to spend for the same level of performance is reflected through the presence of three distinct curves, all of them corresponding to a given profile. Hence, the highest tier of the demand greatly values every improvement and accepts to pay high premiums for it while more price-sensitive customers appearing at the bottom of the figure prefer economical options.

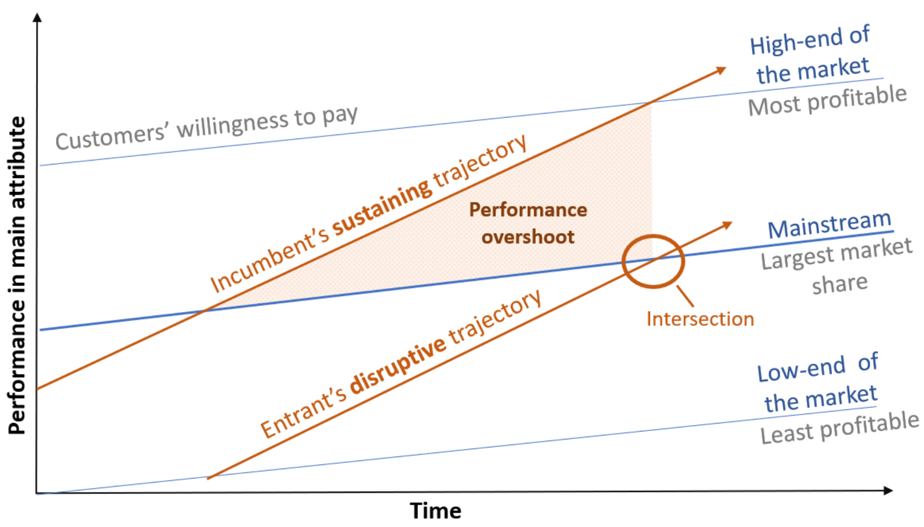

Figure 3.1 - Performance trajectories (own illustration based on Christensen (1997, p. 12))

As a reminder, disruptive innovations are expected to propose low levels of performance in the early-stage of their development (e.g. the poor quality of the first pictures made with digital cameras). Hence, they are presented as starting from a lower position than sustaining ones, selling products that only manage to convince the lowest tier of the market which particularly values its new package of attributes (cheaper price, ease of use, …).

This being said, the situation is not static, and the performance of both innovations increases over time. In doing so, large incumbent firms usually improve faster than the others thanks to their ability to sustain their existing customer base. Profiting from important economies of scale, they are designed to develop products of increasing quality. At some point, this improvement even exceeds the demand curve of the majority of users who no longer want to pay for additional performance. It is considered that the incumbent has reached its performance overshoot threshold, and now only attracts the minority segment of highest-end users.

Meanwhile, the entrant firm has also improved the whole quality of its offer, especially concerning the critical dimensions along which it was it was initially underperforming. Even if slower and more hesitating, the performance enhancement process through which it has engaged now allows this entrant to capture mainstream customer segments which used to be linked with incumbent's offer. The excessive level of performance proposed by incumbents has indeed created a large vacuum of dissatisfied users. Oversupplied with the main performance that they no longer value sufficiently, these customers are now looking for new value propositions. In a way, technological progress has reordered the importance they assign to the various performance attributes. This is why they are increasingly interested in offers that Christensen depicted as typically "cheaper, simpler, smaller and more convenient to use" (1997, p. 11).

It is often too late for managers of incumbent companies when they realise that their customer segments have been overtaken, and this is why they are left with only two possibilities (Adner, 2002). The first invites them to strike back and refocus their offer on the large segment of mainstream users they just lost. The risk associated with this strategy is that the entrant firm already has a strong foothold in the market, where it is proposing a new set of attributes by playing on its low-cost structure to gather momentum. Having lost their competitive advantage, incumbents are now forced to cannibalise their remaining sales by adapting their cost structure. This phenomenon is observed in the aviation sector where many companies such as Brussels Airlines are downgrading in order to compete with low-cost airlines. Their cost structure is, however, unable to bring them as much profitability as a competitor such as Ryanair, which has always operated in this way.

The second option put forward by Ron Adner (2002) consists of relocating their production into the highest tier of the market by continuing with sustaining innovations to justify high prices. However, it is a hazardous strategy given the strong likelihood that disruptor firms keep improving their performance on the main dimension, and eventually capture the ultimate segments of the market. As an example, this second stance has been adopted by the vinyl market, whose ultimate customer segment is now limited to a small community of nostalgic individuals.

3.1.2.4. Reflection on the model

Thanks to its straightforwardness, the performance trajectory model has regularly been employed in the predictive analysis of disruption (Adner, 2002; Christensen, 1997; Serra, Ars, Solanilla, & Bermudez Miquel, 2014; Sood & Tellis, 2006; 2011). It is particularly useful to situate an innovation compared to the rest of the market in order to assess if it is taking the disruptive way or not. However, one must always be cautious when employing this approach since the real-world situation is often fuzzier than what theory would suggest.

One of the biggest challenges for predictive modellers, therefore, is to identify customer demand for the various attributes. In the car industry, for instance, the list of selection criteria is so heterogeneous that it is difficult to isolate one single attribute that would attest to the quality of a certain model. Whereas some users prefer powerful vehicles, others prioritise comfort or low carbon dioxide emissions. Hence, one cannot distinguish a single key attribute, but rather a series of characteristics that are highly valued by a majority of users. This nuance has noteworthy implications and will be used later in the evaluation of the LiFi disruptive potential.

3.1.3. The disruptive susceptibility framework

3.1.3.1. Objectives

As has been presented in the literature review, the theory of disruption suffers from a lack of predictive capacity. Even though it has been coined as a forecasting theory by Christensen (2018), the small amount of existing research analysing the emergence of disruptive innovation ex-ante weakens the interest of such a concept.

Deploring this gap, Klenner, Hüsig and Dowling coined the concept of disruptive susceptibility to "analyse the readiness of established value networks for a successful market entry of disruptive innovations" (2013, p. 915). The objective here consists of establishing a set of criteria to assess how likely a market is expected to be disrupted in the near future. Rather than describing the path taken by disruption, the objective is to explain the factors favouring its emergence. Furthermore, another specificity of this framework is that it can be applied even before the innovation has entered the market.

It must also be noted that authors made the decision to focus on the disruptive innovations entering the market from the low-end customer segments. Even though they acknowledge the existence of other forms of disruption, i.e. those taking place through the creation of a new market or by the adoption of high-end strategies, their choice is justified by the better reliability it offers to the model. The possibility of extending the scope of this framework to the other categories of disruption will be considered at a later stage.

3.1.3.2. Creation of the framework

To elaborate their model, Klenner and his colleagues followed a deductive method similar to the framework proposed by Kuipers in his article, *Reasoning with qualitative models* (1993, p. 128). Such a circular structure is presented in figure 3.2 and details the process behind the generation and testing of a model based on hypotheses.

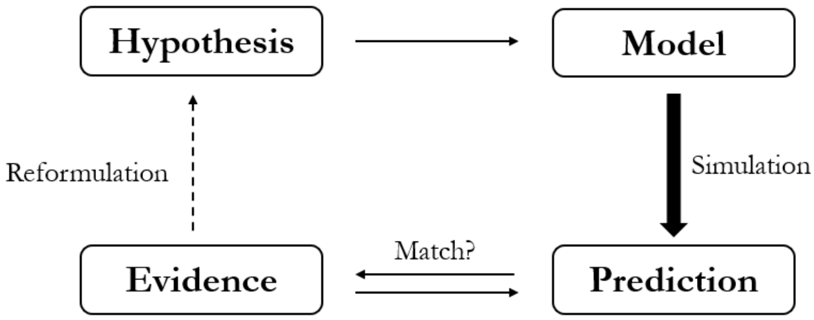

Figure 3.2 – Deductive method (own illustration based on Kuipers (1993, p. 128))

Klenner first compiled a list of 14 theoretical propositions based on existing ex-ante approaches proposed by prior scholars. All linked to factors influencing the readiness of a market to be disrupted, these 14 hypotheses were operationalised with indicators using qualitative and quantitative criteria. This led to the creation of a preliminary theoretical framework, i.e. the primary version of their model, that they first applied to a case study. The objective here was not so much to determine the disruptiveness of an innovation, but rather to investigate the market conditions behind it. This is why researchers selected an already confirmed case of past disruptive innovation, with the development of the digital cameras sector in Germany during the nineties.

The outcome resulting from this simulation generated theoretical predictions which they were able to compare with empirical evidence. Closing the first loop of their research method, the application of the preliminary theoretical framework of disruptive susceptibility with an ex-post perspective allowed them to evaluate the consistency of the 14 initial propositions. The resulting modified framework was consequently stripped of 6 assumptions judged inconsistent in view of the empirical testing. Klenner and his colleagues conversely decided to add 3 novel propositions that were absent from the existing literature on which they relied to elaborate their first model.

They finally dedicated the ultimate part of their article to the ex-ante application of the modified framework to the German car market in 2013, a value network which exhibits a medium-high disposition for disruption.

3.1.3.3. Content of the framework

Conditional versus accelerating propositions

Under its final configuration, the disruptive susceptibility framework is composed of 11 propositions judged as consistent and positively related to the emergence of disruptive innovation in a given value network. Klenner's team of researchers decided to divide them into two main categories: conditional and accelerating propositions.

Conditional propositions entail all the factors that must be present in a market before the emergence of a disruptive innovation. Although being an essential prerequisite for this process to happen, these elements alone are not sufficient to enable disruptive change because they are incapable of triggering a change in market values on their own. This latter property is on conversely held by the second category, i.e. *accelerating propositions*, whose presence makes the introduction of disruptive innovation on the occasion of new market entries very likely.

The three states regarding disruptive susceptibility

Neglecting the sectors in which disruption is highly unlikely, the model divides the others into three principal states depending on their predisposition for disruption. The three stages are in order: low, medium, and high disruptive susceptibility. As can be observed in figure 3.3, they gradually include more theoretical propositions which, if fulfilled, increase the chances of imminent disruption.

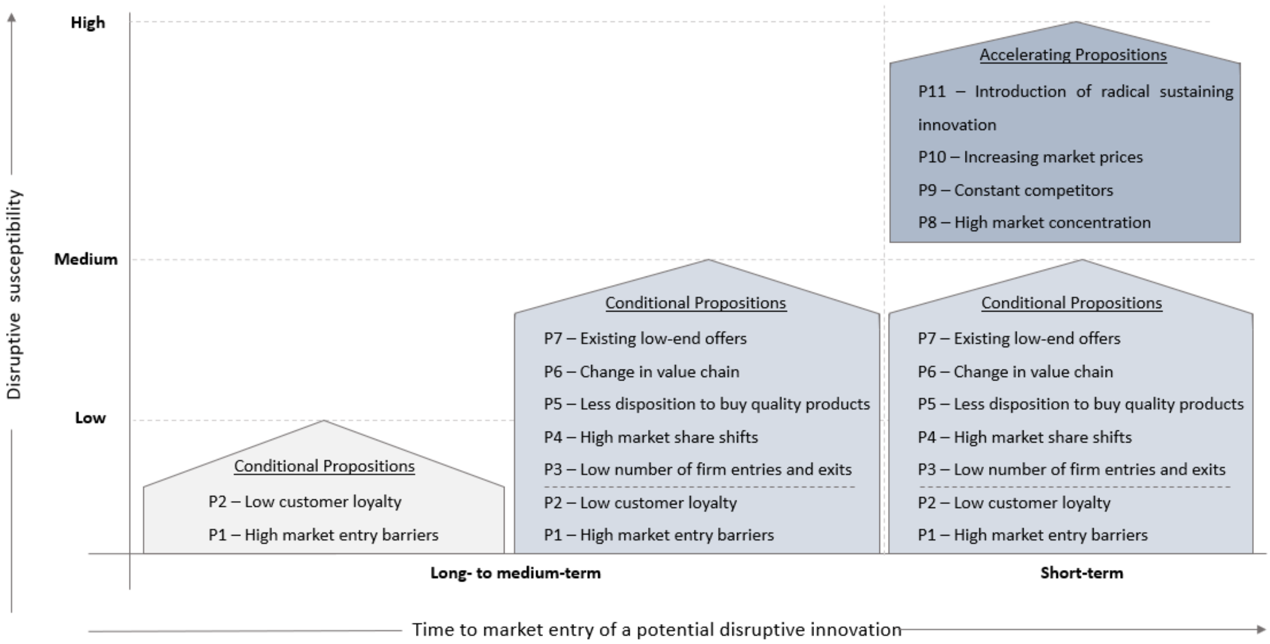

Figure 3.3 - Disruptive susceptibility framework (own illustration, inspired from Klenner et al. (2013, p. 921))

Markets with low disruptive susceptibility are those imposing high entry barriers to new entrants at the very least (P1). Moreover, customer loyalty in these markets tends to be relatively low (P2). The presence of both propositions implies that, to enter the market, entrant firms will have to propose products largely differing from the currently existing ones with which it has become difficult to compete. This context generates an environment conducive to disruption. However, this opportunity is rarely seized if the other factors are not met.

This is not the case for markets with medium disruptive susceptibility. There, the common presence of the two factors mentioned above, as well as the other conditional propositions, make the disruption concretely possible. Additional enabling factors are a low frequency of firms' entries and exits (P3), high market share shifts to low-end offers (P4), a smaller disposition from customers to buy products of quality (P5), and a change in the value chain[10] (P6). Finally, the presence of a pre-existing critical mass of low-end users on which the disruptive innovation may rely to transform the market is also important (P7). This last proposition is especially relevant because of the presumed impossibility for disruptive innovations to open the low-end segment of an existing market by themselves.

Even if possible in this latter configuration, the successful development of disruptive innovations is still hindered by the absence of accelerating factors. Thus, an ultimate category exhibiting a high susceptibility of disruption has

[10]A value chain is "the series of stages involved in producing a product or service that is sold to consumers, with each stage adding to the value to the product or service" (Cambridge Dictionary, 2020).

been highlighted by Klenner and his colleagues. In addition to the seven conditional propositions mentioned above, it also includes a high market concentration (P8), as well as the presence of constant competitors (P9). Evidence has also underlined the impact of an increase in the established products' market price (P10) because of the growing low-end demand it generates for potential disruptors. The final accelerating proposition formulated by the model concerns the repeated introduction of sustaining innovation by established companies before the introduction of disruptive innovations (P11). In accordance with the literature written on the topic, it usually reduces the attention paid by established firms to new innovative projects.

Furthermore, even if partially transmitted through some of the propositions, the overshooting factor, as theorised by Clayton Christensen, represents a critical extra factor of disruptive susceptibility.

3.2. Research Methodology

3.2.1. Justification of the choice of the disruptive susceptibility framework

The disruptive susceptibility framework has been selected to answer the research question of this work because of its ability to encompass market-based factors in the prediction of disruption. Taking advantage of various proposals previously put forward by experts, this model presents a well-defined set of easily applicable propositions conducive to the reversal of a value network. So, there is no surprise behind the increasing interest it has gained among analysts over the last decade. What is particularly valued is the consistency brought by empirical testing of every theoretical concept as well as its complementarity with the other ex-ante approaches such as the disruptive potential (Hüsig et al., 2005; Hüsig & Keller, 2009) or the quantitative measurement of the Disruptive Innovation Index developed by Guo et al. (2018).

Moreover, predicting the evolution of the wireless communication market through the lens of disruptive susceptibility permits to further evaluate the disruptiveness of one of its newest components, LiFi technology. This assessment is all the more reliable as it is carried out using an acknowledged model grounded by both theoretical and empirical evidence.

3.2.2. Reusing the same approach

The way the disruptive susceptibility framework will be used in the course of this work is similar to the method that has been employed in its shaping (see appendix I). The validity of the model will first be confirmed through its application to previous cases of acknowledged disruption (the hard disk drive and flash memory industries). This ex-post analysis will further enable the refinement of the underlying theoretical propositions.

It is only during a second stage that the refined version of the framework will be used to realise an ex-ante evaluation of the disruptive susceptibility of the wireless communication value network through a case study. More precisely, the emphasis will be put on the potential success of a disruption triggered by the emergence of LiFi technology.

3.2.3. Interest of proceeding through a case study method

In order to conduct this analysis, and to demonstrate on a broader perspective the market-based roots of disruptive innovation, the choice has been made to apply the theory of disruptive susceptibility using a case study approach. Far from being the result of a random choice, this method has been judged as that most adapted to the field of study addressed by this thesis.

Disruption is certainly a widely discussed topic, creating intense debate among experts who regularly formulate novel theoretical propositions. Basing themselves on the work of Robert Yin (2003), Klenner et al. (2013) affirm that case studies allow analysts to apply these theoretical propositions in order to assess both their consistency and their functionality. Other experts of qualitative research similarly highlight the ability of case studies to test hypotheses (Eckstein, 1975), which often results in the reformulation of some of the initial propositions with respect to their applicability, or not, to particular cases (Flyvbjerg, 2006).

The relative nature of the concept of disruption must also be stressed. As already mentioned, a technology or a business model is not disruptive in itself but is rather portrayed as such depending on the interpretation given to its development (Yu & Hang, 2010). It can happen that innovations considered by some as disruptive are being denied this title by other scholars. It is therefore hardly desirable to adopt quantitative approaches which discriminate innovations according to restricted criteria. On the other hand, a narrative, in-depth analysis based on the careful study of the specificities of some cases with respect to the expected general rules must be favoured. It is indeed the sole way to approach an issue in all its complexity, without limiting its analysis to summarised numbers and figures (Bourdieu, 1977).

Finally, the use of a case study as a research method is also particularly suited to the objective of predictive analysis underlying this work. In his article responding to the various misunderstandings existing around case studies, Bent Flyvbjerg (2006) indeed claims that this latter represents an excellent tool for testing the validity of ex-ante models. He further advances that it is perfectly able to confirm or refute hypotheses if applied to appropriate cases.

3.2.4. Reasons behind the choice of LiFi technology

The dramatic growth of the wireless communication market over the last few decades has played an important role in the choice to select LiFi technology for this analysis. Indeed, new innovations are made at regular intervals, what increases the likelihood of disruption. At the same time, the speed of data transmission has surged, which will sooner or later lead to market saturation if Christensen's theory of overshoot performance is anything to go by. Finally, the growing importance of LiFi technology, and the frequency at which it is presented as the future disruptor of Wi-Fi communication increase the interest of assessing today the disruptive susceptibility of such a market. To do so, it has been decided not to focus on a particular geographical area and to study this innovation on a global scale since its challenges are not limited to national borders.

3.2.5. Limitations of such methods and how they may be countered

This being said, the inherent nature of any ex-ante approach represents its main weakness. Indeed, the results obtained are, by definition, uncertain and must be confirmed by further research. The LiFi sector is undoubtedly at its infant stage and it is actually impossible to assert whether or not it will fully replace wifi technology (Guo et al., 2018). This limitation is further accentuated by the relative lack of literature and figures on such a recent field of study. Hence, only predictions can be made, which necessarily involves some unpredictability. In order to reduce it, analysts are forced to adopt a highly consistent methodology. This work is no exception to the rule, reason why it relies on a proven framework that it even reformulates in view of historical evidence.

Even though reformulating the disruptive susceptibility framework based on a twofold case study (hard disk drive and flash memory industries) may seem hazardous at first glance, it must be emphasised that the changes brought to the theory developed by Klenner and his colleagues are, on a broader perspective, motivated by a whole part of the literature not taken into account under its current version (e.g. additional entry doors for disruption).

3.2.6. Data collection and analysis

In addition to the importance of selecting appropriate methods to correctly answer a research question, the necessity to select reliable data to conduct the analysis must be highlighted. The legitimacy of the criticism, or the validation, of any theoretical assumption certainly depends on the quality of the base material employed.

To be as credible as possible, the reformulation of the framework and its application must therefore be based on valid information. For this reason, the sources employed in the realisation of this work must come from serious authors, regardless of whether they are academics or employees in a private company.

The data concerning the theory of disruption, as well as the industries to which it has been applied (storage devices, cameras, smartphones, …) has been mostly retrieved from peer-reviewed, widely quoted scientific articles or acknowledged books. Collected on various academic e-libraries (LibSearch, Cible+, …), about a hundred of documents coming from all over the world have been analysed to propose a sound argumentation, consistent with the current debates surrounding this widely discussed topic. Although few of them are actually coming from STS scholars, they always highlight the societal roots of innovation and have been chosen for this reason.

The same rigour has been applied to the selection and analysis of articles concerning the wireless communication market, but the newness of the technologies involved has severely limited the number of available studies. This is why a review of various annual reports and corporate websites made by the actors evolving in this sector (Cisco, Oldecomm, pureLiFi, …), as well as the studies undertaken by private independent companies (e.g. Mordor Intelligence, Markets and Markets) and publicly available databases (Statista, Our World In Data, …) has been carried out. Once again, a critical approach has been adopted to tackle the possible bias with which these various sources could present the same information[11]. Moreover, particular attention has been paid to the selection of quantitative data in view of the ease with which such information can be manipulated. This vigilance is all the more important as the technology being dealt with is currently being developed, which implies that no historical hindsight can help in judging the veracity of the available data.

[11] The market forecasting of LiFi enthusiasts such as Harold Haas, for example, had to be contrasted with the research carried out by wifi developers.

4. Analysis

4.1. Refinement of the disruptive susceptibility framework

4.1.1. Criteria used in the case selection

The purpose of this section is to test the consistency of the disruptive susceptibility framework as it has been coined by Klenner et al. (2013). To do so, the model will be applied ex-post to markets that have already experienced disruption.

The criteria used for the selection of these markets will follow the logic they formulated in choosing the German camera market. Therefore, this choice has to meet four conditions (p. 918).

- "Being an acknowledged case of disruption
- Having entered the market in the near-term past
- Having successfully taken over the majority of the market
- Presenting a detailed data basis to apply the theoretical propositions".

4.1.2. A first emblematic case: the hard disk drive industry

4.1.2.1. Specific motivations

The first case of disruption that will be analysed through the prism of disruptive susceptibility is the evolution of the hard disk drive industry in the United States between 1976 and 1992, and more precisely the switch from the 5.25 to the 3.5-inch model that took place during the 1980s. In addition to meeting the four criteria listed above, the interest in selecting this market is justified by its historical significance. In his pioneering writings of 1995 and 1997, Clayton Christensen indeed presented the replacement of the large diameter disk-drives by smaller models as one of the most emblematic examples of disruption that happened in the last decades. Over time, this case has even become the symbol of a whole theory whose popularity has never ceased to grow. A suitable starting point for the ex-post analysis of the disruptive susceptibility framework is, therefore, its application to this iconic example from which many other pieces of research have followed. Most of the information presented in the following paragraphs are coming from the extensive research that Christensen and his colleagues (1993; 1995; 1997) conducted on the topic.

4.1.2.2. Case description

The first hard disk drives (HDD) models were developed by the American firm IBM in 1952. Integrated into the composition of more complex electronic devices such as computers, their function consists of reading and writing the information manipulated by these machines (Christensen, 1997). The volume of data that disks are capable of handling is therefore crucial for end-product users and directly depends on their storage capacity, a measure traditionally expressed in megabytes (MB). Intermediate users of hard disks, i.e. computer manufacturers, have therefore historically directed their purchasing decision to the best performing options in this attribute.

At its introduction, the first disk could only store 5 megabytes of information. However, this number rocketed and reached hundreds of megabytes in the 1970s through the hard work performed by manufacturing companies. Even if these improvements may seem minor in view of the performance observed nowadays, the progress they represent was truly impressive for the time.

In a nutshell, what made the evolution of this industry one of the most striking cases of disruption in modern history is the trajectory taken at the turn of the 1980s by the manufacturers of 5.25-inch models compared to their 3.5-inch rising competitors. In fact, the former ones pushed the storage capacity of their devices so far that they oversupplied the least demanding segments of their customer base. Meanwhile, the 3.5-inch disruptive entrants developing less performing, but smaller and less consuming disks gradually managed to capture their market segments and became the new reference in the sector. Later on, this pattern was repeated several times with the introduction of novel formats like the 1.8-inch drive in 1991, or the 0.85-inch version in 2004 (Gans, 2016, p. 118).

4.1.2.3. Application of the framework

Conditional propositions

At first, it can be considered that the disk drive market was consistent with the first conditional proposition put forward by the framework. Significant barriers (P1) were indeed preventing new competitors from entering the 5.25-inch drives market. The cost-structures required by a firm to compete on the market was highlighted by Christensen (1997) as the main obstacle for new entrants to thrive. Large investments in research and development were indeed needed from the very first day of activity. Moreover, the sale of 5.25-inch models was characterised by an in-depth customisation of the disks depending on the customer needs. To sustain the important costs it implied, a profit margin of 50 to 60% was necessary. However, such results were impossible to achieve for freshly arrived entrants unable to profit from the important scale economies of established manufacturers. Moreover, the latter were profiting from both the technical expertise and network effects that they had developed throughout their activity.

Regarding the second proposition, the value that established manufacturers were proposing to their customers was essentially built on the price-performance ratio they were able to reach. Hence, no strong emotional commitment was connecting suppliers and customers, especially given the low brand recognition of disk manufacturers.

Taken together, these two parameters defining the disk drive value network in the 1970s and early 1980s set up a climate conducive to the arrival of a disruptive challenger, forced to reinvent its offer if it wanted to thrive. It was indeed hardly conceivable for new entrants to challenge an already existing value network with such entry barriers by simply replicating or slightly improving the current offer. They were therefore obliged to commercialise a novel value proposition based on a new package of attributes. Moreover, the absence of a strong relationship linking disk suppliers and consumers ensured that these candidate disruptors were easily able to capture incumbents' market segments once their performance requirements in terms of storage capacity had been satisfied.

With regard to the other conditional propositions making up the disruptive susceptibility model, the 5.25-inch disk drive market could be seen as fairly stable before the introduction of smaller formats (P3). The restricted pool of 17 established firms (Control Data, Century, Memorex, …) were so far not disturbed by a myriad of new entrants as would be the case later with a total of 129 new startups capitalising on the success of smaller devices (Christensen, 1997; Rosenthal & Rosenthal, 2012).

The propositions related to the presence of already existing low-end offers (P7), that attract increased interest from customers (P4) whose readiness to buy quality products is diminishing (P5) may also be considered as quite consistent with the disk drive case at first glance. It has clearly been shown that established drive manufacturers like Seagate had initially designed prototypes of HDD that were less efficient in terms of storage capacity than what was realisable with the technology of the time. However, these same companies preferred to turn back to a strategy which consisted of refocusing research efforts on sustaining their main customers. Requiring larger storage capacity than what any 3.5-inch disk could provide at that time, manufacturers of mainframe computers indeed represented a sales potential of $300 million, far above the $50 million initially expected from the smaller model applications (Christensen, 1997).

Unfortunately for them, through this decision the 5.25-inch disk manufacturers neglected the growing dissatisfaction of a large proportion of their customers who did not value incremental improvements in storage capacity sufficiently to pay the corresponding premiums (Adner, 2002). Mainly composed of portable computing and desktop personal computer manufacturers, these customers consequently favoured lower quality options, i.e. disks with lower storage capacity than average, because of their cheaper prices and their capacities judged as sufficient to integrate their machines. For comparison, whereas the average willingness to pay for an incremental gain of one megabyte of capacity in 1988 was equal to $1.65 in the mainframe computing value segment, it was respectively worth $1.50 and $1,17 for the minicomputer and portable computing developers (Christensen, 1997).

This growing shift to low-end propositions may also be understood via the performance trajectory framework developed in the section 3.1.2. As can be observed in figure 4.1, even at its introduction, the lower capacities of the 3.5-inch drive technology in terms of storage capacity were already high enough for the average demand in portable markets. Three years later, their performance curve also intersected the capacity level usually required by PC producers (Christensen, 1993). As a result, their demand for 5.25-inch models declined and they went in search of lower-end options.

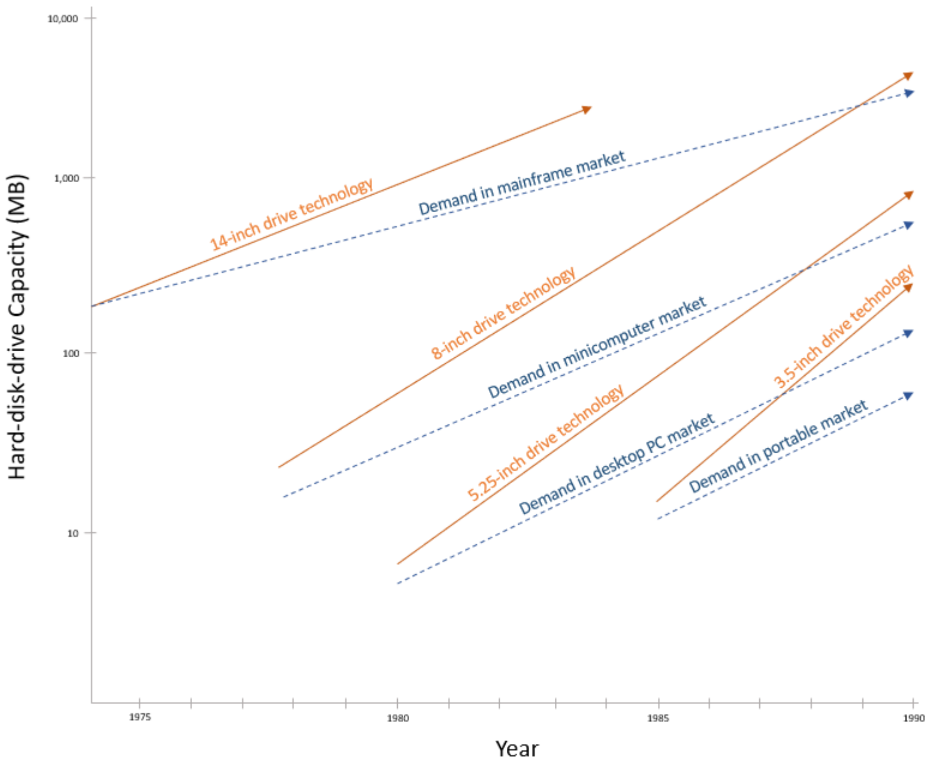

Figure 4.1 - Intersecting trajectories of capacity demanded versus capacity supplied in rigid disk drives (own illustration, inspired from Christensen (1997, p. 29))

Even though partially confirmed by historical evidence, the acceptance of these last assumptions, and more particularly of the fifth proposition (fewer incentives to buy quality products) must be nuanced. Although there was a clear decline in the marginal demand for more storage capacity from HDD users, not all of them could be considered insensitive to the quality of the products they were purchasing. This was especially true for the early adopters of the 3.5-inch format, who highly valued attributes other than storage capacity. Hence, some PC manufacturers not only wanted to save on storage capacity (i.e. the main performance dimension) by buying low-end products but were also eager to acquire drives that were light and robust enough to fit into their machines (second dimensions), even if it would have implied higher costs. Moreover, some authors refute the proposition that 3.5-inch models would have profited from an already existing low-end offer to build their success. Glen Schmidt and Cheryl Druehl (2008, p. 351) rather assert that it opened up a new *fringe-market segment*[12] of portable computers that otherwise would not have existed, and therefore would not have purchased disk drives.

Thus, the exact meaning of the concept of *quality* and its desirability to different categories of customers as well as the identification of the markets affected by the disruption will need to be considered in the reformulation of the model.

To conclude with Klenner's conditional propositions, the one that gave full magnitude to the disruption phenomenon analysed here was the major shift in the value chain of the entire HDD sector (P6) for the benefit of companies promoting drives of smaller diameter. Indeed, computer end-users developed growing desirability for portability in their purchase decisions. Aware of the potential of this hitherto underestimated demand, small entrants started to commercialise the disruptive 3.5-inch model given its better fit with the newly popular computers.

Accelerating propositions

In addition to the aforementioned factors that render a market disruption likely in the near future, accelerating conditions indicate its imminence. Two of them, which are a high market concentration (P8) and the presence of constant competitors (P9), are largely consistent with the disk drive case. Before its upheaval, the 5.25-inch disk market counted 17 multinational companies fighting with each other in a highly competitive way to conquer market shares. The different firms having thrived beforehand following successive waves of previous

[12] Fringe-market segments are defined by Schmidt and Druehl as market segments where "customer needs are incrementally different from those of current low-end customers" (2008, p. 348).

disruptions (switches from 14 to 8, and finally to 5.25-inch models) had reached their cruising speed and the market dynamics resulted in apparent stability. Some of the world's largest industries (IBM, Seagate, Control Data, …) were ruling the competition without any of them being able to fully dominate it (Christensen, 1993; Christensen & Bower, 1995). In their desire to expand their customer base, these companies had therefore a tendency to focus their attention on direct competitors, which often led them to overlook external threats coming from small-sized entrants. This lack of hindsight obviously enabled the disruption of the entire market and completely reshaped the identity of HDD manufacturers, whose only survivor has been the firm IBM.

On the other hand, one cannot assert that the tenth proposition of the model, an increase in the market prices (P10), has been observed in the HDD market during the period prior to disruption. The amount at which 5.25-inch disks were sold remained relatively stable between the end of the 1970s and the early 1980s. It was notably due to the twofold objective of disk vendors who wanted to sell products with ever-increasing storage capacity at a lower price per megabyte (Christensen, 1997). Thus, the dramatic drop in price/MB observable in figure 4.2 was offset by an equally dramatic surge in the storage capacity proposed by disk drives until the disruption of the market.

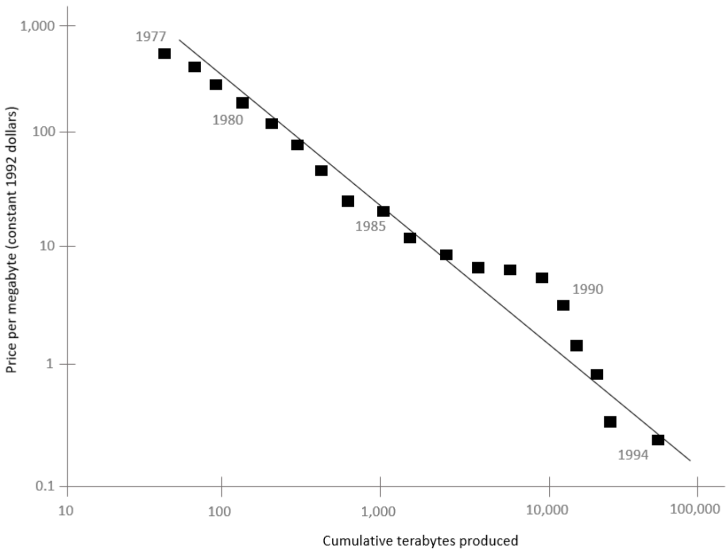

Figure 4.2 - Disk drive price experience curve (own illustration, inspired from Christensen (1997, p. 23))

It is worth noting that this tendency came to an end with the popularization of 3.5-inch models. First, this new technology offered products with a significatively lower price/performance ratio. An incremental gain of one MB was indeed costing 20 cents more than compared with the 5.25-inch generation (Adner, 2002). However, the storage capacity of these disks was also reduced given its low desirability among users who were rather rewarding other improvements such as size or absolute[13] cost reductions. The final outcome of this alteration resulted in a lower average selling price for the newly introduced technology compared to the 5.25-inch one (see figure 4.3), a trend consistent with what one would expect from a low-end disruption (Schmidt & Druehl, 2008).

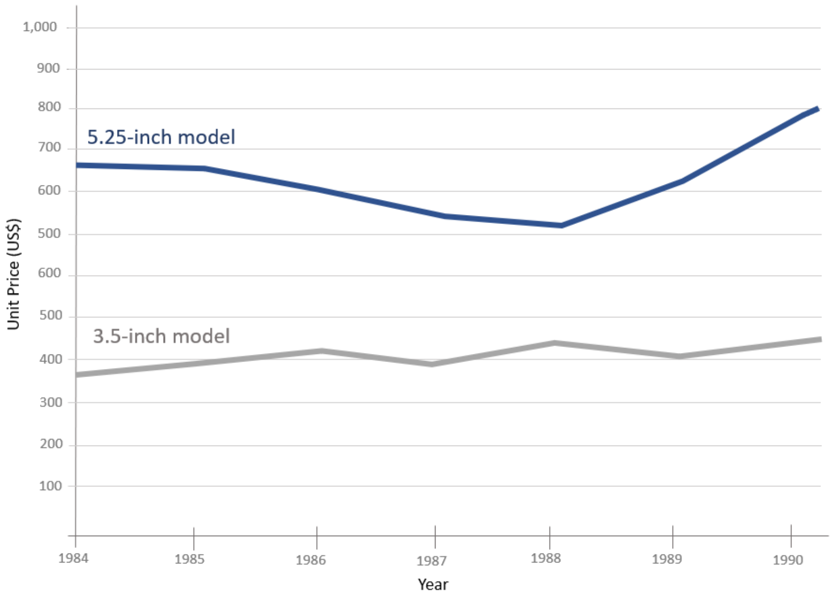

Figure 4.3 – Average unit prices for 3.5-inch and 5.25-inch models of HDD, from 1984 to 1990 (own illustration based on Adner (2002, p. 685))

Studying the disruptive change represented by the development of 5.25-inch hard drives should not make one neglect the flood of sustaining innovations that have been brought to this industry in the near past (P11). The explosion in the number of megabytes that can be stored in a disk[14] and the vertiginous drop in their marginal cost are indeed resulting from this latter category.

Its best example is undoubtedly the replacement of ferrite-oxide heads of the disks by thin-film components that took place simultaneously with the introduction of the 3.5-inch model. Here, the objective behind this technological change was not to play on the size of the disk to attract new customer segments, but rather to sustain the already existing ones by improving even more the storage capacity of the disk.

As illustrated in figure 4.4, Christensen argues that every technology possesses its own limits in the level of capacities it is able to reach. Leaders of the market therefore decided to largely invest both capital and time in the development

[13] As opposed to price/performance reductions
[14] Christensen indeed portrays the growth of the number of MB per square inch of disk drive as improving by 35% every year between 1976 and 1992 (Christensen & Bower, 1995).

of new techniques in order to delay as long as possible the reaching of a performance. With this in mind, the newly introduced thin-film components rekindled the forward momentum of IBM and Seagate to overshoot their customers with ever-increasing storage capacities. However, all efforts spent on these sustaining innovations were not devoted to the fight against the 3.5-inch format, which undoubtedly benefited its manufacturers who eventually took advantage of the unprecedented performance overshoot it caused.

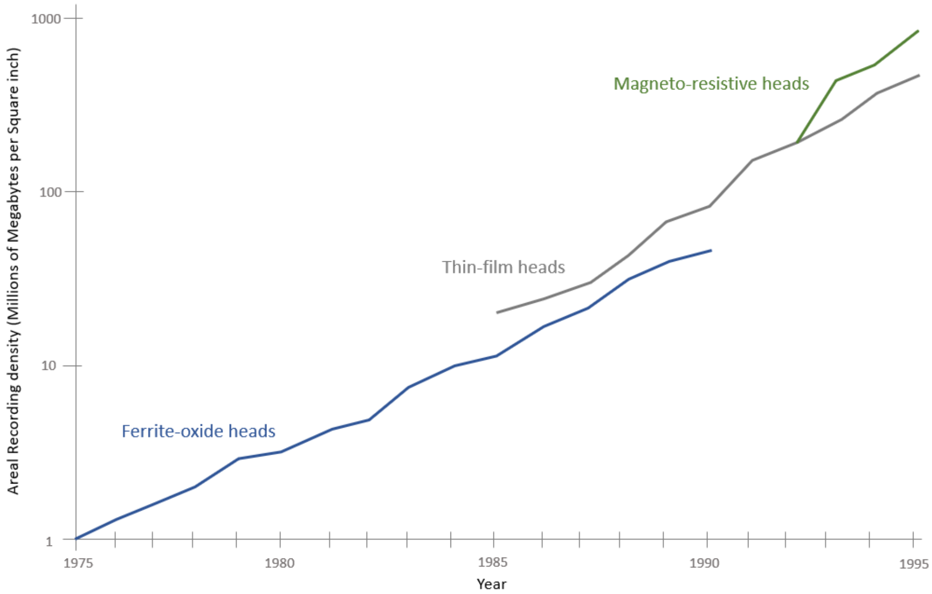

Figure 4.4 – Trajectories of sustaining innovations in the HDD industry, from 1975 to 1995 (own illustration based on (Christensen & Bower, 1995, p. 45))

Conclusion

Considered as a whole, the application of Klenner's theoretical framework to the early 1980s US hard disk drive industry indicates a disruptive susceptibility ranging from medium-high to high (see figure 4.5). This means that incumbent business managers developing the 5.25-inch models could have anticipated the latent threat posed by smaller hard drive developers by analysing the situation through this model, whose majority of assumptions were met.

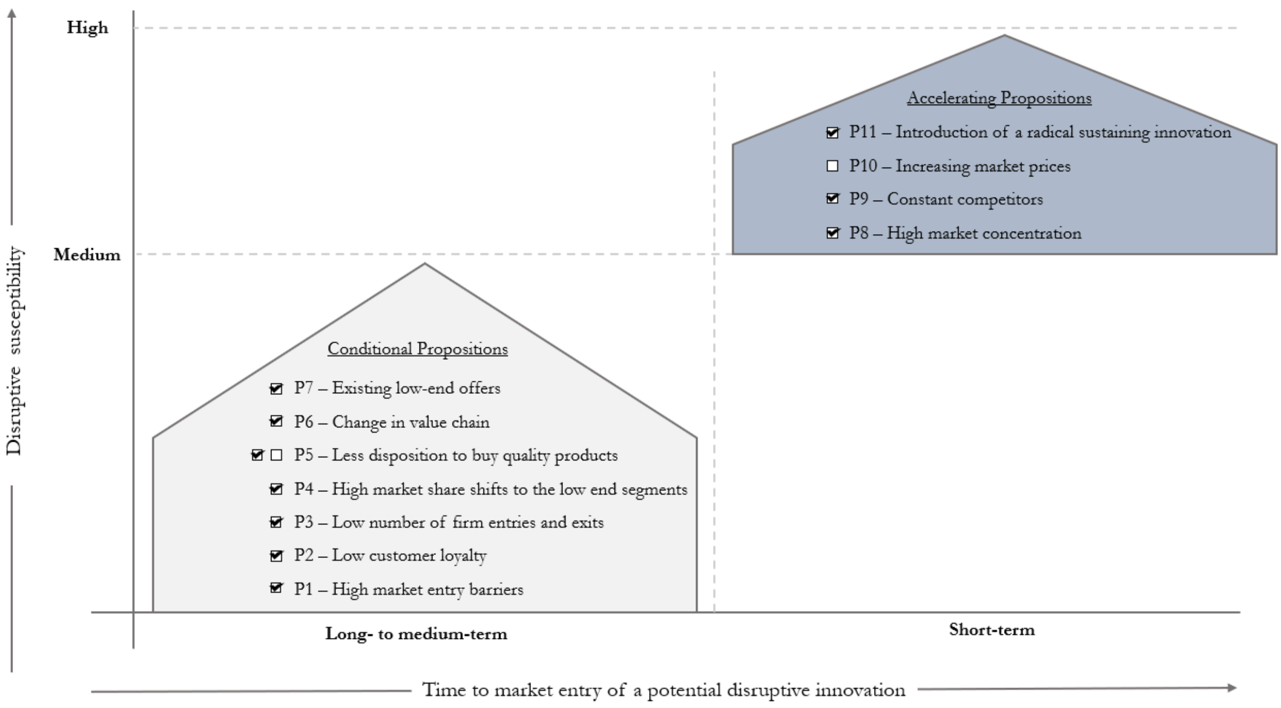

Figure 4.5 – Disruptive susceptibility framework applied to the hard disk drive industry before the emergence of the 3.5-inch model (own illustration based on Klenner et al. (2013, p. 922))

Only the hypotheses concerning the quality of the products requested by customers (P5), as well as the increase in the prices at which they were sold (P10), seem inconsistent with what the framework suggests. Regarding the former proposition, its acceptance lies in the criteria used to assess the quality of innovation. In view of the low initial requirements of PC manufacturers for storage capacity, this condition can only be seen as fulfilled if it just evaluates performance along one main dimension (Schmidt & Druehl, 2008). However, the situation largely differs if the added value brought to users by secondary attributes, extremely high for some of them, is also considered (Hardman et al., 2013).

Before discussing the way in which the disk drive example can help to redefine the disruptive susceptibility framework, its application to a different case study is presented in the next paragraphs.

4.1.3. A complementary case: the flash memory

4.1.3.1. Case description

As demonstrated earlier, the disruption of the hard drive market by the 3.5-inch model could have been predicted by the application of the disruptive susceptibility framework. With the exception of a few differences such as the rising price of old technology (P10), the state of the hard disk drive market at the end of the 1970s is indeed highly consistent with the set of propositions put forward by Klenner et al (2013).

This being said, the same cannot be affirmed for all the disruption phenomena that have occurred in the past. A striking illustration of this concerns the market of flash memory, a technology subsequent to the 1.8-inch model and which totally redefined the hard disk drive industry in the 1990s. Put in the spotlight by Christensen (1997) who described it as a "solid-state semiconductor memory technology that stores data on silicon memory chips" (p. 51), it differed mainly from traditional technologies in that the flash memory devices retain data even when they are no longer powered, i.e. when the computer is turned off. Moreover, these chips were also smaller, lighter, less consuming and more rugged than any existing model of HDD. These novelties considerably broadened the range of possibilities for devices incorporating flash memory chips into their composition and revolutionised an entire industry.

Such as the 3.5-inch model a decade earlier, this technology also followed the disruptive path. Early flash memory producers were unquestionably selling their products to the marginal segments of cellular phones, heart monitoring or industrial robot manufacturers. The reason for that was the impossibility of these customers to integrate the smallest models of hard drives in their final products for which they were still too large. As with laptop manufacturers adopting 3.5-inch disks in the previous example, some developers therefore agreed to sacrifice a large amount of storage capacity to take advantage of these additional properties. Conversely, the main market segment of computer creators could not afford to reduce the memory of their machines to such low levels[15]. Thus, they kept purchasing incumbent models and stayed insensitive to this radical innovation. However, as is often the case in such contexts, flash memory developers quickly brought the capacity performance of their products to quite acceptable levels, satisfying requirements of a majority of users as early as 1996 (as shown in figure 4.6). In accordance with the S-curved pattern followed by disruptive technological development, this performance-enhancement originated from a series of sustaining innovations they conducted jointly with incumbent actors of the HDD industry. Initially, leading firms of the drive industry such as Quantum and Western Digital were considering them as complementary rather than a substitute for their market. This judgment quickly proved to be unfortunate as flash memory vendors began to encroach on hard drive sales. Their overall market size indeed grew from $45 million in 1993 to $230

[15] They were demanding at least 350 MB (Christensen, 1997, p. 54)

million in 1996 (Christensen, 1997, p. 52). Thereafter, this amount has continued to skyrocket, and has even reached $64 billion today (Statista, 2020).

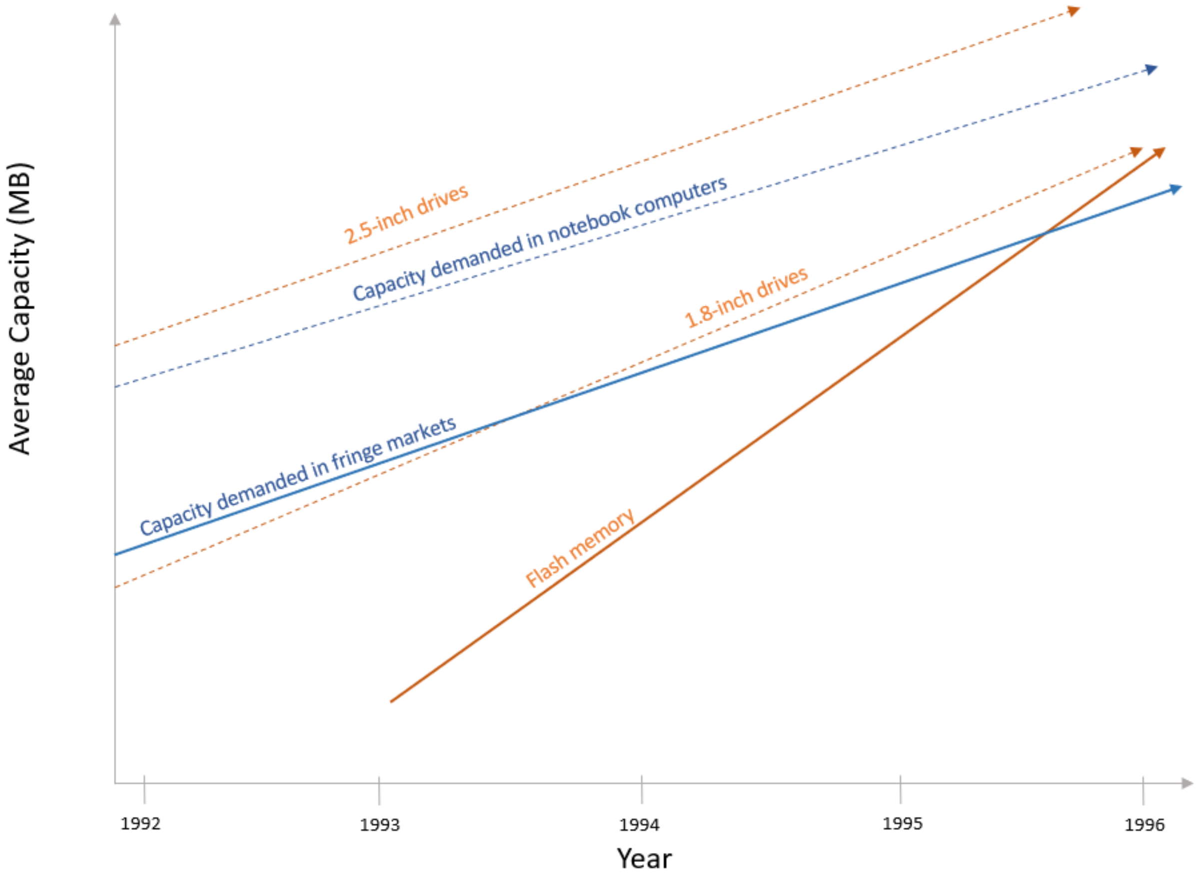

Figure 4.6 – Comparison of Disk Drive Memory Capacity to Flash Memory Capacity (own illustration inspired from Christensen (1997, p. 55))

4.1.3.2. Specificity of this case

Although very similar to the evolution of the market that followed the introduction of the 3.5-inch disk, the road taken by the popularization of flash memory largely differed in at least one core attribute: its price. While a significant proportion of hard disk drive users were attracted by the lower-priced 3.5-inch disks because of their diminished willingness-to-pay for high-end devices, such economic considerations played a minor role in the early diffusion of flash memory devices. At their introduction, the selling price of flash memory devices was indeed so prohibitive compared to traditional disks of similar performance that it would be inappropriate to portray their early adopters as belonging to a low tier of the market. In accordance with the theoretical reformulations put forward by many theorists such as Druehl and Schmidt (2008; 2009), Hardman et al (2013), and Christensen himself (Christensen & Raynor, 2003; Christensen et al., 2015), the trajectory taken by flash memory during the 1990s rather constitutes a compelling example of disruption occurring through the creation of a new market (see subsection 2.5).

In view of the abyssal difference with which customers of both storing devices valued their respective attributes (storage capacity, weight, size, ...), it seems quite unlikely that cell phone producers (as well as others having chosen to implement flash chips) and laptop manufacturers belonged to a common market. The introduction of lighter alternatives rather enabled the development of the former which would probably not have existed otherwise. It is therefore logical that phone developers were willing to pay much higher prices for a component allowing them to finally produce previously unrealisable devices.

4.1.3.3. The implications for the theory of disruption

Whereas a traditional and incomplete perspective depicted disruptive innovation as necessarily simpler and cheaper than the prevailing solutions, looking through this complementary lens allows analysts to study the development of breakthroughs sold at high prices[16]. In this respect, innovations which do not meet the low-price expectations do not necessarily lose the disruptive title as a result (Christensen & Raynor, 2003). Certainly, the way flash memory evolved in the 1990s closely meets the rest of the criteria set out by Schmidt and Druehl (2008) to differentiate between the two types of breakthroughs. First, flash memory technologies were not designed to sustain the sales currently made by the storage hardware producers among their most profitable customer segment, i.e. computer manufacturers. Instead, the promoters of flash memory rather designed products only able to satisfy small fringe markets offering less short-term potential of sales. This strategy enabled them to avoid attracting incumbents' vigilance who initially considered them as unable to capture their market segments. Secondly, these innovations were not made with the aim of improving the product over and over along the same dimension, i.e. its storage capacity, but rather to open up a new range of possibilities by working on its solidity, weight and ability to retain information once switched off. The situation to which progressively led the popularisation of the flash memory is therefore compatible with one of the key indicators put forward by Ron Danneels to identify a market disruption: "the change of the bases of competition by changing the performance metrics along which firms compete" (2004, p. 249).

[16] Theoreticians actually put forward a third category of disruption (in addition to the ones starting from low-end or new markets) that would start with higher prices AND higher performance (in every dimensions). Called high-end disruption, this supplementary possibility has been discredited by many opponents arguing that the boundary between such concept and sustaining innovations was becoming too thin (Schmidt & Druehl, 2008, p. 361). To be qualified as disruptive, an innovation must indeed present at least one drawback compared to its competitors.

To provide a better illustration, the figure 4.7 highlights from a selling price-based perspective the impact that a disruptive innovation such as flash memory has had on the market when it entered it with higher prices than incumbent technologies. Whereas in phase I, it only managed to convince the very demanding niche markets of companies developing heart monitoring or electronic cameras, the cost reductions and economies of scale that it was gradually achieving allowed it to rapidly reduce its production costs (Hardman et al., 2013). Combined with the price stability of sustaining innovations[17], this trend enabled sellers of flash memory devices to enter phase II in which they were able to seize mainstream customers by aligning themselves with the competition[18]. Disruption was then completed in phase III where there was no objective criterion left for main customers to favour the incumbent technology. The latter is now supported only by a minor user segment searching for devices with extra-high storage capacities.

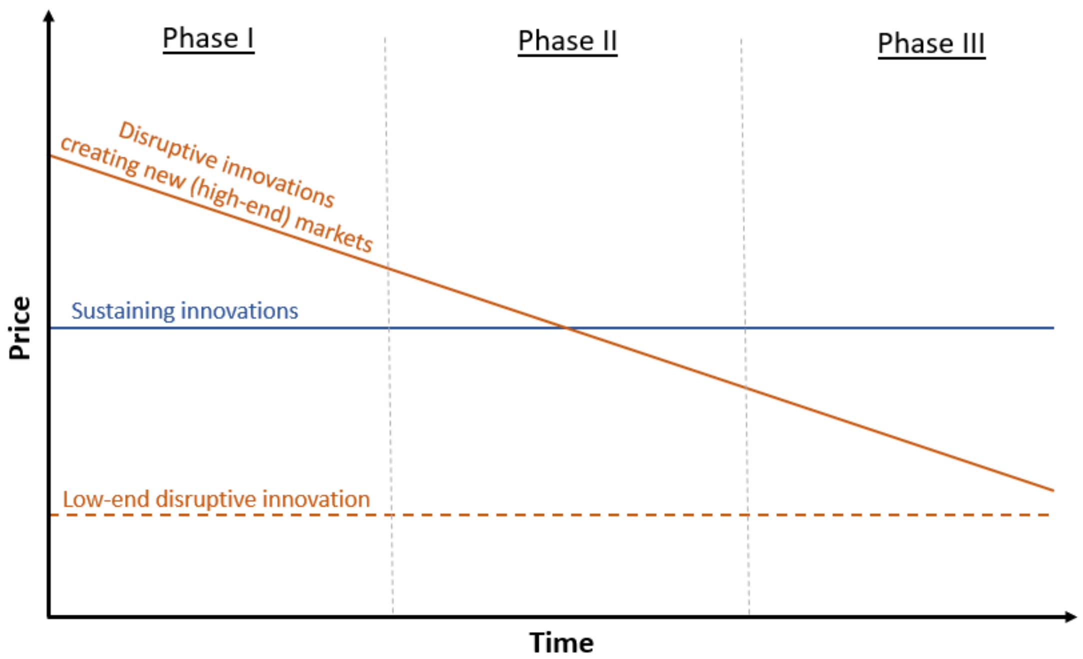

Figure 4.7 - Price comparison of different types of innovations (own illustration, inspired from Schmidt and Druehl (2008))

[17] As illustrated in the case of HDDs, where disk manufacturers tended to increase the capacity of their products as the price of adding a megabyte was decreasing, the selling price of sustaining innovations generally remains similar over time. In addition, Christensen (1997) demonstrated how difficult it was for their manufacturers to go below a certain threshold given a number of fixed costs.
[18] In 1997, buying a storage device with a capacity of 40 MB was indeed equally expensive for both technologies (Christensen, 1997, p. 59).

4.1.3.4. Application of the framework to the flash memory case

As previously explained, the flash memory disruption shares many similarities with its precursors, i.e. disruptions of small-sized HDD. For this reason, the analysis presented here will only focus on their main points of divergence and the above-mentioned specificities that are likely to matter during the refinement of the disruptive susceptibility framework. It is worth noting that most of these points of attention stem from the fact that flash memory has never been a low-end alternative to incumbent technologies, while this framework was initially designed solely to evaluate such situations.

Firstly, it appears that the proposition concerning the decline in market demand for quality (P5) continues to be confusing. A decreasing number of customers were indeed consuming the highest-capacity storage devices. However, the quality of such product is not simply limited to its number of megabytes. A clarification of this proposition is therefore needed.

Another point of disagreement with the theoretical assumptions composing the model concerns the preliminary presence of a low-end offer on which the emerging technology has been able to rely (P7). By its new package of attributes, and more specifically the possibility for its chips to retain data without a power supply, flash memory technology has opened up a whole new market for storage devices for which no solution had been found so far.

Lastly, the suggestion that the price of the incumbent technology increased prior to its disruption (P10) is inconsistent, as in the case of the 3.5-inch disk.

4.1.4. Refinement of the model based on ex-post analysis

4.1.4.1. The motivations behind the refinement

The refinement of the disruptive susceptibility framework is not solely motivated by its divergences with the two cases studied above. Multiple cases sharing similarities with the popularisation of flash memory undoubtedly highlight the coexistence of different entry points for disruption. Building upon famous historical precedents such as the disruption of the photography and MP3 sectors, respectively by digital cameras and iPod, Hardman et al. (2013) even argue that breakthroughs are usually sold at a price 4 to 30 times higher than incumbent technologies at their market entrance.

However, the disruptive susceptibility framework in the way it is presented by Klenner et al. (2013) does not encompass these alternatives in its predictive analysis. It is particularly damaging since it does not allow today's analysts to anticipate tomorrow's iPod, or any other potentially disruptive innovation that would not base its strategy on lower costs. Bringing modifications to this model is therefore critical to extend its applicability and enhance its predictive capability. Hence, the ex-post analysis carried out on the hard disk and flash memory markets leads to the restatement of 4 out of the 11 theoretical propositions.

4.1.4.2. Reformulated propositions

Modification 1 - Removal of P5

Firstly, the decision was taken to limit the evaluation of the quality of a product to its performance along the dimension traditionally valued by the majority of its users. In line with Schmidt and Druehl's theory (2008), this modification is consistent with the twofold ex-post analysis presented in the course of this work. The quality yardstick indeed suffers from its vagueness and has not been empirically verified, neither here nor in the German car market case presented by Klenner et al. to develop their model. Moreover, these authors assign a very similar meaning to both terms. After having replaced the notion of quality with high performance, the reformulated P5 (lower disposition to buy products performing highly along mainstream dimensions) becomes somewhat redundant with respect to its predecessor (high market share shifts to the low-end segments). P5 has therefore been removed in the interest of greater legibility.

Modification 2 - Reformulation of P4 in "High market share shifts to niche segments"

With regard to P4, its modification was also critical to encompass the disruption phenomena that do not start from low-end positions. In the broader perspective, the selling price of the incoming technology becomes an attribute (primary or secondary), just like any other features such as weight or energy consumption. Hence, disruptions are not only facilitated by market share shifts to low-end segments but more generally to any growing demand for ground-breaking alternatives that distance themselves from the mainstream offer. The highly popular term "niche" is used to describe the specific nature of these marginal segments which particularly value secondary attributes.

Modification 3 – Reformulation of P7 in "Growing shift to new value propositions"

The relevance of the proposition requiring the existence of a critical mass of existing low-end offers (P7) subsequently replaced by disruptive innovations has also been called into question throughout this analysis. Although present in the case of 3.5-inch disks, it appeared that this was not a necessary condition for technologies such as flash memory that were able to disrupt an established value network by unilaterally opening up a new one. Moreover, the term "low-end" is once again inaccurate in light of what has been discussed above.

Modification 4 – Removal of P10

The final modification brought to the disruptive susceptibility framework concerns its tenth proposition, i.e. the increase in market prices before disruption. Bearing in mind the cases analysed in this work, as well as those considered by Klenner et al. (2013) this proposal has indeed proved to be inconsistent with the trends effectively observed.

4.1.4.3. Refined version of the framework

Once refined, the framework is composed of 9 theoretical propositions (see figure 4.8). More consistent considering the diverse historical examples of disruption, it can now be used to more accurately assess the disruptive susceptibility of markets witnessing the emergence of novel innovations.

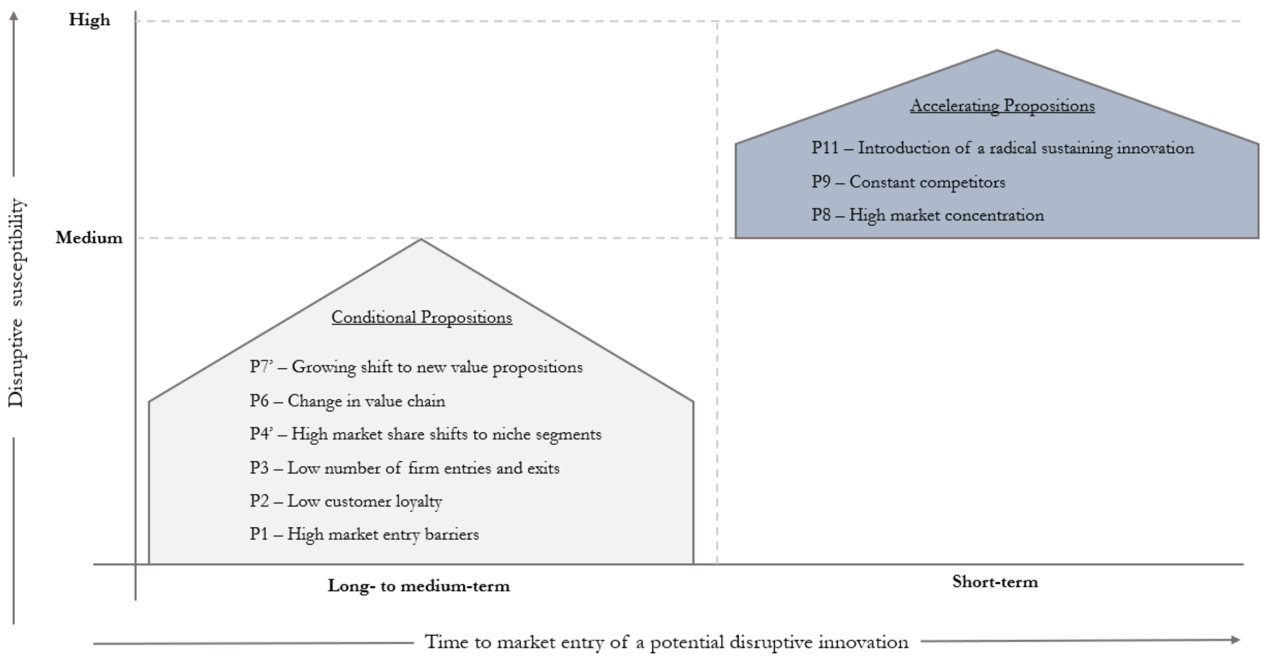

Figure 4.8 – Refined disruptive susceptibility framework

4.2. Case study: how likely is the wireless data transfer market to be disrupted by LiFi?

4.2.1. Case description

An example of such a value network can be found in the wireless data transfer market, whose principal application is WiFi. Since its launch in 1997, the potential of this wireless communication protocol has been proven. Today, the adoption rate of a household wifi[19] connection has even reached 86% in a developed country like France (Statista, 2020). This technology also outpaces the similar standards (4G, ...) by far. The IEEE (2018) has indeed asserted that indoor connectivity (mainly enabled by wifi) accounts for 80% of the whole volume of wireless communication. Particular attention will therefore be devoted in this analysis to the evolution of this communication standard. For this reason, the terms wifi and wireless communication will be used interchangeably in the course of this work, mobile and Bluetooth standards requiring further analysis that do not fall within the scope of this work.

Although wifi technology is extremely popular nowadays, it suffers from several limits that will sooner or later hinder its impressive development curve. On the other hand, an emerging innovation called LiFi has been gaining momentum over the last decade and is presented by some specialists (Bao, Yu, Dai, & Zhu, 2015; Haas, 2018; Mukherjee, Lloret, & Lv, 2018) as the upcoming successor to wifi.

The objective of the upcoming section is twofold. First, it will aim at determining the disruptive susceptibility of the wifi market in general. Klenner's modified framework will therefore be carefully applied to its current configuration. In a second step, the likelihood of LiFi engaging in a disruptive pattern will be assessed. This evaluation will be conducted by using the performance trajectory model, but also the other identification criteria highlighted in the literature review.

First and foremost, a basic understanding of the nuts and bolts of both technologies and in which way they differ is required.

[19] The term has become so popular that it made its way into all dictionaries under the form "wifi".

4.2.2. Exploring the functioning of wifi

Wifi is a wireless networking technology enabling devices to exchange information. Although it is generally used to link a computer or smartphone to an internet modem[20], wifi also serves the remote management of devices such as printers and drones. What differentiates wifi from other forms of wireless communication is that it is based on its own family of standards, the IEE 802.11, which specifies the protocol required to organise communication in various frequencies (NetSpot, n.d.).

To enable someone to watch a video on the internet, the data of which it is composed must first be broken down into small packets of binary information, i.e. the only form of information that can be interpreted by a computer, and then converted into an electronic signal before being carried by a wire to a router. It is only then that wifi technology comes into play. Whereas old-fashioned ethernet cables physically carried the information to the computer, which in turn transformed it into an actual video, this innovation has made it possible to do away with wires and transports the data remotely within a limited radius.

Whether it be in this example of internet access or in the communication taking place between smart vehicles, the information is always transmitted by radio signals (or radio waves), modulated and sent from the transmitting source to the receiver (and the other way around given the bi-directional property of wifi). As shown in figure 4.9, radio waves represent a small proportion of the so-called electromagnetic spectrum. This spectrum displays all the existing categories of signal according to their frequency or wavelength. Expressed in Hertz (Hz), the frequency of a signal represents the amount of information (i.e. waves) it transmits every second (Clarke, 2014). It also acts as a real trademark for networking technologies: each frequency may be conceived as a different language that will only be understandable by receivers designed accordingly. Thus, talkie-walkie communications operate over a certain frequency range, distinct from the one used by smartphones or TV remotes. Being at the extreme left of the spectrum and encompassing various sub-ranges, radio waves have the lowest frequency band, ranging from 3kHz to 300 GHz (Lumen, n.d.). This means they send between $3x10^3$ and $3x10^{11}$ waves per second. At first glance, these amounts may seem tremendous, but they are far lower than infrared or gamma rays. Everything else being equal,

[20] The modem gets its name from the fact that it modulates and demodulates the data so that it can be interpreted by the other components of the chain. Previously, it was systematically connected to a router whose role was to send via its antennas the generated information around it. Today, these two devices are almost always combined into a single one, this is why the terms "router" and "modem" can be used interchangeably (Test Achats, 2016).

this means that these higher-bandwidth signals are able to carry more data par second, whose traditional unity is the bit per second bps (Bps) (Clarke, 2014).

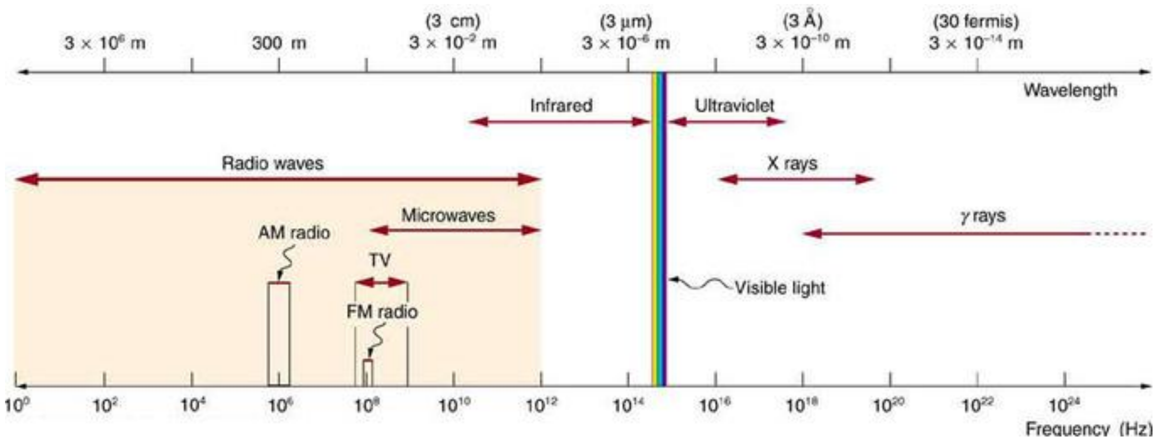

Figure 4.9 – The electromagnetic spectrum (Lumen, n.d.)

Wifi is a sub-range of radio waves, usually located around the 2.4GHz and 5.0 GHz frequency bands of the spectrum (Ayyash,, et al., 2016). However, the competition for frequency spectrum is fierce and other wireless communication technologies limit the possibilities for wifi expansion. As represented in figure 4.10, each of them has its own bandwidth, i.e. the spectrum breadth that may be used by their applications. However, it happens that these bandwidths overlap. This is notably the case of microwaves or Bluetooth waves whose frequency is very close to the one emitted and received by wifi routers. It can eventually result in interference, which negatively affect the throughput of data transmission between a laptop and its modem (Electronics Notes, n.d.).

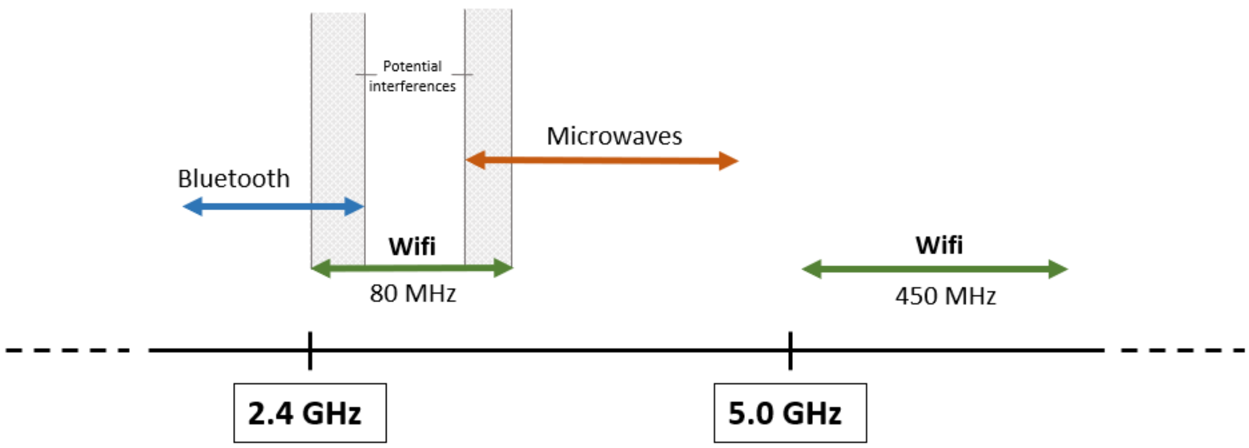

Figure 4.10 - Wi-Fi bandwidths (own illustration, inspired from ANFR (n.d.)*)*

In the coming years, the key challenge for wifi stakeholders will therefore consist of taking up larger bandwidth in order to transmit more information at higher speeds, while avoiding as much interference as possible. This necessity becomes all the more urgent as the worldwide demand for wifi is surging due to the emergence of a vibrant middle class in emerging countries, whose growing appetite for connectivity is sustained by the popularisation of smartphones and tablets (Haas, 2018). Moreover, the period of quarantine globally observed during the first semester of 2020 has brought to light how fast wifi bandwidths can be put under pressure when the transfer volume that used to be divided between the office and home internet connections is now concentrated into one single place (Bicheno, 2020). Potential solutions such as the unlocking of new frequency bands around 6 GHz have been investigated (ANFR, n.d.; Cisco, 2020), but many analysts feel that radio frequency-based wireless technologies are nowadays pushed to their limits and that more radical innovations are required to support this expanding demand (Bao et al., 2015; Mordor Intelligence, 2019). Without any concrete solution, these specialists indeed warn that the world will "run out of radio frequency" by 2025 if nothing is done to offload this mobile data congestion (pureLiFi, 2017, p. 1).

4.2.3. LiFi as a solution to the *Spectrum Crunch*[21]

With this objective in mind, research into the use of new frequency bands away from buzzy radio frequencies has attracted growing interest over the last twenty years. One of the most conclusive and high-profile advances has been the development of LiFi. Standing for Light Fidelity, this latest application of the family of VLC[22] transmits data through the modulation of the visible light spectrum, visible at the centre of the electromagnetic spectrum presented in figure 4.9 (Mordor Intelligence, 2019). Unlike wifi, which works with radio waves not exceeding 300 GHz, LiFi communication can take advantage of a 2600 times larger, unregulated and free light spectrum (Haas, 2018). In addition, the data transfer speed it can achieve far exceeds the level of performance reached by the best wifi devices.

4.2.4. How data is transmitted through LiFi

The German engineer Harold Haas was the first to coin the term LiFi when he presented its first prototype to the general public in 2011 (TED, 2011). The outline of what he presented during this globally acclaimed

[21] This term refers to the scarcity of available bandwidth (Mordor Intelligence, 2019)
[22] Visible Light Communication. For more information, consult Wang, Wang, Huang and Xu (2017)

conference is presented in figure 4.11 and still defines the design that companies working on the commercialisation of this innovation are following today.

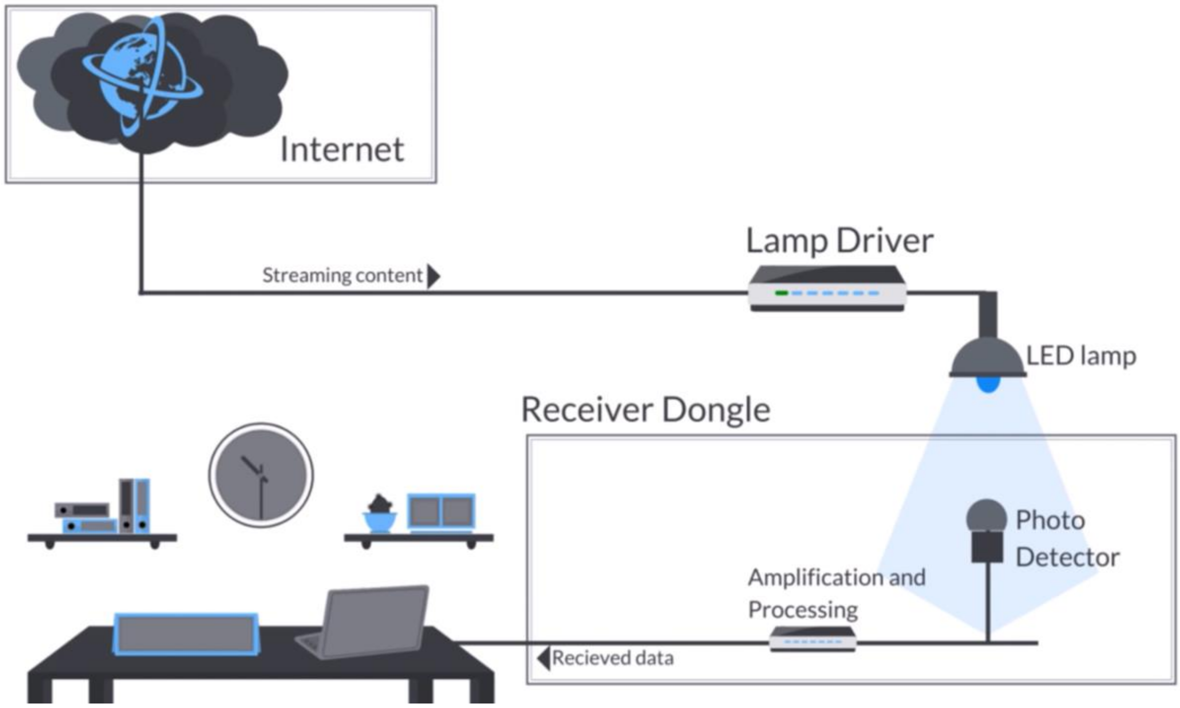

Figure 4.11 – Schematisation of data transmission through LiFi technology (Juice Tech Entertainment, 2016)

Every Light-Emitting Diode (LED) bulb is equipped with a lamp driver, i.e. its own router, that directly receives binary information through the internet network it is connected to. This driver is in charge of modulating the incoming data and sending it to the LED lamp which optically transmits it to a laptop or a smartphone. Once emitted under the form of flickering light intensity[23], this information is first received by a photo detector plugged into the device, and then converted into readable data to provide the end users with an ultra-speed connection. As with wifi, LiFi communication is bi-directional, which means that the electronic devices simultaneously send data back to the core network (Haas, 2018; Juice Tech Entertainment, 2016).

Given the astonishingly high frequency it is able to reach, Visible Light Communication offers tremendous opportunities in terms of speed of data transfer. Moreover, the possibility to combine multiple access points (by connecting several LEDs to the core network) further enhances the capacities of such technology, whose theoretical

[23] The light indeed transmits this information by flickering very quickly. It happens so fast that it cannot be perceived by human eyes. Moreover, the combination of several LEDs within the same place makes this type of communication seamless as other radio systems. This allows every user to stay connected while changing room, switching from one access point to another (Scace, 2017).

transfer speed already reaches 100 Gbps (compared to 7 Gbps for wifi) (Li Fi Tech News, 2018; Mukherjee et al., 2018).

4.2.5. LiFi and the theory of disruption

4.2.5.1. Motivations behind the selection of LiFi

The decision to apply the disruptive susceptibility framework to the wifi market is in line with the objective of this work. As will be shown later, the current situation in the wireless communication market indeed provides a striking evidence of a saturated market situation in which a profound change is needed to maintain innovation. Moreover, it shares interesting similarities with past cases of disruption that will be analysed in more detail.

These indicators do not, however, ensure that any innovation that would turn this market around should be considered as disruptive. Previous research conducted by Christensen et al. (2015) and Hüsig et al. (2005), respectively on Uber and WLAN[24] communications, has indeed demonstrated that one must be careful when affirming the disruptive nature of an innovation. The repeated assertion by many stakeholders such as pureLiFi or Oledcomm that LiFi is the brand-new disruptive breakthrough should not prevent a theoretical reconsideration of the concept dear to Christensen and its in-depth application to the present case. The last step of this work will therefore consist of the verification of the disruptive potential of LiFi-based applications. This analysis can be considered as ex-ante since it addresses an overhaul that has not yet occurred, with an emerging disruptive candidate, i.e. LiFi technology, whose first tangible applications have just started to be marketed (Mordor Intelligence, 2019).

4.2.5.2. Why predicting the disruptiveness of this market matters

Although it could first seem to be a simple theoretical distinction, determining how likely the wireless communication market is likely to be disrupted is critical for several reasons.

First, it involves concrete implications for the managers of leading incumbents. In effect, identifying the nature of an emerging new technology helps them to overcome the *innovator's dilemma* put forward by Christensen (1997). To do so, the American scholar advise these managers to set up separate flexible units in order to compete with new entrants, or even acquire them (Markides, 2006) if the disruption is bound to happen. On the other hand, continuing

[24] The Wireless Local Area Network (WLAN) is a synonym for wifi communication (TechTerms, 2020). However, this term will refer to the situation analysed by Hüsig et al. (2005) to not mix it with the current state of the wifi market.

with a traditional strategy of sustaining their current customer base would be a better-suited option if the market exhibits a low disruptive susceptibility (Klenner et al., 2013).

Numerous historical examples such as the replacement of Kodak by digital camera competitors have demonstrated the capacity held by disruption to unsettle the status quo of well-anchored markets. Thus, being able to forecast its emergence has become a key competitive advantage for entrant and established decision-makers, particularly in fast-evolving markets such as that of wireless communication (Guo et al., 2018; Hardman et al., 2013).

As noted by Kumaraswamy et al. (2018) the relevance of the concept of disruption also goes way beyond the corporate world and impacts society as a whole. Indeed, the 21st century is an "era of continual disruption" (p. 1026) each of them largely conditioning the trajectory taken by the future innovations of the sector concerned. Given its numerous applications and the global scale on which it is used, the trajectory taken by the wireless communication market impacts the whole of society, and not only its direct users. One only has to look at the worldwide uproar caused by the introduction of the 5G network in several major cities to realise how closely technological advances and societal issues are intertwined. In this way, anticipating such a technological development would increase the chances for it to be successful and sustainable once it had occurred, notably because it would allow every stakeholder to prepare in advance for this possible market overhaul.

Some optimists (Ahlstrom, 2010; Diamandis, 2016; Hart & Christensen, 2002; Mahto, Belousova, & Ahluwalia, 2017; Markides, 2012; Prahalad, 2011) even find in disruption a potential solution for fighting social inequality, considering for instance the emergence of 5G and LiFi to be an opportunity for the most isolated parts of the world to have access to the web, and therefore to eventually reduce the development gap separating them from the industrialised world. On a broader perspective, Ron Adner and Peter Zemsky stress (2005) the great social welfare brought by the cost reductions that the disruptive phenomenon is bound to cause.

For these reasons, the disruptive susceptibility of the wireless communication market, and more precisely the wifi market, will be assessed in the following paragraphs.

4.2.6. Application of the reformulated disruptive susceptibility framework to the wifi market

P1 – High market entry barriers

In addition to the high level of technological expertise and the large economies of scale developed by established wifi providers, this market opposes a specific kind of barrier to the entrance of new challengers: bandwidth allocation. As already shown (see subsection 4.2.2), the radio frequency spectrum is of limited size and is already shared by many other sectors such as maritime navigation or satellite communication (see appendix II) (Encyclopaedia Britannica, 2020). Bandwidths must therefore be considered as rare and critical resources, whose appropriation by one industry irretrievably leads to its corresponding loss from another. Indeed, their overlap would cause undesirable issues of interference to users, this is why there are avoided as much as possible.

For this reason, a vastly regulated market has developed around the buying and selling of frequency bands (Bao et al., 2015; Hüsig et al., 2005). However, demand largely exceeds the supply of available bandwidth, which leads Richard Clarke to affirm that society is facing an actual "spectrum shortage" (2014, p. 693). Hence, entrant SMEs desiring to improve the performance of wifi connection (throughput, latency, …) in traditional ways are limited since it would generally require a broadening of the available bandwidth (Markets and Markets, 2017). Moreover, norms are not homogeneous worldwide. Thus, efforts made in the extension of wifi bandwidths have resulted in a successful appropriation of those located around 6.0 GHz in the United States, while this spectrum has not been conceded by its current European owners (i.e. the satellite industry) (Randroid, 2020).

This congestion of the radio frequency spectrum is escalating over time and significantly limits the prospects for the improvement of local wireless communications in the way they are conceived now. This is particularly true for newly created firms unable to influence governmental decisions. Just as it has been the case with flash memory developers in the past, they are more likely to engage in a successful trajectory by finding a way around these barriers. This solution came to the world's attention in 2011 during Harold Haas' presentation of a wireless communication system exploiting for the first time the wide, unregulated frequency bands of visible light.

P2 – Low customer loyalty

Given that the different wifi providers are proposing an offer considered to be performant enough for a majority of users, their selection is generally made on the basis of price comparison (Eleven, 2013; Hassan, Omar, Imran, Qadir, & Jayakody, 2018). As it is the case with commodities such as gas and electricity, the service provided is effectively so intangible that most households are simply favouring the cheapest option. Indeed, despite high demand, it is becoming very difficult for firms to justify higher prices (Cabling, 2016), a situation that highlights the absence of any emotional relationship between wifi providers and their customers.

Aware of such a deficiency, those firms have rapidly tried to cope with this lack of commitment. Whether by imposing contracts of minimum duration, or by proposing bundled packages including fixed telephony and television channels with their offer, wifi providers have consequently contractually established a form of customer loyalty. Ranganathan et al. (2006) have indeed demonstrated the impact of such clauses that significantly increase the *switching costs* associated with a change of internet provider.

However, Kah Boon Lim, Sook Fern Yeo and Goh Mei Ling (2018) claim that the premise of an extremely high improvement in the performance/price ratio achievable with LiFi technology could be a sufficient argument to induce consumers to change their internet provider, even with the presence of such switching costs.

P3 – Low number of firm entries and exits;

P9 – Constant competitors

Here, both propositions will be considered together for more clarity. Given its recent existence, the wifi market is quite dynamic and has witnessed the emergence of many new players every year. This leads to a rejection of the third proposition.

This being said, most of these entrants do not make the cut in the long run. In the end, the main wifi developers are generally long-established firms (Cisco, HPE-Aruba, Huawei…) that capture the bulk of the sales (see appendix III) (Cabling, 2016; What Competitors, 2020). For instance, Cisco has remained the market share leader for several years, with revenues estimated at $734 million in 2018 (44.7% share) (IDC, 2019). Newcomers' sales are conversely stagnating, unable to reach 25% of market shares.

According to Klenner et al. (2013), this market configuration contributes to high disruptive susceptibility as large incumbents are incentivised to prolong a strategy that has proven its worth over the years. Hence, the poor allocation of corporate resources and the overconfidence that could result from these decisions lead them to overlook the threat posed by new competitors.

P4' – High market share shifts to niche segments

Pushed by the popularisation of internet hotspots (nearly 628 million by 2023 (Cisco, 2018)) and the omnipresence of free wifi access in places of passage (hotels, train stations, retail shops, airports, …), growing demand for a cheap, ubiquitous internet connection has recently emerged. This trend has been supported by the decreasing prices of the wifi network and its access points, i.e. the modems (cf. P7') (Duan, Huang, & Shou, 2014), and contributes to the common view increasingly considering access to the internet as a right to which everyone should have access (Bao, Yu, Dai, & Zhu, 2015; Hameed, Mian, & Qadir, 2016). Hence, a large proportion of the market demand shifted towards products with moderate levels of performance as long as their price made them affordable to a large audience.

However, the examples of flash memory or digital cameras demonstrated that disruption does not necessarily start from the low-end market segments and that other eventualities have to be considered in its prediction. Indeed, while the customer segments of individuals searching for internet access are showing a declining willingness to pay for high-end services, corporate customers are following an opposite trajectory. Implementing wireless communication technology in their devices, manufacturers of smart vehicles or Virtual Reality devices are looking for cutting-edge components (Mordor Intelligence, 2019). Moreover, this very demanding customer category is further consolidated by the growing number of companies surfing on the IoT[25] wave (Ayyash,, et al., 2016; Haas, 2018). In the same way portable computers needed small-sized disk-drives to start their activity, these customers are totally dependent on the advancements made in wireless communication technologies to successfully commercialise their breakthroughs (Khandal & Jain, 2014). Hence, the price (and potentially the level of main performance) they will have to pay is relegated to a lower level of importance.

It can be concluded that both of these marginal consumer groups have their own requirements. Thus, whether by reducing prices, or by increasing bandwidths, reaches, and data transfer speed, the wireless communication market offers several compelling starting points for potentially disruptive candidates.

P6 – Change in value chain

The value chain of wireless communication is composed of different actors: wireless service providers, network engineers, telecommunication providers, governments and so on. All of them are following the two above-mentioned trends, with a particular focus on the development of IoT technologies. Indeed, the expected market is

[25] The term Internet of Things gather all the "objects with computing devices in them that are able to connect to each other and exchange data using the internet" (Cambridge Dictionary, 2020). For more information, consult Cirani, Ferrari, Picone and Veltri (2018)

huge (the number of connected devices should reach 50 billion by the end of 2020 (IEEE, 2018)), and so is its economic potential.

In this fast-moving sector, public authorities also have a key role to play. Understanding the societal impact of wireless communication, governments are working together with private actors to answer to its growing demand (expected to be 12,000 higher by 2040 (Haas, 2018)). To this end, they are making entire bands, such as the 6 GHz one in the US, available for unlicensed use of wifi (Bicheno, 2020), and participate to investment plans by way of public-private partnerships (Gatti, 2016; Lucey & Mitchell, 2016). Through the *Institute of Electrical and Electronics Engineers Standard Association* (IEEE), they also officialise new standards that are enabling the large-scale democratisation of innovations. In May 2018, they notably implemented the 802.11.bb communication standard making the commercialisation of LiFi-based technologies possible (IEEE, 2018).

This innovation can eventually benefit from important changes occurring in the lighting sector. For example, the share of households equipped with LED lighting has exploded in recent years[26], which could greatly facilitate the implementation of communication technologies based on visible light modulation.

P7' – Growing shift to new value propositions

A large variety of wireless communication developers have already stopped participating in the race for ever-increasing performance (in terms of throughput, bandwidth, reach, …) and propose instead novel attributes to their users (Li Fi Tech News, 2018). In addition to free, low-quality internet access, innovations bringing wifi connectivity to airplane passengers have also been investigated. Since 2008, firms such as Gogo are effectively spending their time and money to satisfy this marginal customer segment, but the resulting solutions remain unsatisfactory because of significant constraints (high costs, interference with pilots' radio signals, ...) (Wifi Travelers, 2018). The airline sector is not an isolated case, and many other wifi developers are trying to convince industries with specific demands (medical equipment, oil refineries, subsea transportation, …)[27] through new value propositions (Mukherjee et al., 2018).

Whereas HDD developers such as Seagate (see subsection 4.1.2.3) backtracked on their project to develop smaller models before the arrival of disruptors because of their low expected profitability, wifi developers' difficulties to

[26] A report from Mordor Intelligence (2019) indicates that the market share of LED technology increased by 61% in 10 years.
[27] Radio frequency signals are often banned (or unusable) in such "wave-isolated" environments where alternatives to enable wireless communication still need to be found (Oledcomm, 2020).

meet the expectations of fringe customer segments are mainly due to physical limitations. It is indeed impossible for them to reorganize the radio frequency spectrum on their own. This being said, by their presence, they have stimulated and delineated certain market segments on which disruptive candidates could build when setting up their business.

This happened in 2019 when the French company Oledcomm introduced LiFi technology in an Air France plane for the first time (Mordor Intelligence, 2019). Having understood the economic potential associated with meeting the demand of data-hungry passengers[28], these disruptors have taken advantage of the opportunities offered by such innovation to replace incumbent technology. This being said, it should be noted that, conversely to what is advanced by a major part of the theory, these entrants are not exclusively composed of small companies. Indeed, some large firms not yet involved in the wifi sector such as Philips or Panasonic have recently invested in this innovation (Transparency Market Research, n.d.).

Concerning the IoT, solutions are already proposed by established firms (Cirani, Ferrari, Picone, & Veltri, 2018). But the explosion of *machine-to-machine* communication volume over the next few years will soon become unmanageable under the current standards[29]. Once again, LiFi has a key role to play and can acquire a significant foothold in a market that it could subsequently invade.

P8 – High market concentration

In their annual report, Mordor Intelligence (2019) highlight the high market concentration of the wifi sector. Competition is very intense and more than twenty major international companies are fiercely fighting for market share (IEEE, 2018). Thus, a misstep can be highly detrimental to each of them, which is why they are reluctant to explore risky avenues in marginal market segments. It results in a static environment that new entrants are likely to disrupt if they manage to change the basis of competition (Danneels, 2004).

P11 – Introduction of a radical sustaining innovation

[28] According to a study of the London School of Economics (2019) 12% of passengers would agree to change from company to have access to a high-speed, stable internet access onboard. This represents a $33 billion market share increase for the companies taking the plunge.
[29] M2M communications are expected to represent 50% of the connections by 2023, with applications ranging from home surveillance to tracking applications (Cisco, 2018).

As observable in appendix IV, a vast series of innovations has been brought to wireless communication techniques since the launch of wifi in the early 2000s. Most of those innovations can be considered as sustaining since they targeted the same identified customer segment (cf. ferrite-oxide heads in subsection 4.1.2.3). The most recent is the introduction of WiFi 6, i.e. the new protocol using frequency bands located around 6 GHz, in 2019. Largely promoted by incumbents, this innovation is supposed to offer "improved speed, capacity and control" to its users (Cisco, 2020).

Here again, the objective is not to redefine the market by satisfying marginal customer segments and this latest improvement, as radical as it may be in terms of technological advancement, is in direct line with what has been done in the past. However, it attracts substantial interest from incumbents that are investing billions of dollars in its development. Thus, Klenner et al. (2013) would suggest that these incumbents are even less likely to react to any innovation that would not be associated with WiFi 6, which increases the chances of observing a successful market disruption.

Conclusion and market saturation

As summarised in figure 4.12, the application of Klenner's framework has allowed the detection of the strong disruptive susceptibility of the wifi market. Indeed, it bears many similarities with other value networks having experienced it in the past, which suggests that a disruptive candidate could easily take advantage of this favourable environment.

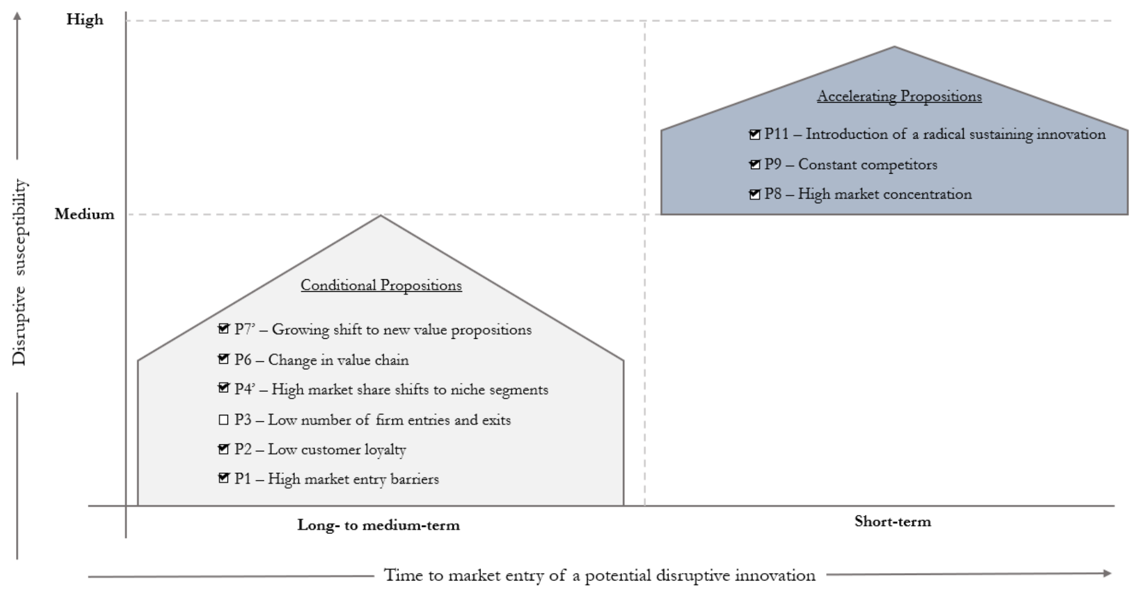

Figure 4.12 – Refined disruptive susceptibility applied to the wifi market under its current configuration

The situation is somewhat different concerning performance overshoot, a factor presented as fundamental by Christensen and which has been also emphasized by Klenner and his colleagues. While the surge in the speed of data transfer achievable with wifi technology (expected to grow from 30.3 Mbps in 2018 to 92 Mbps in 2023 (Cisco, 2018)) is likely to exceed the performance required by a majority of households, it remains unable to meet the demand of businesses such as IoT and VR developers. Consequently, one cannot assert that the entire wifi market is in a situation of performance overshoot[30]. Nevertheless, the latter can still be considered as congested. Contrary to the previously mentioned cases where saturation was due to a low willingness to pay for extra performances from oversupplied customers (cameras, HDD, light bulbs, …), it results here from too narrow a frequency band limiting, potential sustaining innovations.

Because of its supposed ability to satisfy both the demand of oversupplied individuals (through expected cost reductions) and companies seeking cutting-edge technologies, LiFi is regularly portrayed as the future market disruptor. But the research of Christensen et al. (2015) and Hüsig et al. (2005) has demonstrated that many innovations cannot be labelled as disruptive if they do not comply with the whole set of criteria set out in the literature review. Therefore, a thorough investigation of the similarities between the development of this technology and what is suggested by the theoreticians of disruption is necessary.

4.2.7. Considerations concerning the disruptiveness of LiFi

4.2.7.1. Proposition of a novel package of attributes

Firstly, it is evident that LiFi offers an unprecedented package of attributes to its users. In addition to enabling wireless communication in wave-isolated environments (petrochemical plants, oil platforms, …), this technology is also a perfectly adapted solution for the confidential transfer of information[31] (Bao et al., 2015; Mukherjee et al., 2018). Finally, it also creates huge opportunities for reductions in energy consumption (Yole Development, 2018). Hence, the hitherto unseen value proposed by LiFi stands for a decisive competitive advantage over incumbent technologies when attracting fringe customer segments.

[30] As explained in the literature review, the absence of performance overshoot does not necessarily prevent an innovation from being disruptive (Adner & Zemsky, 2005; King & Baatartogtokh, 2015).

[31] Due to its physical property, light is unable to go through walls. Unlike wifi signals that are regularly targeted by cyber-espionage because of the large area in which it transmits information, the signal here does not leave the room from which it is emitted (Mukherjee et al., 2018).

4.2.7.2. Low performance in the main dimensions

To be considered as truly disruptive, LiFi should conversely underperform these incumbent technologies in their core attributes, i.e. those most in demand from major customer segments. In their past analysis of WLAN innovation, Hüsig and al. (2005) denied it this title because WLAN performance was not inferior in comparison with established communication networks. Hence, the bandwidth that could be reached with the new technologies was overshooting even more the average demand for main performance that of wired connection. This remark could also be applied to every indicator defining the quality of information transfer at that time (coverage, mobility, …): WLAN was simply better than its competitors.

As shown in previous subsection, the case of LiFi is also particular in the sense it provides the market with what it is currently looking for: more data speed. However, one simply has to look at the rest of market preferences (see figure 4.13) and how LiFi is able to deal with them to understand that the situation is not similar to that of WLAN in 2005.

Basing themselves on a survey conducted among 628 US users, Taylor, Young and Noronha (2012) identified the features considered to be most important for wifi users. Apart from the fact that a majority of them are still looking for high-speed networks, additional purchase criteria have emerged as almost as important. A particularly relevant observation in the context of this work is the presence at the top of this list of two attributes for which LiFi-based applications are underperforming compared with their competitors: their cost and the area they are able to cover.

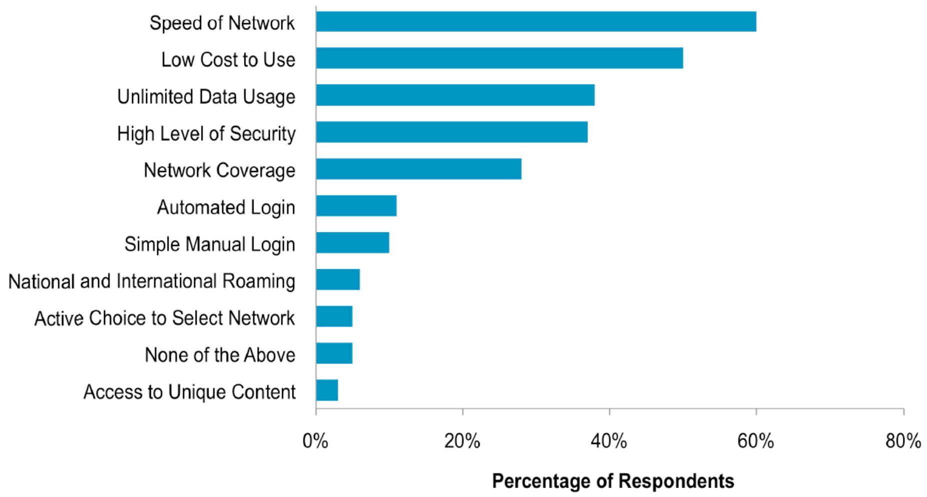

Figure 4.13 – Most demanded wifi features (Taylor et al., 2012, p. 7)

Indeed, the price of the starter kit launched by pureLiFi in 2018 (3000$) remains prohibitive for the major part of the market (Li Fi Tech News, 2018). Moreover, the inherent nature of visible light prevents it from transmitting information at distances comparable to wifi, especially in the physical world full of obstacles that light is unable to cross (walls, humans, …). This leads to an average uniform reach of LiFi-emitting LEDs of 10 meters, lagging way behind the 30 meters of wifi routers (Cisco, 2017). To these issues is added another challenge, i.e. the difficulties of coordinating the information sent and received by different access points (the LEDs) belonging to the same network (Haas, 2018).

4.2.7.3. Starting by targeting marginal markets

Although sharing many commonalities, the emergence of LiFi today is therefore not similar to the launch of WLAN communications that took place at the beginning of the 21st century. The many challenges this breakthrough poses to the firms working on its development suggest that time will pass before the replacement of every wifi modem by communicating LEDs takes place. Hence, the first LiFi sales have been made in low-profit, B2B niche segments of customers such as museums, airplanes, or hospitals that were dissatisfied with the established offer (EDF, n.d.; Mordor Intelligence, 2019; Oledcomm, 2020; Yole Development, 2018). It contrasts with “false” disruptors like Uber, which actually represented a sustaining innovation in the way in which they were immediately directing their offer towards the profitable and safe segment of mainstream taxi users (Christensen et al., 2015; Schmidt & Druehl, 2008).

4.2.7.4. Shifting upmarket through performance improvement

To be considered as truly disruptive, the performance of LiFi applications should gradually improve along the main dimensions it is presently underscoring (cf. S-shaped curve). The avowed desire of firms such as pureLiFi is indeed to ensure the presence of LiFi chips in most of laptops and tablets in the near future (Li Fi Tech News, 2018). To achieve this objective, they are aware that the price paid by end users must be as low as possible, but also that they should be offered the possibility to move from room to room without seeing any weakening of their connection. To this end, large investments are made on lowering the production costs of LiFi-based technologies and on improving the coverage of signal-emitting units (Mordor Intelligence, 2019).

4.2.7.5. Disregarded by incumbents

The theory of disruption finally advocates a late reaction from incumbents, either because they do not see the threat coming or because it does not seem financially worthwhile for them to compete with new entrants.

As noted in the previous section, wifi developers' interests are currently focused on the development of sustaining innovations. By investing heavily in the development of Wi-Fi 6, they indeed attempt to improve the experience of their current customers (Cisco, 2020). In the same way that hard disk drives allowed the flash memory manufacturers to develop in the 1990s (Christensen, 1997), wifi developers consider LiFi as a complementary technology unable to capture their market share (All About Electronics, 2017). Its current low performance in terms of price and reach indeed makes a rapid market overhaul unthinkable[32]. Moreover, in view of the upcoming surge in data transfer volume, most of the incumbents rather appreciate the data offloading that a joint presence of both technologies on the same market would enable (Mukherjee et al., 2018). It even led Cisco to enter into a partnership with pureLiFi to develop their first 5G RuralFirst project in 2018 (Mordor Intelligence, 2019).

This being said, the case of flash memory has shown that such enthusiasm on the part of incumbents for the emerging technology may eventually become detrimental to them. At a certain stage of its development, LiFi applications are indeed expected to lower their prices to such an extent that they will be susceptible to attract a growing share of wifi users (see 3rd phase of figure 4.7).

4.2.7.6. Discussion

It has been demonstrated that the wireless communication market has a high disruptive susceptibility and that LiFi is a serious candidate for its disruption. However, some specificities, whether related to the current state of the wifi market or to the LiFi properties, contrast with this conclusion. Table 4.1 gathers all the similarities and differences existing between this case and the theory of disruption.

[32] Authors such as Dinesh Khandal and Sakshi Jain (2014) rather present LiFi as ideal for "high density wireless data coverage in a confined area"(p. 1692), whereas wifi communication would remain indispensable in many situations such as the wireless coverage of buildings.

Pro disruption	Room for debate	Against disruption
• High disruptive susceptibility of the wifi market	• High prices	• Outperform competition in data transfer speed
• Proposition of a new package of attributes (no interference, transmission security) which tackles non-consumption	• No performance overshoot for a large share of customers	
• Underperforming in some key dimensions (price and reach)	• Only respect the 2nd version of the S-curve model	
• Start with low-profit segments and shift upmarket	• Small entrants (pureLiFi, Oledcomm) and large incumbents (Philipps, Panasonics) working on its development	
• Not perceived as a threat by incumbents		

Table 4.1 – Comparison of LiFi characteristic with the theory of disruption

In addition to the characteristics that may be debatable, the main counter-argument concerning the disruptive potential of LiFi lies in its performance on the main attribute, i.e. data transfer speed. Referring to the performance trajectory model (see figure 4.14), no intersection between the rising performance supply of LiFi and the limited market demand can be identified since the former is already starting from a higher position.

The situation largely differs when considering two other main attributes, i.e. reach and price. The 2nd quadrant indeed shows that serious improvements are necessary for LiFi to offer a level of performance at least meeting the market demand, which represents the final step of the disruption process.

Whether considering this innovation as disruptive or not will therefore depend on the classification of such attributes as being of primary or secondary importance.

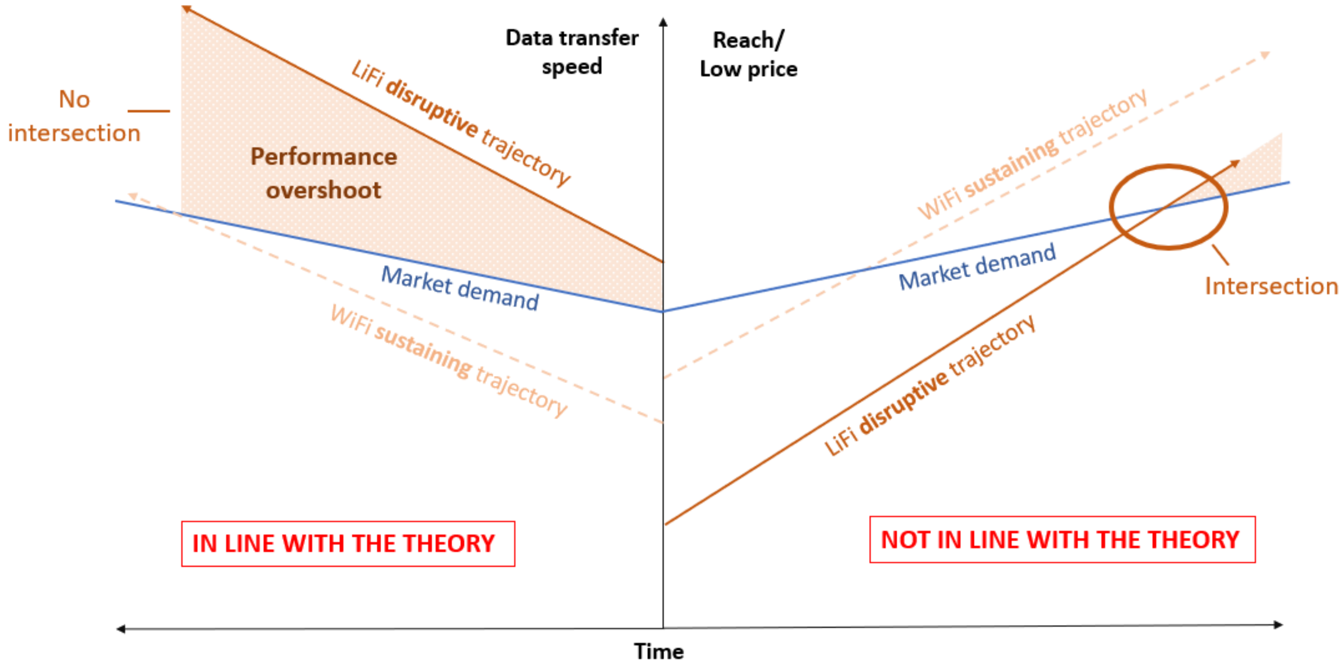

Figure 4.14 – Compared performance trajectories of attributes (own illustration inspired from (Christensen, 1997, p. 12))

5. Conclusion

5.1. Reflection path

The main purpose of this thesis was to investigate the dynamics behind innovation. Reflecting on market saturation and its impact on technological development, the choice was made to conduct this analysis through the particular lens of disruption. Thanks to its "game-changing" nature, this concept has indeed crystallised the way various technologies manage to distinguish themselves from the established ones by developing new, initially unpopular attributes.

Throughout this work, it has been shown that a great deal of research had already been carried out in this field. What remained under-explored, however, was the predictive analysis of the emergence of disruptive innovations. In order to take into account the role of market saturation, and at the same time to highlight the social construction of innovation, the choice was made to focus more precisely on the specific market-drivers of disruption rather than the degree of radicalness of the breakthrough. Considering factors such as customer loyalty or the density of competition, the selection of this perspective is all the more consistent as it reinforces the originality of the present thesis.

5.2. Findings and contribution

Drawing heavily on the disruptive susceptibility framework, the study of historical cases of disruption enabled the formulation of nine theoretical assumptions positively correlated with the emergence of disruptive innovation. This refined model presents three main advantages compared to its predecessor:

(i) it rejects the false assumption requiring the increase in market prices before disruption;

(ii) it clarifies the vagueness and the low empirical validation associated to the concept of quality by replacing it by the level of performance in the main attribute;

(iii) it broadens the applicability of this predictive framework to any market which would witness the emergence of an innovation that would not start from a low-end position.

But the contribution of this work is not limited to these conceptual considerations. Indeed, it is the first time that the disruptive susceptibility framework has been applied to the wireless communication market to assess the likelihood for its newest innovation, i.e. LiFi, of disrupting the current wifi protocol. This results in very promising findings: although this market presents a high number of firm entries and exits, its current configuration is highly consistent with the rest of the propositions of the refined framework. Moreover, LiFi shares many similarities with previous cases of disruptive innovations and can therefore be conceived as a future one.

These findings are essential for several reasons. First of all, they allow an answer to the research question underlying this work by confirming that, whether for cameras, storage devices or wireless communication standards, disruption is an outstanding strategy to get around the issues brought by market saturation. Anticipating the disruptive potential of LiFi is also fundamental for wifi developers such as Cisco if they do not want to follow the same trajectory as Kodak. Finally, it is crucial for policymakers to realise the potential of this innovation, whose growth expectation is certainly underestimated[33]. Beyond its economic potential, LiFi undoubtedly represents a key component of tomorrow's communication sector whose responsible development requires an appropriate regulatory framework.

5.3. Limitations and further research

The main limitation of the present work concerns the ex-ante approach that has been used to identify the disruptive nature of LiFi. It implies that the resulting findings necessarily involve a dose of uncertainty that must be addressed by future research, confirming or not the disruption of the wireless communication market by the Light-Fidelity technology. Such research can, for instance, investigate whether another innovation will take advantage of the exceptional data transfer speed enabled by LiFi to disrupt it in turn by selling lower-end options to its oversupplied customer segments (see figure 2.3). Analysing the reaction of traditional wifi actors facing disruption could also be a valuable starting point.

Another field for potential research would consist of looking at the disruptiveness of LiFi through two other lenses, either technological or environmental (see subsection 2.10). Adopting these complementary perspectives would consequently strengthen the consistency of the above-mentioned results.

It must finally be emphasised that disruption is just one of the many patterns describing the dynamics of innovation. Thus, some breakthroughs can displace established markets, including the saturated ones, without being disruptive

[33] A report from Yole and Piseo values it at $2.7billion by 2028 (as cited in Ghesquier (2019).

or presenting a high disruptive sensibility. Focusing on these alternatives, and to what extent they apply to the case of LiFi, could therefore represent another valuable field of study.

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Appendix

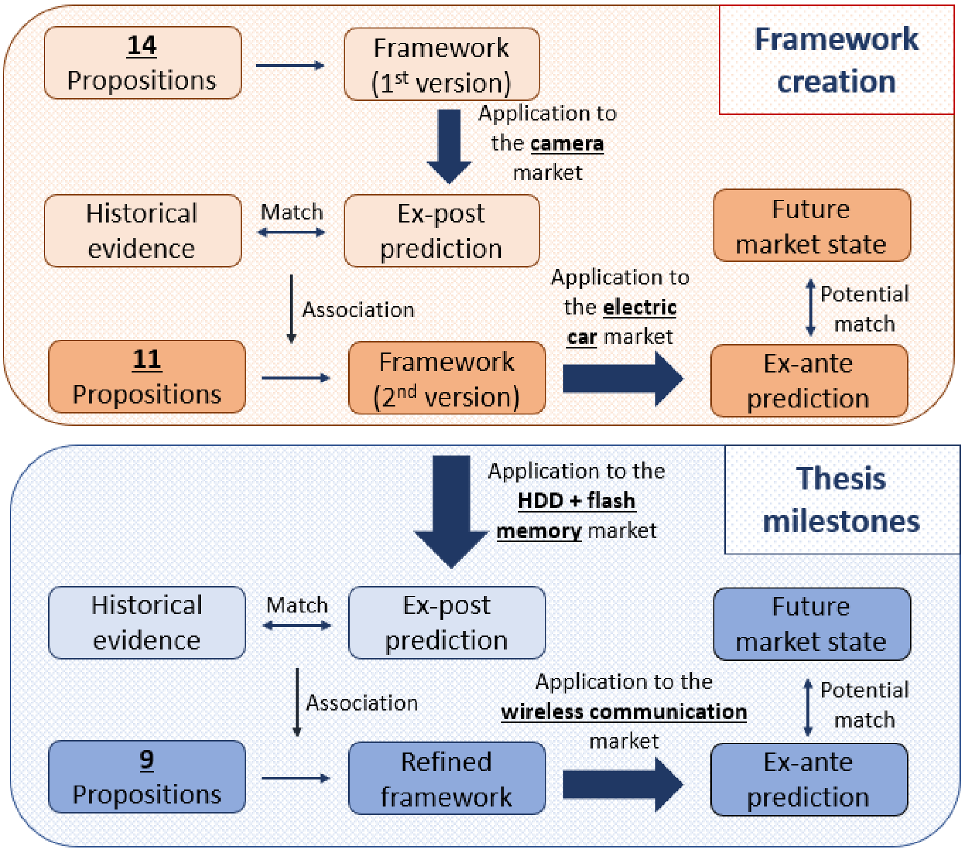
I. Framework creation and refinement

II. Radio spectrum and its applications

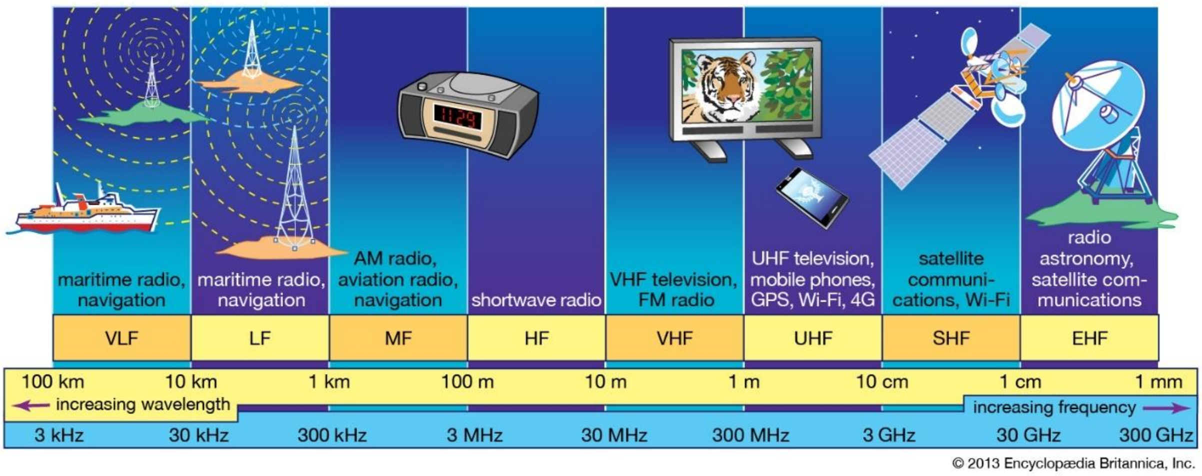
III. Competition in the wifi sector

IV. Sustaining innovations in the wifi sector (from 2008 to 2019)

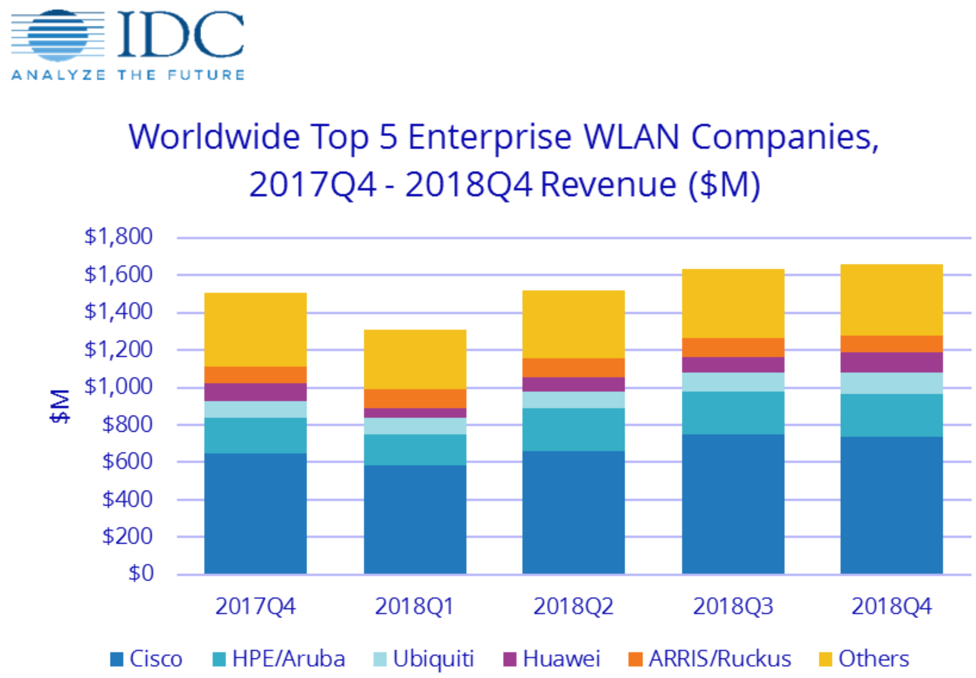
Appendix I – Framework creation and refinement (own illustration)



Appendix II – Radio spectrum and its applications (Encyclopaedia Britannica, 2020)



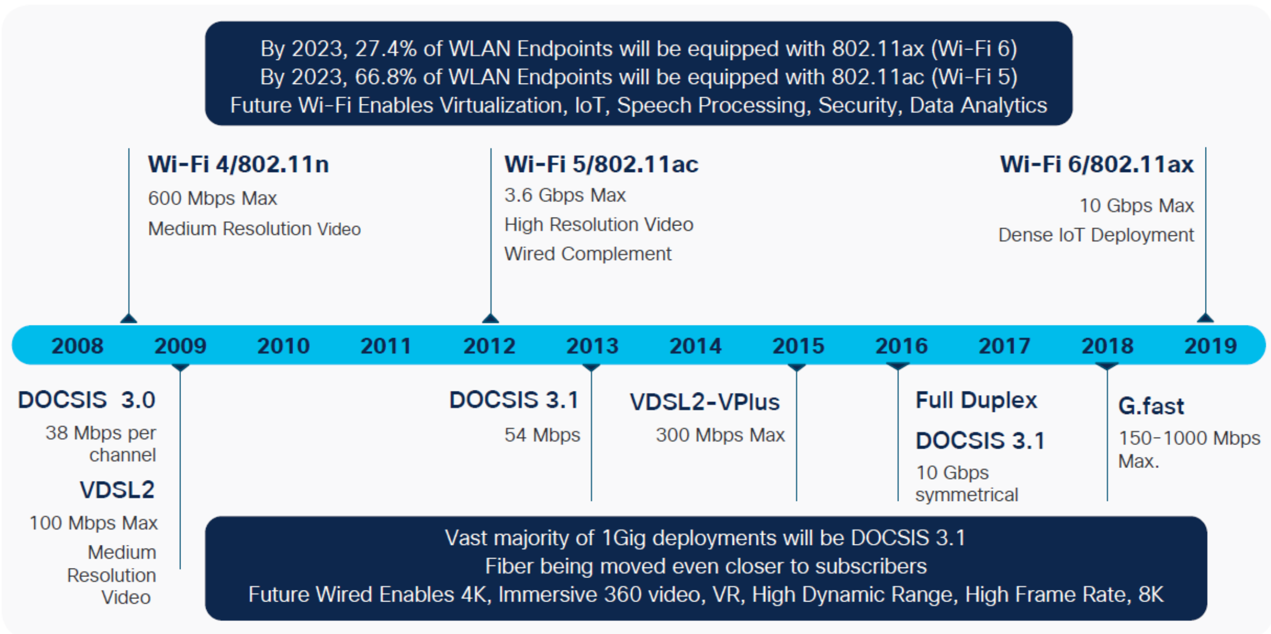
Appendix III – Competition in the wifi sector (IDC, 2019)



Source: IDC 2019

Appendix IV – Sustaining innovations in the wifi sector (from 2008 to 2019) (Cisco, 2018)

Figure 12. Historical evolution and future of wired and wireless technologies



Source: Cisco Annual Internet Report, 2018-2023