An Improvement to Disruption Theory from a Macro Perspective: Evidence from the Personal and Mobile Computing Industries

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Abstract

This research studies the concept of disruptive innovation and its patterns from a macro perspective. By using quantitative and qualitative evidence from the personal and mobile computing industries, this research serves to corroborate Clayton Christensen's disruption theory, the main theory proposed today as an explanation of this phenomenon. It identifies the strengths and weakness of the theory, and builds upon it in order to propose an improved theory of disruption that takes into account the evolution of the market.

In order to measure disruption in the personal and mobile computing industries this research collected data for 58 product lines, including personal computers and smartphones from 1974 to 2015. A correlation analysis validated the foundations of Christensen's model, except for the distinction between incumbents and entrants. Other results showed the importance of radical innovation and architectural innovation, as well as the possibility of self-disruption. Further qualitative historical analysis corroborated these results.

The main finding of this research was identifying three different phases of disruption and proposing an original categorization for them: 1) disruption by creation of a new market, 2) disruption by mainstreamization of the market, and 3) disruption by commoditization of the market. This represents an improvement over the current understanding of the theory from a macro perspective.

Keywords: innovation, disruption, management, computing, mobile

Introduction

One key and not often discussed characteristic of Clayton Christensen's theory of disruption is the predictable and methodical manner in which disruption takes places in the market according to it. While the theory acknowledges that the ignition itself of disruption might be unpredictable, once disruption begins entrants disrupt incumbents in a methodical manner that is as much inexorable as it is systematic, at least according to the theory.

In disruption theory parlance, as a market evolves sustaining innovations overshoot customer needs and incumbent companies start over-serving the mainstream market. In turn, these gaps between performance's supply and demand allow for the emergence of disruptive innovations that lower performance, usually introduced by new entrant companies. Once a disruptive innovation takes hold in the low-end of the market, it relentlessly improves its performance and begins to move from the low-end to the high-end of the market, displacing in this process the previous technology and incumbent companies. Incumbents flight, instead of fight, and withdraw to the high-end of the market until they get cornered. Unrelenting, the disruptive innovation and entrant companies capture the mainstream market, and eventually the whole market including the high-end (Christensen, 1997, 2003).

Incumbent companies might become frantic at the late stages of this process once they realize that they are facing an existential threat, however until that point disruption had been building up slowly. According to the theory, disrupted companies go out of business two ways: gradually, and then suddenly. This is a reference to Ernest Hemingway that is often used to emphasize the slow buildup of disruption until it is too late (Sinofsky, 2013; Dediu, 2015; Thompson, 2016). Despite the attractiveness of this narrative, this research proposes that disruption does not take place in just these two stages. The historical evidence from the evolution of the personal and mobile computing industries is at odds with Christensen's characterization of the evolution of markets that get disrupted.

Infamously, Christensen predicted in 2007 that the iPhone was not truly disruptive and that it would fail against incumbent companies like Nokia (McGregor, 2007). Instead of being anecdotal, this miscalculation suggests that aspects of disruptive innovation have yet to be explained, and that the case studies of the personal and mobile computing industries can provide valuable evidence for improving disruption theory. Besides the iPhone, many product lines studied in this research did not fit Christensen's description of how a market evolves or gets disrupted.

In order to understand this problem this research analyzed quantitatively and qualitatively the history of the personal and industry from 1974 to 2015. The main finding of this research was identifying three different phases of disruption and proposing an original categorization for them: 1) disruption by creation of a new market, 2) disruption by mainstreamization of the market, and 3) disruption by commoditization of the market. This represents an improvement over the current understanding of disruption theory from a macro perspective.

Before presenting in more detail the results of this study, however, we need a precise understanding of the concepts of disruption theory.

The Theory of Disruptive Innovation

The confusion surrounding the concept of disruptive innovation has frequently been blamed on its popularization, as seen in Figure 1. Surprisingly, both supporters and detractors of the concept seem to agree on that (Danneels, 2004; Christensen, 2006, 2015; Dediu, 2014b; Thompson, 2013b; Gans, 2014; Lepore, 2014; Sood and Tellis, 2011; Yu and Hang, 2010; Yamaguchi, 2006).

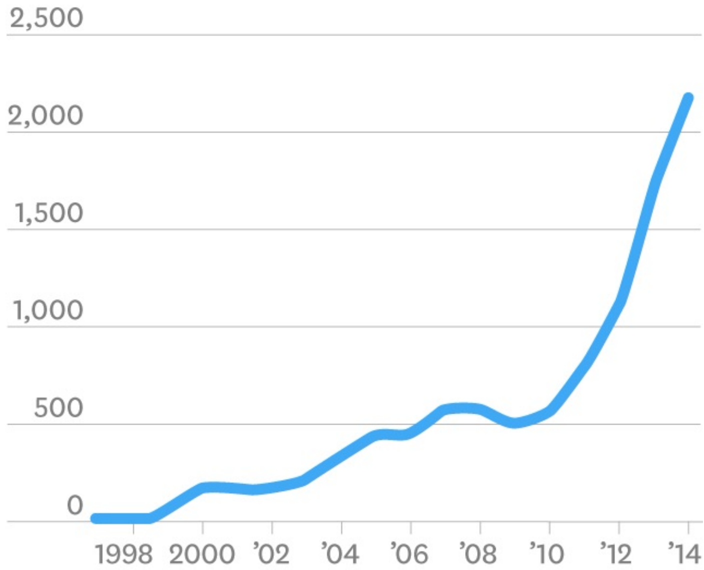

Figure 1: Number of articles using "disruptive innovation" and "disruptive technology" (Christensen, 2015).

While the popularization of the concept of disruptive innovation is true and has added to the polemic, this research considers that the problems in the understanding of disruption cannot be blamed only on this. There are profound disagreements inside academia in regard to disruption, and Christensen's conceptualization of disruptive innovation has been difficult to define, measure, and corroborate (Sood and Tellis, 2011). Furthermore, many of the most emblematic case studies of disruption have been questioned to date: disk drives (Nishimura, 2014; Lepore, 2014), personal computers (Thompson, 2013b), transistors (Yamaguchi, 2006), steel minimills and hydraulic excavators (Lepore, 2014).

Nowadays there are two main variants of the theory of disruptive innovation. In its orthodox interpretation disruption has come to mean the same as Christensen's theory of disruption (1997, 2003, 2006). On the other hand, a pluralistic interpretation considers the theory of disruption to be a broader field of study (Sood and Tellis, 2011; Schmidt and van der Rhee, 2013; Čiutienė and Thattakath, 2014; Gans, 2016). The pluralistic interpretation is the one preferred on this research, but the preeminence of Christensen's work as the father of disruption's theory is also acknowledged.

Christensen's theory of disruption is actually composed of two sub-theories: new market disruption, and low-end disruption (Christensen, 2006). Both theories share many concepts and study similar phenomena, however they have yet to be successfully unified into one consistent theory (Thompson, 2013a, 2014b). Christensen's latest effort for unification in an improved 'Theory of Disruption 2.0' (2016) is a work in progress that has yet to be tested and widely adopted by the research community.

Christensen (1997, 2003) has explained systematically the four key concepts of his original interpretation of disruption theory, shared both by new market disruption and low-end disruption. These four concepts are: 1) product performance, 2) sustaining technology, 3) disruptive technology, and 4) customer needs.

Product performance is a variable which measures the traditional dimension of performance of a product, or in Christensen's words "the dimensions of performance that mainstream customers in major markets have historically valued" (1997). For many products, performance is not just one dimension, but actually a combination of several dimensions in an intricate value proposition. Today, this abstract measure of product performance is frequently referred as "the basis of competition".

Product performance allows us to define sustaining and disruptive technologies. According to Christensen, sustaining technologies

> foster improved product performance. Some sustaining technologies can be discontinuous or radical in character, while others are of an incremental nature. What all sustaining technologies have in common is that they improve the performance of established products, along the dimensions of performance that mainstream customers in major markets have historically value. (1997)

On the other hand, disruptive technologies are

> innovations that result in worse product performance, at least in the near-term. Disruptive technologies bring to a market a very different value proposition than had been available previously. Generally, disruptive technologies underperform established products in mainstream markets. But they have other features that a few fringe (and generally new) customers value. (1997)

Despite their naming, disruptive technologies do not cause disruption by definition, although causation is implied. For Christensen a technology only needs to lower product performance in order to be called a disruptive technology. Because of this, other researchers prefer the term "potentially disruptive technologies" (Sood and Tellis, 2011).

Intuition would tell us that disruptive technologies should not succeed in the market since they offer worse performance. However, performance has to be understood in relation to customers. Customer needs are "the rate of performance improvement that mainstream customers demand or can absorb" (1997). Christensen found that the pace at which technologies performance improve is usually much faster than the pace at which customer needs increase. Because of this, in certain scenarios the performance of a superior traditional technology and an inferior disruptive technology can be equivalent for mainstream customers.

According to Christensen, is not the case that disruptive technologies underperform, but rather that traditional technologies overshoot mainstream customer needs. The views of the authors on this hypothesis and the relation between product performance and costumer needs can be found in a different paper soon to be published (Montoya and Kita, 2017). We believe that the jury is still out on this hypothesis, but Christensen's model can be adapted if needed.

These four key concepts: 1) product performance, 2) sustaining technology, 3) disruptive technology, and 4) customer needs, are all that is need to visualize disruption, which is frequently done as illustrated in Figure 2.

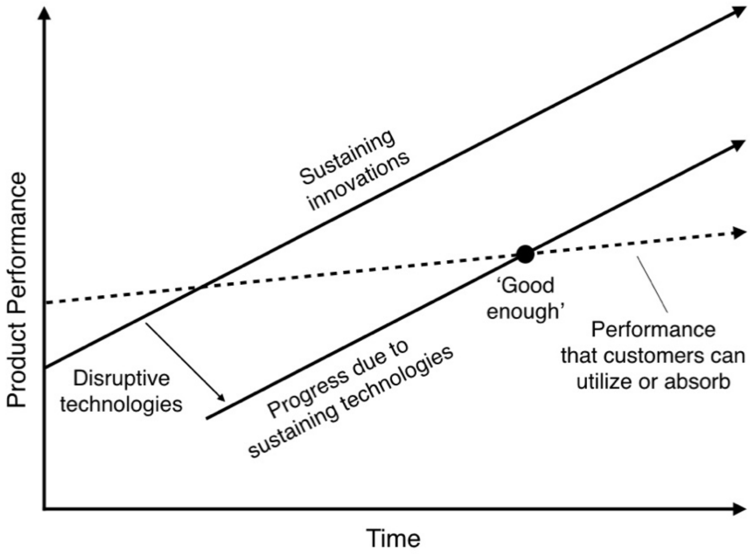

Figure 2: Trajectories of sustaining and disruptive technologies (Christensen, 1997).

As seen in Figure 2, once a disruptive innovation takes hold in the low-end of the market, it relentlessly improves its performance and begins to move from the low-end to the high-end of the market, displacing in this process the previous technology and incumbent companies. The disruption diagram and the four key concepts of disruption theory describe how disruption takes places, but not why it happens. The study of the causal mechanism of disruption has often focused on the innovator's dilemma from a micro perspective, in other words the reasons why managers at incumbent companies fail to fight entrants. However, disruption theory also has an implicit macro perspective.

From a macro perspective, the explanation of disruption varies slightly depending on which of two mechanisms of the theory are used. In the most common case, the process is explained in terms of achieving performance-competitiveness. Christensen described it using the case study of the computing industry as follows:

> In their efforts to provide better products than their competitors and earn higher prices and margins, suppliers often "overshoot" their market: They give customers more than they need or ultimately are willing to pay for. And more importantly, it means that disruptive technologies that may underperform today, relative to what users in the market demand, may be fully performance-competitive in that same market tomorrow.
>
> Many who once needed mainframe computers for their data processing requirements, for example, no longer need or buy mainframes. Mainframe performance has surpassed the requirements of many original customers, who today find that much of what they need to do can be done on desktop machines linked to file servers. In other words, the needs of many computer users have increased more slowly than the rate of improvement provided by computer designers. (Christensen, 1997)

However, the same disruptive process can be explained alternatively in terms of economies of scale. Using a more recent understanding of disruption pioneered also by Christensen (2003, 2006), Benedict Evans described the process of new market disruption using the same case study of the computing industry as follows:

> Until recently, the PC ecosystem was the centre of gravity of the tech industry: it was where the investment and innovation was centred. It took that role away from mainframes, minicomputers and workstations slowly and in stages over the previous 30 years or so. Crucially, though, PCs didn't start out selling to customers of mainframes, minicomputers or workstations - rather PCs were able to access a new and much larger pool of customers, and that gave PCs scale that, a decade or two later, allowed them to replace almost everything else. PCs could be sold to so many more people that their economies of scale became overwhelming. Eventually, there was no way that, say, the workstation industry could match the investment of the PC industry, and Sun and SGI were overtaken. And today, even a 'data centre' just means millions of 'personal computers'. Ecosystem scale won. (Evans, 2016)

While disruption through performance-competitiveness is a direct process that is a consequence of customers' choices in the market, disruption through economies of scale is an indirect process that is caused by changes in the supply chain. On the later explanation suppliers and investors play a role as vital or more than customers.

It must be stressed that these two types of macro explanations frequently overlap, as the case study of the computing industry shows. One explanation is not intended to replace the other, both are explanations from a macro perspective and use shared concepts, but they describe different aspects of disruption. For the purposes of this research we have decided to focus on their most important common characteristic, which is they way disruption is described as a gradual and almost methodical process from a macro perspective, regardless of whether it is low-end or new market disruption.

The effect desired by the above descriptions from Christensen (1997) and Evans (2016) is to stress the inevitability of disruption. Fatalist descriptions are the norm in studies about disruption (Lepore, 2014). But in their effort to stress the final upheaval of the market, researchers have paid less attention to the evolution of the market and the possibility of phases in disruption. In Christensen's model, previously shown in Figure 2, disruption takes place steadily, and the focus is on how the disruptive technology overtakes the previous technology 'eventually'. But how and by whom is the disruptive technology propelled is not considered in detail by the model, it is assumed that the disruptive technology gets better simply by sustaining improvements, and that the participants in the market (entrants and incumbents) remain the same throughout the whole process.

Besides the key four concepts previously explained, an additional concept called 'the innovator's dilemma' has been proposed by Christensen as the causal mechanism that enables disruption from a micro perspective. This concept deals with the managerial reasons why incumbent companies under disruption are almost always unable to fend off the treat of disruptive technologies. The innovator's dilemma has been the focus of ample research, both for and against it (Danneels, 2004; Christensen, 2006, 2015; Dediu, 2014b; Thompson, 2013b; Gans, 2014; Lepore, 2014; Sood and Tellis, 2011; Yu and Hang, 2010; Yamaguchi, 2006). While acknowledging the importance of this debate, this research does not focus on the micro perspective of disruption or the innovator's dilemma, instead this research addresses the problem of the causal mechanism of disruption from a macro perspective.

Methodology

In order to measure disruption in the personal and mobile computing industries data for 58 product lines was collected, including personal computers, smartphones, personal digital assistants (PDA), tablets, and operating systems from 1974 to 2015. Each product line should be understood as all versions of a product from its introduction until its discontinuation as seen in Table 1.

Table 1: Product lines in the computing industry.

Product line	Company	Introduction year	Form factor
Altair 8800	MITS	1974	Personal computer
Atari 400/800	Atari, Inc.	1979	Personal computer
Commodore PET & 64	Commodore	1977	Personal computer
Commodore (Amiga)	Commodore	1985	Personal computer
TRS-80	Tandy Corporation	1977	Personal computer
Olivetti M24	Olivetti	1983	Personal computer
ZX80 & ZX Spectrum	Sinclair	1980, 1982	Personal computer
IBM PC	IBM	1981	Personal computer
Compaq Portable	Compaq	1982	Personal computer
HP series 80	Hewlett-Packard	1980	Personal computer
HP Pavilion / HP branded Compaq Presario	Hewlett-Packard	1993, 1995	Personal computer
Dell (online store)	Dell	1996	Personal computer
Packard-Bell	Packard-Bell	1986	Personal computer
PC-8800 and PC-9800	NEC	1981	Personal computer
Fujitsu Micro (FM)	Fujitsu	1981	Personal computer
Toshiba T1100	Toshiba	1985	Personal computer
Acer Aspire	Acer	1995	Personal computer
Asus Eee PC	Asus	2007	Personal computer
Lenovo ThinkPad	Lenovo	2005	Personal computer
Xerox Alto & Star	Xerox	1973, 1981	Personal computer
Apple I and II	Apple	1976, 1977	Personal computer
Lisa	Apple	1983	Personal computer
Macintosh	Apple	1984	Personal computer
NeXT Computer	NeXT	1988	Personal computer
Newton	Apple	1993	Handheld device
Palm Pilot	Palm	1996	Handheld device
Palm Pre	Palm	2009	Handheld device

Blackberry	RIM	1996	Handheld device
BlackBerry Z10	RIM	2013	Handheld device
Nokia 7650 (Symbian OS, S60 platform)	Nokia	2002	Handheld device
Nokia Lumia	Nokia	2011	Handheld device
iPaq and HTC Canary	HTC	2002	Handheld device
HTC Dream	HTC	2008	Handheld device
iPhone	Apple	2007	Handheld device
Motorola Droid	Motorola	2009	Handheld device
Samsung Galaxy	Samsung	2009	Handheld device
Xiaomi	Xiaomi	2010	Handheld device
Lenovo branded as Motorola	Lenovo	2014	Handheld device
Oppo	BBK	2008	Handheld device
Vivo	BBK	2009	Handheld device
iPad	Apple	2010	Tablet
HP Compaq TC1100 (Microsoft Tablet PC)	Hewlett-Packard	2002	Tablet
Surface	Microsoft	2012	Tablet
Android (Tablet)	Google	2011	Tablet
BlackBerry PlayBook	RIM	2011	Tablet
HP TouchPad	Hewlett-Packard	2011	Tablet
Kindle Fire	Amazon	2011	Tablet
MS-DOS	Microsoft	1981	Operating System
Windows	Microsoft	1985	Operating System
Microsoft Tablet PC	Microsoft	2002	Operating System
Windows CE, Pocket PC, Mobile	Microsoft	1996	Operating System
Windows Phone	Microsoft	2010	Operating System
Linux (desktop)	GNU GPL	1991	Operating System
OS/2	IBM (partly Microsoft)	1987	Operating System
BeOS	Be Inc.	1991	Operating System
NeXTSTEP	NeXT	1993	Operating System
Android	Google	2008	Operating System
Symbian	Symbian Ltd. (Nokia)	1997	Operating System

Instead of using a random sample, this dataset was built by exhaustively collecting information on as many product lines as we could identify, in such a way that the sample resembles the population as much as possible in order to avoid selection bias. We believe this dataset to be comprehensive and are not aware of important omissions (Reimer, 2005, 2012a, 2012b; Dediu, 2012b), but keep working on expanding it.

Spearman correlation was calculated across 18 dummy variables: 10 independent variables represent concepts about innovation, and 8 dependent variables represent market effects. To corroborate the validity of this test it was confirmed that the results of Spearman's coefficient, Pearson's phi coefficient, point biserial correlation, and Kendall's tau-b were exactly the same for the dataset employed in this research, however the preferred interpretation is Spearman correlation.

Following Sood and Tellis (2011) this researched first attempted to define disruptive technologies strictly as "innovations that lower product performance", regardless of their market effects (Christensen, 2006; Sood and Tellis, 2011). However, this approach probed insufficient, because of this more variables and flexible definitions were introduced to reflect the variety of interpretations present in disruption literature today.

Five of the independent variables represent concepts from the orthodox interpretation of Christensen's theory (1997, 2003, 2006), they are: entrant, worse performance, shifts basis of competition, new market disruptive innovation, and low-end disruptive innovation. The other five independent variables represent concepts from the pluralistic interpretation of disruption based on alternative theories, such as the research of Sood and Tellis (2011), Schmidt and van der Rhee (2013), Dosi (1982), and Henderson and Clark (1990), they are: first mover, high-end, self-disruptive intent, radical innovation, and architectural innovation. The definitions for each variable are presented below:

- Entrant: Was the company who developed the product a new entrant to the industry at the time of its introduction as Christensen proposes?
- First mover: Was the product introduced to the market before mainstreamization took place as Sood and Tellis propose?
- Worse performance: Did the product worsen performance in the dimension historically valued by customers as Christensen proposes?
- Shifts basis of competition: Did the product shift competition from the dimension historically valued by customers to a new dimension as Christensen proposes?
- New market disruptive innovation: Does the product conform to Christensen's definition of new market disruptive innovation?
- Low-end disruptive innovation: Does the product conform to Christensen's definition of new market disruptive innovation?
- High-end: Was the product high-end in comparison to other products in the market at the time of its introduction, as Schmidt and van der Rhee propose?
- Self-disruptive (intent or risk): Did the company intentionally introduce a product that carried the risk of self-disruption, as Sood and Tellis propose?
- Radical innovation: Did the product introduce a radical innovation as defined by Dosi?
- Architectural Innovation: Did the product introduce an architectural innovation as defined by Henderson and Clark?

On the other hand, the eight dependent variables represent market effects. Besides studying disruption as a whole, more discrete market effects are also considered:

- Disrupts market: Did the product disrupt the market conforming strictly to Christensen's model: the capture of most of the market starting from the low-end?

- Disrupts market (flexible): Did the product disrupt the market according to a more flexible definition based on the pluralistic interpretation of disruption: the capture of substantial market or profit share?
- Creates market: Did the product contribute to the creation of a new market?
- Expands market: Did the product contribute to the expansion/mainstreamization of the existing market?
- Commoditizes market: Did the product contribute to the commoditization of the market?
- Self-disrupts (effect): Did the product cannibalize different product lines of the company?
- Success in market: Did the product succeed in the market taking into account the size of the market at the time?
- Lasting success: Did the product succeed for a long time in the market?

Notes and Limitations

The categorization was done using binary variables whose value was assigned by the authors after researching every product's history in detail. While the use of binary variables introduces limitations, they also help to avoid a common problem of variables with more than two possible values, which is the accumulation of observations that are assigned an intermediate value when in doubt. For example, a value of 3 in a scale of 1 to 5 that tries to measure 'disruptiveness', which defeats the purpose of categorizing. We found that the additional level of detail of polytomous variables with multiple values did not reflect a real increase in certainty.

This research considers disruptive innovation and other innovation types to be Weberian 'ideal types', a widely used concepts in social sciences. According to Weber, "an ideal type is formed by the one-sided accentuation of one or more points of view and by the synthesis of a great many diffuse, discrete, more or less present and occasionally absent concrete individual phenomena… In its conceptual purity, this mental construct cannot be found empirically anywhere in reality" (1903–1917/1949). This research adopts this methodology and considers innovation types and the other independent variables to be ideal types. That is to say useful idealizations that are rarely found in reality.

On the other hand, the dependent variables or effects of disruption in the market were actually measured using market share, and net profits. There are methodological difficulties in both approaches. Measuring disruption only in terms of market share poses a problem in young markets where first movers can capture a high market share with comparatively few unit sales. On the other hand, measuring disruption only in terms of net profits tends to over-represent companies in mature markets because the market is much bigger. For this reason, both measures were used together.

Results

The results for Spearman correlation are presented in Table 2.

Table 2: Spearman's rank correlation coefficient for at least p < 0.1

	Entrant	**First mover**	**Worse performance**	**Shifts basis of competition**	**New market disruptive innovation**
Disrupts market	-0.2880*			0.4699***	
Disrupts market (flexible)			0.2529	0.5958***	
Creates market	0.2281	0.35737**		0.3472**	0.5868***
Expands market		0.2576	0.2469	0.3126*	
Commoditizes market		-0.3849**		0.3185*	-0.2366
Self-disrupts (effect)				0.2896*	
Success in market			0.3958**	0.4715***	
Lasting success			0.3152*	0.3992**	

	Low-end disruptive innovation	**High-end**	**Self-disruptive (intent or risk)**	**Radical innovation**	**Architectural Innovation**
Disrupts market	0.3738**				
Disrupts market (flexible)		-0.2530*		0.2189	
Creates market	-0.3687**			0.5620***	
Expands market					0.5650***
Commoditizes market	0.6869***	-0.2991*		-0.2654*	
Self-disrupts (effect)			0.7658***		
Success in market	0.4308***	-0.4812***			
Lasting success			0.2957*	0.2820*	0.4128**

One star (*) if p < 0.05, two stars (**) if p < 0.01, and three stars (***) if p < 0.001

As seen in Table 2, being a new entrant correlates negatively with with disruption of the market according to Christensen (-0.2880*), the opposite of what the theory suggests. This contradicts the aspects of Christensen's theory that rely on the distinction between incumbents and entrants.

Being a first mover correlates positively with the creation of new market (0.35737**), but negatively with the commoditization of the market (-0.3849**).

Worse performance correlates positively with success in the market (0.3958**), lasting success (0.31524*), and disruption of the market based on a more flexible interpretation (0.2529), but not with Christensen's strict definition.

Shifting the basis of competition correlates strongly with almost all measures of disruption: disruption of the market according to Christensen (0.4699***), disruption of the market based on a more flexible interpretation (0.5958***), creation of a new market (0.3472**), expansion of the market (0.3126*), commoditization of the market (0.3185*), self- disruption (0.2896*), success in the market (0.4715***), and lasting success (0.3992**).

The notion of 'basis of competition' is a more powerful concept than 'worse performance' in predicting disruption, however it requires more interpretative work (Nishimura, 2014; Dediu, 2012g; Christensen, Raynor, McDonald, 2015).

As expected Christensen's new market disruptive innovation correlates positively with the creation of a new market (0.5868***), and negatively with the commoditization of the market (-0.2366***). Likewise, Christensen's low-end disruptive innovation correlates positively with the commoditization of the market (0.6869***), and negatively with the creation of a new market (-0.3687**).

Being high-end correlates negatively with most measures of disruption. This raises doubts about the possibility of high-end disruption. However, the intent to self-disrupt correlates positively with effects of self-disruption in the market (0.7658***) and lasting success (0.2957*). This result tells us that the concept of self-disruption is promissory.

Radical innovation correlates positively with the creation of a new market (0.5620***), and is a predictor as powerful as Christensen's new market disruptive innovation. On the other hand, architectural innovation correlates positively with expansion of the market (0.5650***) and is its strongest predictor. Architectural innovation is also the strongest predictor of lasting success (0.4128**).

The correlation analysis gives Christensen's theory a very good score. Christensen's theory was controversial at its time for its counterintuitive findings, and today is still strongly criticized by many, however this research validates Christensen's theory. However, some unexpected results were found: being a new entrant does not contribute to disruption, radical innovation and architectural innovation explain things disruptive innovation alone cannot, and self-disruption is possible.

Phases of Disruption

Research has showed that the computing industry is rich in examples of products that lowered the performance in dimensions historically valued by costumers (Montoya and Kita, 2017). In the history of the computing industry the fast pace of improvement of Moore's law frequently generated gaps in which customer needs for raw computing were temporally over-served, and this created opportunities for innovations that temporally worsened performance. Companies were confident that Moore's law would bring improvements later.

In Christensen's model disruption takes place steadily. This might be the case for mature markets where the size of the market is known, however in immature markets disruption can take place at the same time that the market grows. This research found that Everett Rogers' concept of the technology adoption life-cycle (1962) and Geoffrey Moore's concept of the 'chasm' (Moore, 1991, 2001) offer a more detailed description of evolving markets than Christensen's theory. This model can be seen in Figure 3.

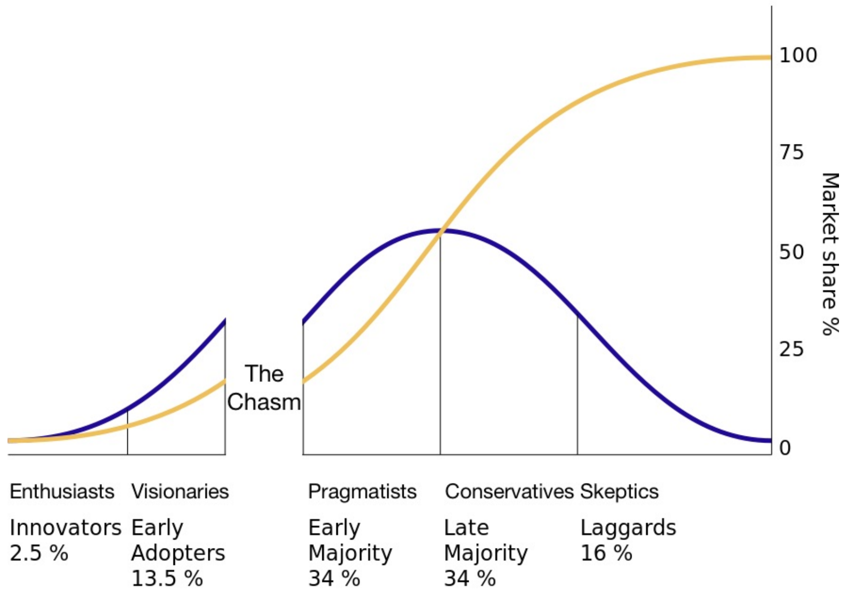

Figure 3: Rogers's technology adoption life-cycle and Moore's chasm (Moore, 1991).

Using historical analysis this research identified three different phases of disruption: 1) disruption by creation of a new market, 2) disruption by mainstreamization of the market, and 3) disruption by commoditization of the market. The timing of these phases can be seen in Figure 4.

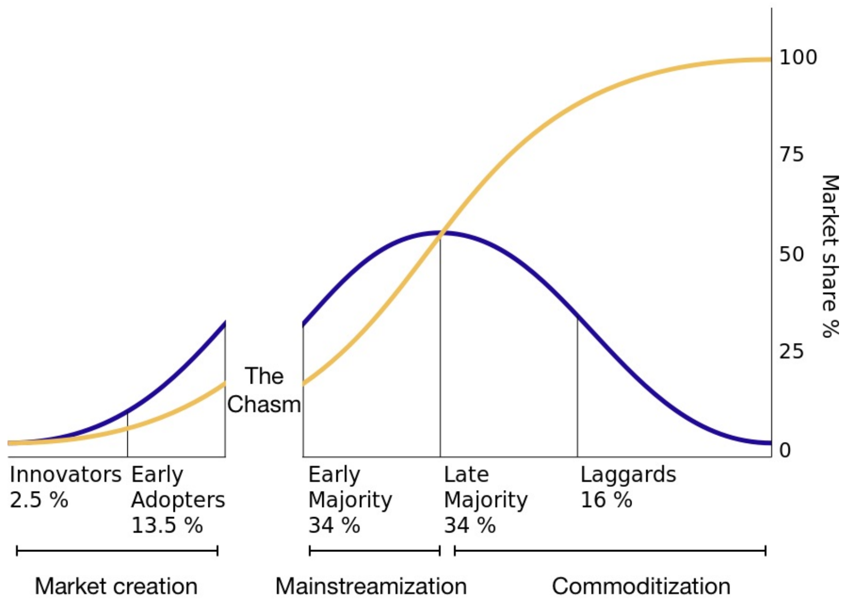

Figure 4: Three phases of disruption identified by this research.

Disruption by Creation of a New Market

The creation of a new market can be seen in the early stages of the personal computing and mobile computing industries respectively. Some examples in personal computing include: Altair 8800, Commodore PET, TRS-80, Atari 400 and 800, and Apple I and II. And some examples in mobile computing include: Newton, Palm, Windows CE, and BlackBerry. Without the companies who introduced the first products in new categories, these industries would not exist at all today. Many first movers were able to succeed at first, however not all of them succeeded for a long time.

Behind the first personal computers was a radical innovation, as defined by Giovanni Dosi (1982). The first commercial microprocessors in the early 70s (specially Intel 4004 and 8008), which incorporated the functions of the CPU on a single integrated circuit, allowed for a new market of cheaper and smaller computers.

Old incumbent companies (Olivetti, Hewlett-Packard, Commodore International) and young entrant companies (MITS, Atari, Sinclair Instrument, Apple) alike were able to enter the market and succeed in this early phase. There was no difference between incumbents and entrants as Christensen's theory predicts.

A similar pattern can be found in the emergence of personal digital assistants (PDA) and smartphones. Behind this new product category was also a radical innovation: low-power microprocessors in the early 90s (specially ARM), which enabled a new market of handheld computers.

Although the Newton was a flop for Apple and was discontinued, other companies' products where able to succeed in the early phase of the market, including Palm, Windows CE, and RIM's BlackBerry. These products were key in creating a new market and their success was considerable for a young market in the 90s, however they have been eclipsed by the huge growth of smartphones in the 2010s.

Disruption by Mainstreamization

After a first wave of products shows the viability of a new market, there is still uncertainty about the size of that market. A second wave of products expands the market to its full potential through mainstreamization. Some examples in personal computing include: Xerox Alto, Xerox Star, Macintosh, IBM PC, and Windows. And some examples in mobile computing include: iPhone and Android.

Mainstreamization is dependent on crossing Moore's chasm. According to Moore,

> whenever truly innovative high-tech products are first brought to market, they will initially enjoy a warm welcome in an early market made up of technology enthusiasts and visionaries but then will fall into a chasm, during which sales will falter and often plummet. If the products can successfully cross this chasm, they will gain acceptance within a mainstream market dominated by pragmatists and conservatives". (2001)

The path to crossing the chasm can be found in the development of a "whole product," or more precisely a "dominant design". According to Anderson and Tushman "a break through innovation inaugurates an era of ferment in which competition among variations of the original breakthrough culminates in the selection of a single dominant configuration of the new technology". (1990)

Henderson and Clark have tied the development of dominant designs to architectural innovation: "the reconfiguration of an established system to link together existing components in a new way" (1990). Joshua Gans (2016) has been a promoter of connecting this research to Christensen's theory. This research found that the mainstreamization of the personal and mobile computing markets was generated by the emergence of dominant designs through architectural innovation.

In the case of personal computing, the first personal computers such as the Altair 8800 and Apple II were products catering to technology enthusiasts in the 70s. The IBM PC targeted the mainstream market in 1981, but it was still difficult to use. The dominant design that helped cross the chasm in personal computing was the result of an architectural innovation in the mid 1980s: the development of the Graphical User Interface (GUI).

While the level of originality of Xerox, Apple, and Microsoft in developing the GUI can be argued – as several lawsuits attest the accusations of copying are not black and white – from an academic point of view all three companies deserve to be credited for the early adoption of the GUI and helping the mainstreamization of the personal computing market. On the other hand, companies that were too late never won a foothold in the market. After the consolidation of the market, no alternative computing platforms were able to emerge: OS/2, NeXTSTEP, BeOS, AmigaOS 4, all failed.

This same pattern can be found in the mobile computing industry. Architectural innovation at Apple resulted in the iPhone, which helped define a dominant design for smartphones in 2007. This dominant design established multi-touch as the default interface of smartphones. Previous devices like the Newton and Palm introduced touch interfaces before, but they used a stylus and maintained old desktop metaphors that failed to pass the test of being a new dominant design.

Companies that were late in adopting the dominant design introduced by the iPhone stumbled in the market, such as RIM, Nokia, and Microsoft. In contrast, Google who quickly adopted the iPhone's design for Android in 2008 was successful.

Disruption by Commoditization

Disruption by commoditization takes places after no unforeseen growth of the market is expected. Sales come from the late majority of customers and the replacement cycle, and growth for a company comes at the expense of competitors' market share. Some examples in personal computing include: PC manufacturers like Compaq, Hewlett-Packard, Dell, Asus, Acer, and Lenovo. And some examples in mobile computing include: Android vendors like HTC, Samsung, and Xiaomi.

The main driver of commoditization are "efficiency innovations" that get rid of inefficient structures, unnecessary intermediaries, and reduce costs. As defined by Christensen, efficiency innovations "help companies make and sell mature, established products or services to the same customers at lower prices. Some of these innovations are what we have elsewhere called low-end disruptions, and they involve the creation of a new business model". (2014)

In the personal computing industry lowering performance was a common technique thanks to Moore's law. Because of this lowering performance had to come accompanied of other business innovations to disrupt the market. Entrants did not introduce efficiency innovations when they joined the market, instead they did it later as incumbents once they gained enough inside knowledge of the inefficiencies that could be fixed in their industry.

Examples of efficiency innovations in personal computing in the late 90s and 2000s include Hewlett-Packard's merge and acquisitions, Dell's just-in-time manufacturing and direct sales online, and Lenovo's leverage of the shift of the computing industry supply chain to Asia.

As for mobile computing, some of the examples are Samsung's vertical integration in manufacturing, and Chinese manufacturers Xiaomi, Vivo, and Oppo's model of rapid hardware iteration that leverages their closeness to the supply chain.

The cases of disruption by commoditization show us a picture that resembles the closest Christensen's understanding of disruption: market changes coming from low-end and business models innovations. However, a more detailed analysis reveals significant discrepancies, such as disruptors being more frequently incumbents instead of entrants.

Conclusions

This research found a significant statistical correlation between disruption and technologies that lower performance, just as suggested by Christensen. An even stronger correlation between disruption and technologies that shift the basis of competition was also found, however we caution that identifying these shifts can be highly subjective (Nishimura, 2014; Dediu, 2012g; Christensen, Raynor, McDonald, 2015).

Overall, the quantitative analysis made on this research validates Christensen's theory and most of its concepts, except for the distinction between incumbents and entrants, whose relation to disruption was the opposite of what the theory predicts. Managers, especially those at incumbent companies should be skeptic of Christensen's advice.

Concepts from the pluralistic interpretation of disruption also had mixed results: no evidence was found for high-end disruption, however self-disruption was found to be a promissory concept. Other innovation types like radical innovation, and architectural innovation also were shown to be useful in the study of more discrete market effects associated to disruption.

Further qualitative analysis helped to improve the understanding of disruption from a macro perspective. Using historical evidence this research found three phases of disruption according to the maturity of the market and proposed an original categorization: 1) disruption by creation of a new market, 2) disruption by mainstreamization of the market, and 3) disruption by commoditization of the market.

We also found a linkage between these phases and three different patterns of innovation depending on its type: 1) radical innovations tend to create new markets, 2) architectural innovations define the dominant designs which are needed for the mainstreamization of a market, and 3) efficiency innovations reduce costs and get rid of inefficient structures commoditizing the market.

Managers should be aware of these differences in order to pursue the right type of innovation in each market phase. In order to remain successful as a market evolves companies need to adapt and shift their strategies. Disruption is a concept bigger than disruptive innovation, and there is still place for radical innovation and architectural innovation. Further studies could explore other innovation types.

Finally, this research tended a bridge between disruption theory and separated bodies of research like Geoffrey Moore's chasm. We believe that the findings and contributions of this research have deep implications for disruption theory that go beyond the case study of the computing industry. Further research in other industries would be the next step for testing and improving these contributions.

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