SIMON DEN UIJL

# The Emergence of De-facto Standards

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Het tot stand komen van markt-standaarden

Thesis

to obtain the degree of Doctor from the
Erasmus University Rotterdam
by command of the
rector magnificus

Prof.dr. H.A.P. Pols

and in accordance with the decision of the Doctorate Board.

The public defense shall be held on
Thursday, January 15th, 2015 at 13:30 hours

By

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ERASMUS UNIVERSITY ROTTERDAM

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Internet: http://www.erim.eur.nl

**ERIM Electronic Series Portal:** http://hdl.handle.net/1765/1

**ERIM PhD Series in Research in Management**, 328
ERIM reference number: EPS-2014-328-LIS
ISBN 978-90-5892-381-3


Design: B&T Ontwerp en advies www.b-en-t.nl

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to Marcia and Anna

## Acknowledgements

I hereby present you my dissertation. This is the result of a long and inspiring journey, which started in 2006. Throughout the years, I found my research very satisfying as it taught me a lot about something I am very passionate about; to understand technological progress, and how some technologies are massively adopted by society whereas others are not. In my professional career I strive towards making inventions successful, and my research enabled me to add valuable insights from the academic field to my hands-on experience. From the start, I decided to write this dissertation next to my full time job. Because of this decision, the process was not always easy, but it gave me great appreciation of the end result which lies here before you. I would like to express my gratitude to several people, without whom I could not have written this dissertation.

I would first like to thank Dr. Ir. Henk J. de Vries for offering me the possibility to write this PhD thesis. Henk, I have always much enjoyed our discussions, and I believe over time our relationship has evolved into something that can best be described as friendship. Thanks also for your coaching, the numerous hours that you spent reviewing my work, and being co-author in all of my papers. It has been a pleasure to work with you.

Secondly, I would like to thank Prof. Dr. rer. pol. Knut Blind. I have always greatly valued our discussions and your feedback. Thanks for coaching me and reviewing my work. I had hoped for more opportunities to publish papers together, but I believe we will find a way to collaborate in the future.

Thirdly, I would like to thank my co-authors of the papers that were published in Organization Studies and California Management Review, Prof. Dr. Ir. Jan van den Ende, Dr. Geerten van der Kaa, and Dr. Ir. Ing. Rudi Bekkers. I would especially like to thank Jan for demonstrating how to write a good paper.

To all the students that I have worked with over the years, I would like to say that it has been a pleasure to coach you, collaborate with you and grade your thesis. I would especially like to thank Deniz Bayramoglu and Chris Ismyrloglou for working with me on researching the cases of MP3 and SA-CD respectively. I hope we will stay in touch for many more years and wish you all the best in your careers.

I would like to thank my current employer, Royal Philips, and especially Dr. Ir. Maurice Maes, for providing me with the opportunity to work in the field of standardization and being very supportive of my academic efforts. In addition, I would like to thank my previous employer, the Energy research Centre of the Netherlands, and in particular Dr. Ir. Kees van der Klein, for supporting my academic efforts.

I would like to thank all people that I have had the pleasure to interview for my case studies. I much appreciate that you made time to share your insights. These have been invaluable to understand the dynamics of the emergence of de-facto standards.

I would like to thank my parents, Piet and Gaby, for stimulating me to pursue this dissertation, for being such great examples, and showing that everything is possible with hard work. I would like to thank my brother, Michaël for his ongoing support. I would also like to thank my parents in law, Nico and Bwee for always showing an interest in my research and reading my papers.

Finally, I would like to dedicate this dissertation to my wife Marcia and our daughter Anna. I love you both very much and greatly appreciate that you both tolerated me to invest so much time in my dissertation. Now that the thesis is finalized, I hope to spend much more time together as a family and enjoy our life together.

With warm regards,

Simon den Uijl

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# Chapter 1 - Introduction

Examples of de-facto standards can be found in everyday technologies, for example the dial of a watch, the QWERTY keyboard, and the combustion engine powered automobile. The academic field studying de-facto standards is merely a few decades old, but its increasing relevance in the fields of technology and innovation management, and economics can be attributed to the advent of the industrial revolution and industrial capitalism.

The industrial revolution marked a period of great technological progress, spawning many new complicated products such as the steam locomotive, the telephone, typewriters, electric lighting, and the automobile. Unlike conventional economic theory (centred around resource-based parts of the economy as agriculture, bulk-goods production and mining), consumers of these knowledge based products benefitted from being part of a group that used the same technology.[1] Over time, knowledge based industries have become a substantial part of the economy and new economic theories complemented the old in order to provide insights in the dynamics of these new industries. The pioneer of these new economic theories, Joseph A. Schumpeter, attributed innovation as a central element in capitalism. In his view, capitalism is by nature an evolutionary process.[2] The fundamental impulse that sets and keeps the capitalist engine in motion comes from new consumers' goods, new methods of production or transportation, new markets, and new forms of industrial organization that enterprises create. This ongoing change is a process of ‘Creative Destruction’, whereby the economic structure is revolutionized from within, incessantly destroying the old one and creating a new one. Other economists, building on Schumpeter, have noted that these industry revolutions are caused by shifts in context (e.g., consumer or industry needs)[3] and in technological paradigms.[4] When a paradigm shift occurs, several technological options compete for adoption. At some point during this competition a shake-out occurs, and one technology emerges as the de-facto standard.[5]

An organization that is able to establish its technology[6] as the de-facto standard can earn near-monopoly rents and may dominate a product category through several product generations. However, when an organization sponsors a technology that does not become the de-facto standard, it may be forced to forfeit the capital, learning, and brand equity invested in its technology. In addition, it may lose substantial market share to a new entrant or even find itself locked out of the market. Especially market leaders are prone to this. They are often among the first to identify a radical innovation but choose to bypass the opportunity because it cannibalizes its existing market. This ‘innovator’s dilemma’[7] clears the way for new entrants to catch the next wave of industry growth, often leading to dramatic changes in industry leadership. Competitions for the de-facto standard are high-stakes games, and these ‘winner-take-all’ markets demonstrate very different competitive dynamics than markets in which many competitors can coexist relatively peacefully, as they often have a single tipping point which shifts market adoption to one particular technology.[8]

Increasingly, companies compete on platform technologies that bring together groups of users in two-sided networks.[9] In industries governed by platform technologies, it is common to see one emerging as the de-facto standard because they are especially prone to network externalities (i.e. the benefit that can be derived from the technology increase exponentially with the number of users). These network externalities can cause a market to tip towards one technology.

## 1.1 Standards, dominant designs and platforms

In the management literature, scholars from different disciplines (e.g., evolutionary economics, industrial organization economics, institutional economics, and strategic management) have examined standards, as well as standards-based competitions, pursuing research into concepts such as 'dominant designs' and 'platforms'.

The phenomenon captured by the concept of standards is complex, because it involves both macro (environmental) and micro (firm) level aspects, and standards both drive and are driven by the actions of firms and/or industry associations. The complexity is reflected in the significant volume of research in recent decades, in which scholars pursued this broad phenomenon from their own disciplinary perspectives. Thus the richness of the literature came at the cost of the fragmentation caused by the inconsistent use of terms and the lack of consensus (or standardization if you will) among scholars operating at different levels of analysis or treating standards sometimes as exogenous and sometimes as endogenous variables.

### *1.1.1. What is a standard?*

A standard can broadly be defined as the consensus of different agents to do certain key activities according to agreed-upon rules.[10] De Vries[11] provides a more elaborate, complementary, definition; an approved specification of a limited set of solutions that determine features of different interrelated entities in a way that they harmonize with each other, prepared for the benefits of the parties involved, balancing their needs, and intended to be used repeatedly during a certain period. However, it is helpful to distinguish among several kinds of standards; compatibility standards, quality standards, safety standards, and measurement standards (i.e. the metric system).[12]

This dissertation focuses on compatibility standards, which are *a set of technical specifications that define the interface between two or more elements that are interoperable*, e.g., a plug and a socket, or a transmitter and a receiver.[13] A compatibility standard is often referred to as technology standard, which makes sense considering that technology can be defined as the specifications for a product or a process which when built will 'work'.[14] These standards create value by either allowing interconnectivity directly between products or facilitating the provision of complementary assets.[15] Compatibility standards assure the user that an intermediate product or component can be successfully incorporated in a larger system comprised of closely specified inputs and outputs. The benefits appear on both the demand- and supply side. On the demand side, consumers can benefit from direct network externalities, and complementary goods (e.g. software) become cheaper and more readily available.[16] On the supply side, producers can harness economies of scale in manufacturing, and the cost of new product development can be reduced by utilizing a modular product architecture consisting of numerous components and subsystems that are provided by different suppliers that conform to the same compatibility standard.

Another, much related concept, concerns the standard setting process; how does something become 'a standard'. While studying standards-setting processes, David and Greenstein[17] differentiated between de-facto and de-jure standards.[18]

De-jure standards refer to the acceptance of a set of specifications that has been developed through a formal process by standard development organizations,[19] sometimes mandated by a governmental agency that has regulatory authority. De-facto standards are established by widespread acceptance through market competition involving products embodying unsponsored or sponsored standards. De-facto standards emerge spontaneously, through an undirected competitive process in which many consumers[20] exercise their choice among a potentially wide array of alternatives. Some academics[21] also use the term 'de-facto industry standard'.

This dissertation focuses on de-facto standards. Over the last 30 years, de-facto standards have emerged in many different industries (a non-comprehensive overview is shown in Figure 1), often sponsored by individual firms or industry consortia.

| Overview of de-facto standards, emerged in 1980-2010 | | |
|---|---|---|
| ***Market*** | ***Product category*** | ***Technology*** |
| Consumer electronics | Video | VHS |
| Consumer electronics | Video | DVD |
| Consumer electronics | Video | Blu-ray |
| Consumer electronics | Audio | CD |
| Consumer electronics | Audio | MP3 |
| Video Game Consoles | 8-bit | Nintendo Entertainment System |
| Video Game Consoles | 32/64-bit | Sony PlayStation |
| Networking and communications | Wireless LAN | Wi-Fi vs. HomeRF |
| Networking and communications | Cellular telephones | GSM |
| Networking and communications | Cellular telephones | W-CDMA/UMTS |
| Computers and operating systems | PC operating systems | MS-DOS |
| Computers and operating systems | PC operating systems | Windows |
| Application software | Word processors | Word |
| Application software | Spreadsheets | Excel |
| Internet client software | Web browsers | Internet Explorer |
| Web-based application software | Search engines | Google |
| Web-based application software | Social networking | Facebook |

*Figure 1: Overview of de-facto standards (adopted from Gallagher and West[22])*

*1.1.2. Dominant designs and standards wars*

When the concept of de-facto standards was introduced, it overlapped with the concept of 'dominant designs' that was introduced a decade earlier by Abernathy and Utterback.[23] While studying various industries with complex products,[24] they found that the nature of technological innovation changes over time. In the early period of a new industry, companies focus on product innovation and implement different product architectures (reflecting choices from technological possibilities) that compete in the market. Over time, the market solidifies a preference of a design over its technological alternatives, marking the emergence of a dominant product design. The focus shifts to process innovations, and products become highly 'standardized' in order to obtain production economies. Interestingly, this dominant design is often synthesized from individual technological innovations that have been introduced independently in prior products. When a paradigm shift occurs in an industry with complex products, innovations on different levels of a product design hierarchy (Figure 2) [25] compete for market adoption. After Abernathy and Utterback identified the phenomenon of dominant designs, others followed to refine its definition (e.g. Tushman and Anderson[26], Utterback and Suarez[27]). Anderson et al.[28] define a dominant design as a product or system is considered dominant if it acquires more than 50% market share of the product category and maintains it for four years in a

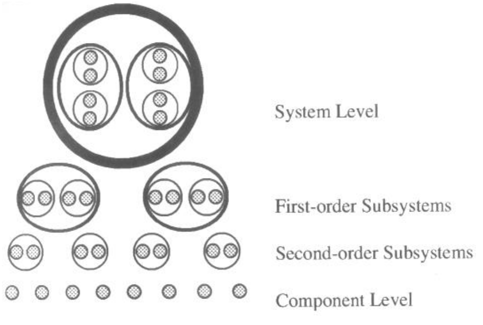


*Figure 2: Overview of product hierarchy (Source: Murmann and Frenken, 2006)*

row. Srinivasan et al.[29] provide an overview of definitions and adopt one that is in line with Christensen et al.;[30] a dominant design emerges in a product category when one product's design specifications (consisting of a single or a complement of design features) define the product category's architecture. For this dissertation, the following definition is used: *a product or system is considered dominant when its design specifications (consisting of a single or a complement of design features) define the product category's architecture (i.e. >50% market share)*. Similar to the concept of de-facto standards, the emergence of a dominant design is a market driven process whereby alternatives compete for adoption, and this eventually leads to convergence in the industry whereby design specifications (consisting of a single or a complement of design features) start defining a product category's architecture.[31]

Clymer and Asaba[32], and Durand[33] note that the work of Abernathy and Utterback may be the most seminal work on strategic management in technological innovation from that period, and the concept of a dominant design has become an essential building block in the innovation management literature. Due to the significant overlap, many researchers have used the terms "industry standard" and "dominant design" interchangeably.[34] In addition, some have used alternate terms for the same concept. Cusumano et al.[35] introduced the term 'dominant standard' and Schilling[36] and Hill[37] used this interchangeably with the term 'industry standard'. In a similar avenue, Shapiro and Varian,[38] and Besen and Farrell[39] focus on 'standard wars'; the competition between incompatible technologies for market dominance, and between companies to establish their technology as the industry standard. Finally, Christensen et al.[40] use the term 'architectural standardization' and use this interchangeably with 'dominant architectural characteristics'.

The overlapping use of the terms in literature has disguised the heterogeneity of the phenomena; while a dominant design is the 'industry' or 'de-facto' standard, an industry standard is not always a dominant design, but can also be a compatibility or safety standard. Some academics have made efforts to distinguish the phenomena (Funk[41], Srinivasan et al.[42], and Gallagher[43]). Although Funk and Srinivasan et al. agree that the concepts of industry standards and dominant designs are very similar, they emphasize that compatibility standards are often elements of dominant designs. This is illustrated by referring to mobile phone telephony (whereby phones and base stations can have dominant designs, but must work with the same air-interface standard) and computers (which can have a dominant design, but require standards that define the interface between hardware and software). In addition, Srinivasan et al. note that compatibility standards serve a functional purpose, separate from market acceptance, whereas market acceptance is an integral aspect of a dominant design. Gallagher complements this by stating that firms frequently engage in discussions over standards before products are introduced because of their importance in facilitating consumer adoption of products, while the architecture of a dominant design can only be known after it has been adopted and it is rarely the subject of supra-firm deliberations. Since a compatibility standard can be identified before it is established, this enables managers to act strategically to benefit from the standard. Gallagher supports Funk and Srinivasan et al. that one or more compatibility standards can be encompassed in a dominant design, however he uses the concepts of compatibility standard and industry standard interchangeably. He makes the point that de-facto standards arise as a result of market competition between compatibility standards. However, the winner of this competition rarely reflects the synthesis of attributes seen in dominant designs.

In this dissertation, we define the relationship between the concept of standards and dominant designs as follows: products or systems that achieve a dominant position can 1) adhere to standards regarding safety, quality, etc., 2) use components or interfaces that are regarded as de-facto standard (such as the

QWERTY keyboard), 3) play an important role in establishing new standards (as happened in the case of electricity supply[44]), and 4) itself become an industry standard (as with the IBM personal computer architecture).

### *1.1.3. Platforms*

With the trend of modular product architectures, the concept of 'platforms' (often used interchangeably with 'industry platform' and 'technology platform') has recently become popular. When Wheelwright and Clark[45] introduced the term 'platform product' (i.e. products that meet the needs of a core group of customers but designed for easy modification into derivatives) in their seminal work on product development, there was little overlap with the concepts of 'de-facto standards' or 'dominant designs'. However, the concepts became intertwined as research continued towards 'platform technologies'[46] and 'platform leadership'.[47] Industrial economists adopted the term 'platform' to characterize products, services, firms or institutions that mediate transactions between two or more groups or agents.[48] Their work broadened the empirical scope to include on-line recruitment and realtors (an overview of 'platform technologies' is provided by Figure 3).

| Networked market | Side 1 | Side 2 | Rival platforms |
|---|---|---|---|
| *Rival providers of proprietary platforms* | | | |
| PC operating systems | Consumers | Application developers | Windows, Macintosh |
| Online recuitment | Job seekers | Employers | Monster, Careerbuilder |
| Web search | Searchers | Advertisers | Google, Yahoo |
| Video games | Players | Developers | PlayStation, Xbox |
| *Rival providers of shared platforms* | | | |
| Wi-Fi equipment | Laptop users | Access points | Linksys, Cisco, Dell |
| DVD | Consumers | Movie studio's | Sony, Panasonic, Philips |
| Gasoline-powered engines | Car owners | Fuelling stations | BP, Shell, Exxon |

*Figure 3: Overview of platform technologies (adopted from Eisenmann et. al, 2006)*[49]

Recent work by Gawer[50] aims to clarify the different facets of platforms. In this work, a platform is defined as a product, technology or service that consists of core components and interfaces (often codified into technical specifications or compatibility standards to facilitate interoperability) which allow the core components to operate with complements as one system.[51] These complements often exhibit high variety and may change over time. Gawer notes that platforms are designed and used inside firms, across supply chains, or as industry platforms.[52] For this dissertation, the focus is on industry platforms, which serve as foundations upon which other firms can build differentiating and complementary products. Examples include the Compact Disc, VHS and DVD. Industry platforms bring together groups of users in two-sided networks; the supply network (which provides complementary products) and the demand network.[53] The platform's value to a user depends on the size of the network on the other side,[54] and jump-starting the network externalities requires solving a 'chicken-and-egg problem'.[55] For this dissertation, platforms are defined as *technological systems that facilitate the interaction between a demand and supply network*.

Although a platform does not necessarily represent technological dominance, its modularity in design increases customers' expectation for interchangeability of components across compatible platforms.[56] Similar to dominant designs, platforms may occur on multiple levels of a product's architecture: a personal computer is a platform, just as its operating system.

### *1.1.4. Integral view on the different facets*

The previous sections have shown that the field of de-facto standards is marked by overlapping concepts that highlight different facets of the phenomenon. *I define a de-facto standard as a compatibility standard, platform, or product design specification that has obtained widespread acceptance (>50% market share in terms of worldwide yearly unit sales) through market competition.* Figure 4 shows the three concepts, notes their main characteristic, and illustrates the overlap of the concepts based on several well known de-facto standards.

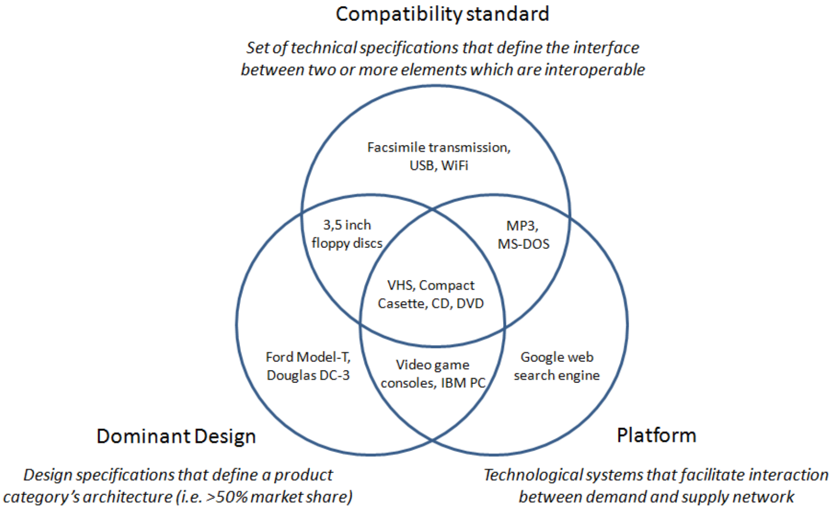


*Figure 4: Overlap between concepts of compatibility standards, dominant designs and platforms*

As the de-facto standard examples show, some incorporate all three facets while others incorporate only one or two. For example, during a particular period the Compact Disc was the dominant design for audio storage and distribution, but it could also be characterized as a compatibility standard and a platform technology. Previous studies have found that the market adoption of compatibility standards, platforms and product design specifications is governed by concept-specific dynamics. For example the two-sided network externalities which are experienced in industries with platform technologies. Therefore, lessons from the market adoption of MP3 cannot simply be applied to for example the case of the Ford Model-T.

The three concepts can also be simultaneously applicable to different levels of a product's architecture; in the case of automobiles, at some point the Ford Model-T became the dominant design, gasoline powered engines are platforms that facilitate the interaction between fuel stations and car owners, and the opening of the gas filler hose adheres to physical requirements described in a compatibility standard.

The focus of this dissertation is on de-facto standards which can be characterized by two or three of the definitions for dominant design, compatibility standard or platform (i.e. the four middle sections of Figure 4). Considering that a compatibility standard, platform or a products' design specifications can only be referred to as de-facto standard after it has gained widespread acceptance, in the remainder of this dissertation I will refer to these simply as 'technology' when widespread acceptance has not occurred yet.

## 1.2 The emergence of de-facto standards

As has become apparent in the previous section, a de-facto standard emerges as outcome of a competition between technologies, whereby the winner is selected by the market. This section provides an overview of the research on the emergence of de-facto standards. Recently, Narayanan & Chen[57] and Van de Kaa et al.[58] have provided a comprehensive overview of the literature regarding the emergence of de-facto standards. As the approaches in both studies overlap, I merged their frameworks to structure my overview.

The emergence of de-facto standards (albeit compatibility standards, platforms, or dominant designs) has been studied from multiple perspectives and disciplines. In order to structure these perspectives, we adopt the organizing framework of Astley and Van de Ven,[59] as suggested by Narayanan & Chen. Astley and Van de Ven developed a two-dimensional framework to integrate the fundamental approaches of organizational theorists. This framework is based on two dimensions, 1) the level of analysis (macro versus micro) and 2) the deterministic versus voluntaristic nature of firms. The level of analysis differentiates between theories on an industry level (macro) and on a single firm level (micro). The second dimension differentiates theories that propose that phenomena are determined by exogenous forces and those that propose that phenomena are created and driven by endogenous forces. Crossing these two dimensions leads to four "central perspectives": 1) natural selection, 2) system structural, 3) strategic choice, and 4) collective action. These central perspectives match with the academic disciplines identified by Van de Kaa et al. The natural selection view has been advocated by evolutionary economists, which regard the survival of a firm as the result of a process of natural selection. The system-structural and collective-action views have been advocated by scholars in the field of industrial economics, which have studied the dynamics of the emergence of de-facto standards and the ability of firms to adapt to technological changes. The strategic-choice view has been advocated by institutional economists, which have focused on strategic behaviors of firms to establish their technology as the de-facto standard. Figure 5 shows the framework of Astley and Van de Ven, and the allocation of the academic disciplines.

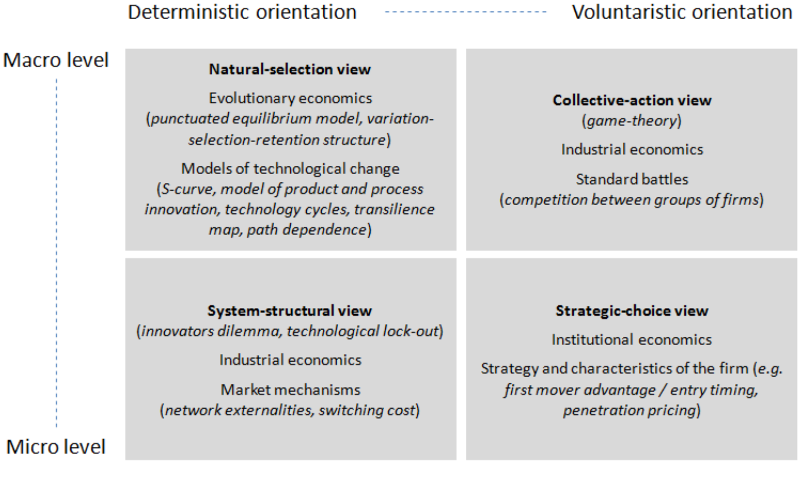


*Figure 5: Organizing framework of Astley and Van de Ven, and allocation of academic disciplines*

In the upcoming sections, we first describe the natural-selection view, which views the emergence of a de-facto standard as an exogenous process along the line of thinking of the punctuated equilibrium model. Subsequently, we take the system-structural perspective to show the influence of market mechanisms (e.g. network externalities) and the ability of firms to adapt to technological change. Then we move over to the collective action view, to show how firms can collaborate (e.g. game theory) and how groups of firms compete to establish a de-facto standard. Lastly, we discuss the strategic-choice view, that takes a resource and capability perspective and argues that innovation is an endogenous process whereby firms can shape opportunities.

*1.2.1. Evolutionary economics and the natural-selection view*

Evolutionary economists have provided several models of technological change. In these models, two concepts from evolutionary theory appear to be particularly relevant: 1) the punctuated equilibrium model, and 2) the variation-selection-retention structure.[60] Punctuated equilibrium characterizes biological evolution as extended periods of stasis, followed by periods of short, feverish evolutionary change.[61] Mokyr[62] noted the similarity, pointing out that technological progress can be characterized by long periods of incremental improvement, interrupted by an event of radical innovation. Concerning the second concept, Dosi[63] notes that an industry's economic and social environment first selects the 'direction of the mutation' (i.e. the technological paradigm) and then selects among mutations within that paradigm in a 'Darwinian manner' (i.e. the market functions as a system of rewards and penalizations, leading to selection amongst technological innovations).

One of the models supporting the punctuated equilibrium model, is the classic 'S' curve of technology development (Jantsch[64] and Foster[65]). As illustrated by Figure 6, this model proposes that technology adoption typically follows a business cycle represented by an S-curve.[66] During the early phase a new technology is introduced into the market but its adoption is limited to a small group of early adopters and small niche markets. As the product gains ascendancy, new capabilities are introduced and refined with the goal of meeting the needs of the broadest possible segment of mainstream users. During this middle phase a de-facto standard begins to emerge, winning the allegiance of the market place. The de-facto standard in turn allows heightened competition as new entrants realize opportunities for further innovation based on cost and scale as well as product performance. This is the period of rapid and greatest growth as a technology matures and reaches the mainstream. During the final phase the product reaches market saturation and hits a plateau. As the market plateaus incumbent firms are increasingly challenged to realize incremental innovation while maintaining market advantage through a variety of management strategies. At one time, a new technology is introduced, which replaces the old technology. At a point in time, the new technology also reaches maturity, and inevitably faces extinction when replaced by another technology.

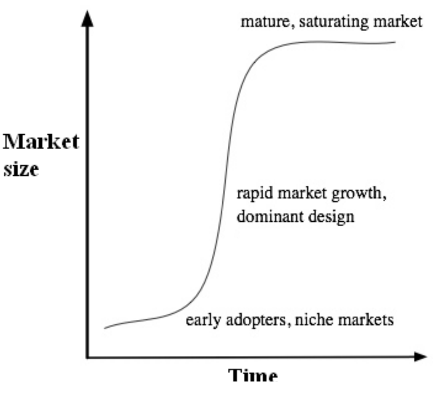

*Figure 6: S-curve of technology adoption (Source: Foster, 1986)*

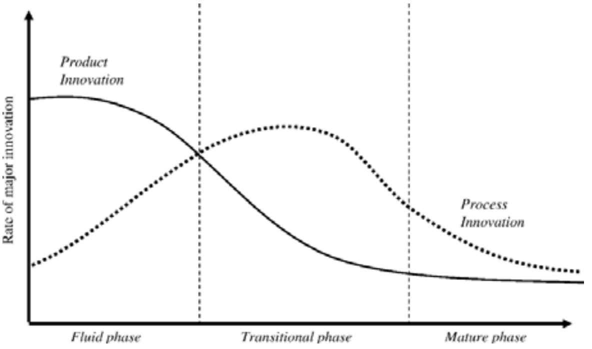


*Figure 7: Model of product and process innovation (Source: Utterback, 1994)*

The S-curve model is complemented by the model of product and process innovation of Utterback and Abernathy.[67] Their model[68] (Figure 7) shows how the character of technological innovation changes over time. Utterback and Abernathy argue that in the formative years of a technological innovation (the fluid phase), there is considerable experimentation with product design and operational characteristics. The phase is characterized by high product innovation, with much less attention given to the processes by which products are made. New product technology is often crude, expensive and unreliable, but it is able to fill a function in a way that is highly desirable in some niche markets. The period of fluidity typically gives way to a transitional phase in which the rate of major product innovation slows down and the rate of major process innovations speeds up. The basis of competition shifts from performance and technological characteristics to price and cost considerations. At this point, product variety is superseded by standard designs (i.e. dominant design or de-facto standard) that have proven themselves in the market as best satisfying user needs.

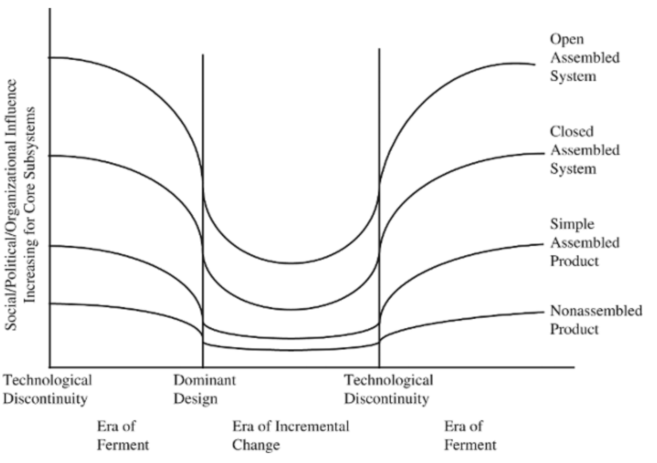


*Figure 8: Level of organization and inter-organizational impact of technology cycles (Source: Tushman and Rosenkopf, 1992)*

Building on Abernathy and Utterback's dominant design concept, and the related model of product and process innovation, Teece[69] and Tushman and Anderson[70] define two phases in a product/industry life cycle. The first is the phase before the dominant design, which Teece refers to as the 'preparadigmatic design phase' and Tushman and Anderson refer to as the 'era of ferment'. According to Anderson and Tushman,[71] this phase is characterized by two distinct selection processes: competition between technological regimes and competition within the new technical regime. The second is the phase after the dominant design, which Teece refers to as the 'paradigmatic design phase', and Tushman and Anderson refer to as the 'era of incremental change'. Anderson and Tushman state that during this phase the selected technical regime evolves through relatively long retention periods marked by incremental technical change, which may be disrupted by technological breakthroughs. Complementing these views, Tushman and Rosenkopf[72] define technology cycles comprised of four components; technological discontinuities, eras of ferment, dominant designs, and eras of incremental change (Figure 9). In addition, they argue that the organizational and inter-organizational impact of technology cycles differs with the complexity of the product, whereby they differentiate between non-assembled products, simple assembled products, and complex products which can either be a closed or an open system (illustrated by Figure 8).

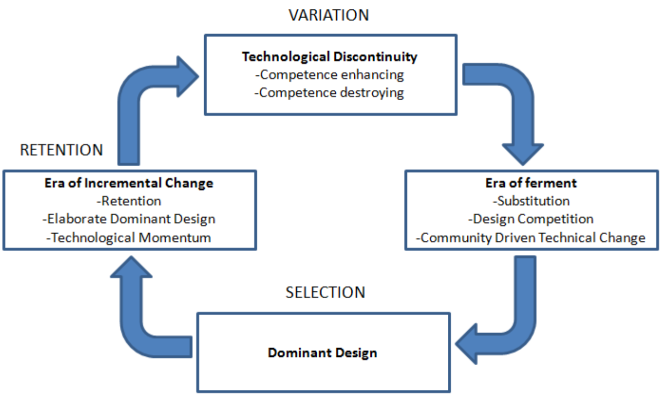


*Figure 9: Technology cycles (Source: Tushman and Rosenkopf, 1992)*

But when is an innovation considered a technological breakthrough? Abernathy and Clark[73] propose that the competitive significance of an innovation depends on what it does to 1) the value and applicability of established competence (competence destroying innovations render obsolete the expertise required to master the technology that it replaces), and 2) the linkage to the market/customer. By combining these two aspects into a two-dimensional diagram called the 'transilience map' (Figure 10), they derive four different categories of innovations; architectural innovations, revolutionary innovations, niche creation innovations, and regular innovations. An architectural innovation departs from established systems of production, and in turn opens up new linkages to markets and users. These innovations lead to the creation of new industries (e.g. xerography or radio) as well as the reformation of old ones by re-defining the basic configuration of a product or process. Revolutionary innovation is innovation that disrupts and renders established technical and production competence obsolete, yet is applied to existing markets and customers. An example is the closed steel body that came to dominate the car industry in the 1920-1930s. A 'niche creation' innovation concerns opening new market opportunities through the use of existing technology, while conserving and strengthening established designs of technical systems. For example, the combination of light weight earphones and a portable cassette player in Sony's Walkman used established technologies to create a new niche in personal audio products. Regular innovations involve change that builds on established technical and production competence and is applied to existing markets and customers. Although the changes involved in these innovations may be minor when examined individually, they cumulatively have a great effect on lowering product cost, and increasing reliability and performance. Clark[74] adds that a dominant design marks the transition from an "architectural phase" wherein fundamental characteristics are defined, to a "regular phase" where the established technical and market linkages are strengthened. We find that, given the broader notion of de-facto standards, architectural,

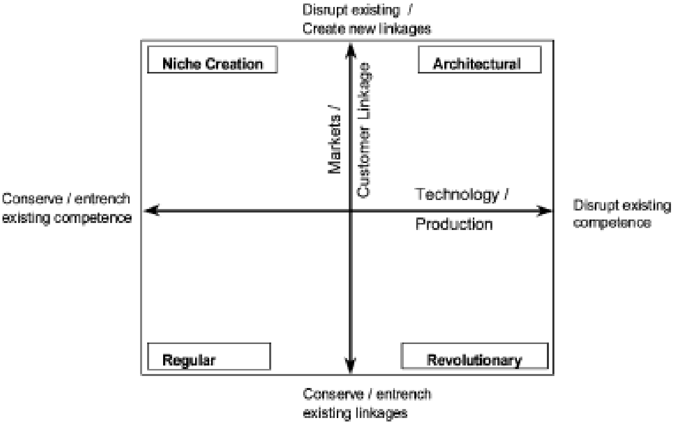


*Figure 10: Transilience map (Source: Abernathy and Clark, 1985)*

revolutionary and niche-creation innovations are all capable of disrupting equilibrium and can lead to the emergence of a new de-facto standard.

The evolutionary 'variation-selection-retention' structure is reflected in the theory of path dependency. Sydow et al.[75] distinguish three phases in the process of creating path dependencies (Figure 11):
1) The pre-formation phase wherein the range of options in the choice of a solution is broad;
2) The formation phase wherein self-reinforcing processes narrow the range of options, and the process becomes partly irreversible – a path is evolving;
3) The lock-in phase. The dominant decision pattern only leaves room for very limited change, this pattern becomes deeply embedded in organizational practice and is replicated.

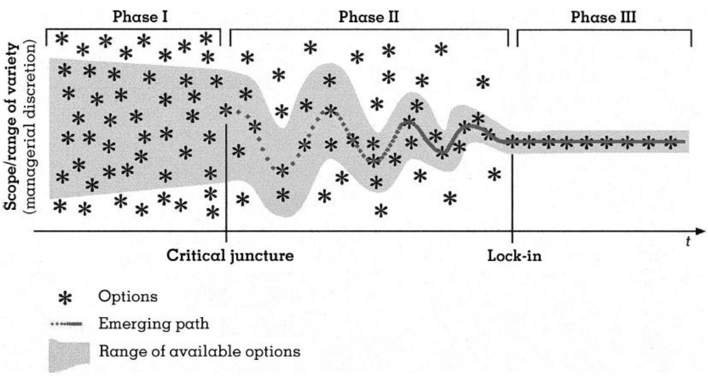


*Figure 11: Three phases of path dependency (Source: Sydow et al., 2009)*

The most prominent example of technological path dependence is the QWERTY keyboard. The QWERTY keyboard has retained its position as de-facto standard for over 100 years, while the technical rationale of the QWERTY lay-out (mitigating typebar clashes) has long been gone and more efficient alternatives are available. David[76] explains this as the result of a path-dependent process which has been subject to network externalities and technological lock-in. In the following sections, we will go into more detail about these concepts.

We finalize the natural selection view by noting that the selection mechanism itself not necessarily converges an industry to a single solution, but rather towards a duopoly or oligopoly. Examples include the personal computer and video game console industry.[77] According to Shapiro and Varian[78] technological competitions can end in a truce (whereby two technologies coexist peacefully together), a duopoly/oligopoly (whereby two or multiple technologies battle toe-by-toe), or a fight to the death. The coexistence of competitive technological systems is influenced by regulatory regimes, strong divergence of customer need or technological functionality, lack of technological selection criteria[79], weak network externalities, and the industries' appropriability regime.[80] In a study on 63 office products and consumer durables, Srinivasan et al.[81] found that no de-facto standard had emerged in 52% of the product categories.

### *1.2.2. System-structural view*

Research on the system-structural perspective has focused on market mechanisms and firm adaptation to technological change. We start by discussing the market mechanisms.

Conventional economic theory is built on the assumption of diminishing returns.[82] Economic actions engender a negative feedback that leads to a predictable equilibrium for prices and market shares. An example is the competition between water and coal to generate electricity. As hydroelectric plants take more of the market, engineers must exploit more costly dam sites, thereby increasing the chance that a coal-fired plant will be cheaper. As coal plants take more of the market, they bid up the price of coal. The two technologies end up sharing the market in a predictable proportion that best exploits the potentials of each. The parts of the economy that are resource-based (e.g. agriculture and mining) are subject to diminishing returns. However, parts of the economy that are knowledge-based (e.g. computers, automobiles, and telecommunications equipment) are subject to increasing returns. Increasing returns are mechanisms of positive feedback that reinforce that which gains success or aggravate that which suffers loss.[83] Products in these industries are complicated to design and to manufacture. They require large initial investments in research, development and tooling, but once sales begin the incremental production is relatively cheap.

The phenomenon of increasing returns in the context of standards was first described by David in his seminal paper on the rise of the QWERTY keyboard as the de-facto standard.[84] He found that the advent of 'touch typing' enhanced the need for 'system compatibility' between keyboard hardware and the 'software' represented by the touch typist's memory of a particular arrangement of the keys. As a result, the value of a typewriter as an instrument of production became dependent on the availability of compatible software created by typists' decisions regarding the kind of keyboard they should learn. The purchase of a potential employer of a QWERTY keyboard conveyed a positive pecuniary externality to compatibly trained touch typists, to the degree to which this increased the likelihood that subsequent typists would choose to learn QWERTY. The overall user costs of the QWERTY typewriter system decreased as it gained in acceptance relative to other systems. These decreasing cost conditions led to QWERTY becoming the de-facto standard in keyboard design. David also notes that the cost of acquiring specific touch typing skills were high and therefore 'quasi-irreversible', whereas the cost of typewriter hardware rapidly decreased with volume production. In addition, with the introduction of novel non-typebar technologies, typewriter manufacturers were freed from fixed-cost bondage to any particular keyboard arrangement and could cheaply switch to QWERTY to achieve compatibility with the existing stock of QWERTY programmed typists. The costs incurred by technology users to move from one technology to another are referred to as 'switching cost'.[85] High switching cost may lead to 'excess inertia', [86] impeding the collective switch from a de-facto standard to a possibly superior new technology.[87]

In addition to David, Katz and Shapiro[88] found that there are many products for which the utility that a user derives from consumption of the good increases with the number of other agents consuming the good. They differentiate between two types of increasing returns: direct- and indirect network externalities.[89] The direct externalities relate to a physical effect of the number of purchasers, whereby the utility that a customer derives from purchasing a product (for example a telephone) depends on the number of others that have joined the (telephone) network. Indirect externalities relate to the 'hardware-software paradigm' whereby someone purchasing hardware will be concerned with the number of others purchasing similar hardware because this has a positive influence on the amount and variety of software that will be supplied for use with this hardware, thereby increasing its utility. Indirect externalities can also refer to the quality and availability of a service network. The scope of the network that gives rise to the consumption externalities varies across industries. The consumption externalities give rise to demand-side economies of scale, which are influenced by consumer expectations. Later, Liebowitz and Margolis differentiate between 'network effects', referring to the circumstance in which the net value of an action is affected by the number of agents taking equivalent actions, and 'network externalities' which refers to 'network effects' in which the equilibrium exhibits unexploited gains from trade regarding network participation.[90]

The value of direct network externalities can be explained according to Metcalfe's law[91] which states that if $n$ people are in a network, and the value of the network to each of them is proportional to the number of other users, the total value of the network to all the users is proportional to $n(n-1) = n^2 - n$. So if the value of a network to a single user is €1 for each other user in the network, then a network size of 10 has a total value of €90. A tenfold increase in the size of the network leads to roughly a hundredfold increase in its value. Metcalfe's Law is related to the fact that the number of unique connections in a network of a number of nodes ($n$) can be expressed mathematically as the triangular number $n(n-1)/2$, which is proportional to $n^2$ asymptotically. In more simple terms, if there are 5 telephones, these can be linked using 10 unique connections (illustrated by Figure 12).

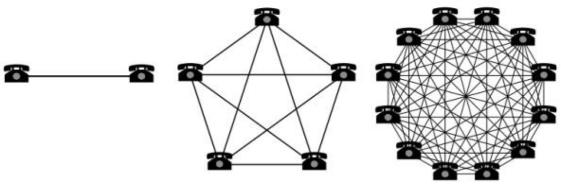

*Figure 12: Number of unique connections as a function of the number of nodes in a network (Source: www.wikipedia.org, network effect)*

Arthur[92] found that complex technologies often display increasing returns to adoption in that the more they are adopted, the more experience is gained with them and the more they are improved. In addition, he finds that in insignificant 'chance' or 'essentially random' events in the beginning of the competitive process can provide one technology with an initial market adoption advantage. The increasing returns to adoption magnify the initial advantage in market adoption by positive feedback loops and 'tip' the market towards one technology. Increasing returns reinforce the evolutionary character of technology competition, whereby random events can set a sequence of events in motion that will lead to one technology emerging as the de-facto standard. As a consequence, industries can get locked into an inferior path of technological development, because network externalities have a greater impact on market adoption than technological superiority.[93]

Following a study of the personal computer industry, Hill[94] introduced a model that depicts increasing returns as a positive feedback loop whereby a technology's increase in installed base (number of users) leads to a greater availability of software applications (complementary assets). This has a positive impact on the value of a particular machine to consumers and leads to greater demand for those machines, which translates into a greater installed base. Gallagher and West[95] extend this model into a more comprehensive version (Figure 13) that includes moderators of the positive feedback loop and several actionable steps available to a technology's sponsor to increase market adoption. As we describe the steps that a technology sponsor can take to increase market adoption in another section, we limit the model's explanation to a few of the additions. Gallagher and West argue that although the supply of software is positively influenced by the number of users, when competing technologies are incompatible the complementary assets are sometimes specifically developed for one or the other technology. Before market share trends become clear, technology sponsors can provide incentives to software producers to invest in 'co-specialization'.[96] These costs can be reduced by converters (allowing software to be used on the competing technology) or when a technology sponsor vertically integrates its business in order to provide software itself. While the product utility increases with the increase of the software supply, Gallagher and West note that the utility creation of indirect network effects can display three patterns; monotonic (each new complement increases the consumers' utility), declining returns (the value for each additional complement is slightly less) and critical value (at some point additional complements no longer provide additional utility for consumers). The 'usage pattern' of the complementary assets determines a technology's pattern for indirect network effects. For example, the video recorder and game console industry are centered on variety seeking buyers and therefore the indirect network effects display a monotonic pattern.

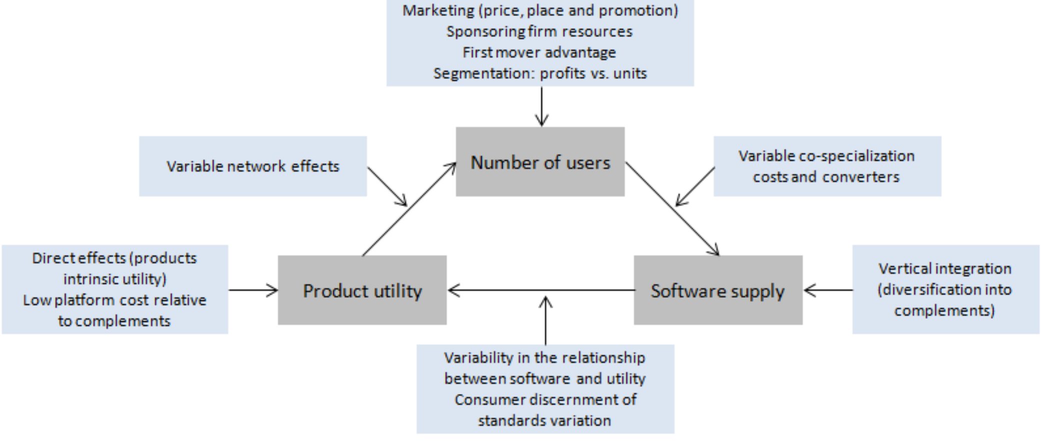


*Figure 13: Technology adoption model incorporating positive feedback (Source: Gallagher and West, 2009)*

Besides the concepts of network externalities and switching cost, the concept of technological lock-out affects firm adaptation to technological change. As described in the section on the natural-selection view, a de-facto standard reflects the selection of a technology over a variety of alternatives. These alternatives are sponsored by a variety of firms, and several scholars have noted that the 'technological shake-out' coincides with an 'industry shake-out'. [97] In a study on the impact of architectural innovation (and thereby dominant designs) on established firms, Henderson and Clark[98] find two reasons why such innovations create problems for established firms:

- Radical innovations requires new modes of learning and new skills, but information that might warn the organization may be screened out by the information filters and communication channels that embody old architectural knowledge. They misunderstand the nature of the threat, shoehorn the unexpected new information, and fall back into the patterns with which they are familiar.
- Once an organization has recognized the nature of an architectural innovation, it faces the challenge to build and apply new architectural knowledge effectively.

This problem was popularized by Christensen,[99] who coined it as 'the innovators dilemma'. Bower and Christensen[100] argue that a company's information filters are based on the feedback that these firms receive from their existing customers. This leads to investments in incremental innovations, aimed at improving the existing technology. Therefore, an excessive customer focus prevents firms from creating new markets and finding new customers for the products of the future. They unwittingly bypass opportunities and clear the way for entrepreneurial companies to catch the next wave of industry growth. In their study of the disc drive industry, Bower and Christensen found that many of the disruptive technologies never surpassed the capability of the old technology, instead companies would have been more successful had they focused on the trajectory of a new technology compared with that of the existing market. For example, the reason why the personal computer took over from the mainframe computer was not because personal computers outperformed mainframe computers, it was because personal computers networked with a file server met the computing and data-storage needs of many organizations more effectively. In later research, Christensen et al.[101] provide three lessons for market entry and probability of survival:

1) When entering an industry, managers should define if a de-facto standard has emerged. If this is not the case, they should specifically monitor any convergence toward a de-facto standard.
2) Firms conforming to the de-facto standard have an increased probability of survival, regardless of whether the firm has entered its industry before or after the de-facto standard has emerged.
3) Firms that have entered the industry at a very early stage have a low probability of survival. The capabilities that such firms develop in the early, fluid, low-volume phase of the industry may render them uncompetitive in a post de-facto standard environment characterized by faster design cycle times, steeper ramps to volume production, and low cost manufacturing.

The second lesson is also supported by the findings of Tegarden et al.[102] In their case study regarding the personal computer industry, they found that firms were not doomed when their entry design choices were not reflected in the de-facto standard; the firms that had made the 'wrong' choices were able to switch to the de-facto standard and this improved their probability of survival. Suarez and Utterback[103] and Baum et al.[104] complement this by showing that firms that enter an industry before the emergence of a de-facto standard have a greater probability of survival than firms that enter after a de-facto standard has emerged. Once a de-facto standard has emerged, early entrants have an advantage over new entrants in terms of market knowledge, distribution networks, reputation, experience effects, specialized processes and economies of scale.

In her research on technological lock-out, Schilling[105] notes that when an industry is in the process of selecting a de-facto standard, firms may be technologically locked out when their technology is rejected in favour of a competing technology. Alternatively, in markets where a de-facto standard exists, a firm may be technologically locked out if it is unable to produce products according to the de-facto standard. Schilling provides a model of the elements influencing the likelihood of technological lockout (Figure 14). She identifies four elements (failure to invest in learning, lack of complementary goods, insufficient installed base, and timing of entry) that have a direct influence, and three elements (margin of technological improvement, entry barriers and network externalities) that have an indirect influence. Schilling argues that firms can influence these elements and use them strategically to reduce the likelihood of technological lock-out.

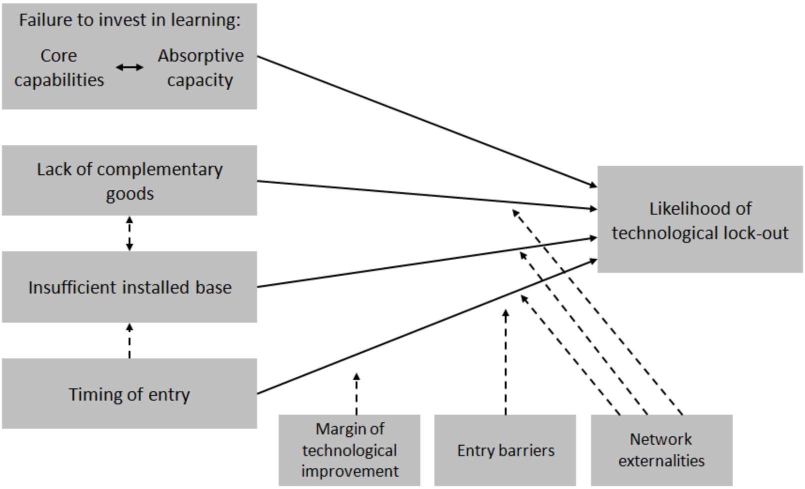


*Figure 14: Framework of elements influencing likelihood of technological lock-out (Source: Schilling, 1998)*

### *1.2.3. Collective-action view*

According to the collective action view, technological change can be driven by a process in which a coalition of firms with conflicting views confront each other and engage in political behaviors to co-create new technologies and aim to establish these as de-facto standard.[106] In this section, we first focus on the drivers for collaboration or competition between firms, and subsequently we discuss the forms of collaboration.

As described above, markets that are subject to network externalities tend to converge to a de-facto standard and become locked into this technological path. Besen and Farrell[107] note that a firm that controls a technology that becomes established as a standard can have an extremely profitable market position. Examples include IBM's historical dominance of the mainframe computer industry and the dominance by Microsoft operating systems and Intel microprocessors in the personal computer industry. When one technology can provide network benefits that another cannot provide, there is a discrepancy in value which a fortunate firm may be able to extract as profit. Because the prize is so tempting, firms may compete fiercely and increase their chances of winning by investing more on product enhancements, advertising, or price reductions. This competition may result in a 'spending war' that dissipates (part of) the potential gains. Besen and Farrell substantiate this by modeling a situation whereby two firms compete by investing resources in e.g. advertising or price reductions. Firm 1 spends $x$, and Firm 2 spends $y$. Whichever firm "wins" gets $W$, and the one that loses gets the smaller amount $L$. Firm 1's chance of winning is $x^a/\,(x^a + y^a)$, with $a \geq 0$. Likewise, Firm 2's chance of winning is given by $y^a/\,(x^a + y^a)$. Note that if $a = 0$, the probability that each firm will win is $1/2$, independent of how much the firms spend. However, as $a$ gets larger, small differences between $x$ and $y$ result in larger differences in the probability of winning. Thus a large value of $a$ implies that extra effort can have a large expected payoff. The Nash equilibrium can be used to determine the optimal amount that each firm should invest in its attempt to win. Firm 1 takes $y$ as given, and chooses $x$ to maximize its expected net gain:

$$\max \mathcal{E}(\pi) = \frac{x^a}{x^a + y^a} W + \left[1 - \frac{x^a}{x^a + y^a}\right] L - x$$

Taking $x$ as given, Firm 2 chooses $y$ in the same way. Hence Firm 1's reaction function is given by:

$$\frac{ax^{a-1}\, y^a}{(x^a + y^a)^2} (W - L) - 1 = 0$$

and Firm 2's reaction function is given by:

$$\frac{ax^a\, y^{a-1}}{(x^a + y^a)^2} (W - L) - 1 = 0$$

Combining these two reaction functions, we get the following symmetric Nash equilibrium:

$$x^* = y^* = \frac{a}{4} (W - L)$$

Thus, the total net profit for the two firms is: $W + L - \left(\frac{a}{2}\right)(W - L)$.

Now, suppose that $W$ = €1000, $L$ = 0, and $a$ = 1. Then each firm will spend €250 trying to win, and total net profits will be €500. If $a$ = 2, each firm will spend €500 trying to win, and total profits will be 0. Finally, if $a$ = 3, each firm will spend €750, and total profits will be -€500, i.e., one firm will win and have a net gain of 1000-750 = €250, and the less fortunate firm will simply lose €750.[108] Although the total net profit is positive at the beginning of the competition, the outcome can be worse than dissipating potential gains when sponsors alternate in making investments. In such cases, the competition takes on characteristics of what is known in game theory as a 'War of Attrition' or 'auctioning the dollar' game where there is no limit to the amount that a firm will spend to win once it has chosen to play.

Competition to become the de-facto standard may also delay market growth because buyers are hesitant to take risk and invest in a technology that may become obsolete, instead they will postpone technology adoption until the technology competition has generated a result. The alternative is that firms agree to support the same technology and to make their product compatible. This channels competition into different, more conventional, dimensions such as price, service, and product features. This leads firms to face the question whether inter-technology competition ('for the market') will be more or less profitable than intra-technology competition ('within the market'). Besen and Farrell, and Grindley[109] define two models (strategic games) that mark the form of the competition. These models are based on two competing firms, but Besen and Farrell note that with more than two firms, competition will involve elements of these models.

The first model is known in game theory as the 'Battle of the sexes'. If technological compatibility is overwhelmingly important in an industry, then firms will prefer intra- to inter-technology competition. This game results in a bargaining problem, whereby the firms will need to agree which technology is preferable. Both firms want compatibility but each prefers their own technology, for example because the thorough understanding of the technology provides the firm with advantages over its rivals in using it. The 'Battle of the sexes' game is shown in Figure 15, which lists the pay-offs to two competitors according to whether they lead or follow (Grindley differentiates a firm's position as 'lead', referring to the role of technology sponsor, or 'follow' which refers to a adopting another firms' technology). When both firms set out to lead, there is a technology competition and the expected payoff to each firm is 3 (e.g. due to duplicated R&D investments). If A leads and B follows, then A receives 6 and B receives 4. The pay-offs are reversed when B leads and A follows. Thus both firms do better by agreeing to a single technology than by entering into a technology competition, but the firm which follows reaps less pay-offs than the leader.

| | | FIRM B | |
|---|---|---|---|
| | | LEAD | FOLLOW |
| FIRM A | LEAD | (3,3) | **(6,4)** |
| | FOLLOW | **(4,6)** | (0,0) |

*Figure 15: 'Battle of the sexes' game (Source: Besen and Farrell, 1994)*

In the second model, the distribution of gains in favor of the leader is so great that the follower prefers risking technology competition and fragmenting the market to an inferior position adopting an outside technology. This is a form of the 'prisoners' dilemma' game, in which all players would be better off agreeing, but by each trying to gain an advantage at the expense of the others they end up disagreeing, to their mutual loss. This 'rather fight than switch' game is shown in Figure 16. Compared to the 'battle of the sexes' game, the distribution of the payoffs is more in favor of the leader. The firm taking the lead could aim to convince the other firm to follow by changing the game and share the gains more evenly, for example by making a side payment of 2 to the other party if it follows (resulting in a payoff distribution similar to the 'battle of the sexes' game). In practice, this side payment could be a reduction in the license fees or technical support in adopting the other firms' technology. This is an essential part of the logic of open standards, which modify the players payoffs and hence change the combined leadership and access decisions.

| | | FIRM B | |
|---|---|---|---|
| | | LEAD | FOLLOW |
| FIRM A | LEAD | **(3,3)** | (8,2) |
| | FOLLOW | (2,8) | (0,0) |

*Figure 16: 'Rather fight than switch' game (Source: Besen and Farrell, 1994)*

Whereas the previous sections show a very theoretical approach, a large body of the academic literature has taken a case study approach, providing a descriptive in-depth historic overview of technology competition, market adoption and the selection of one technology as the de-facto standard. These studies describe the following technologies / industries: typewriter keyboard (QWERTY),[110] videocassette recorders,[111] electricity supply system,[112] microcomputers,[113] disc drives,[114] video game consoles,[115] television receivers,[116] typesetters,[117] electronic initiation systems,[118] ink-jet printers,[119] web browsers,[120] cellular phones,[121] close range wireless connectivity (Bluetooth),[122] personal digital assistants (PDAs),[123] electronic calculators,[124] minicomputers,[125] programming languages (Java),[126] and microprocessors (RISC).[127] These case studies provide valuable insights in the complexity and dynamics of technology competitions and the emergence of de-facto standards. They show that in the competition between multiple incompatible technologies, each technology can be thought of as being supported by a community of organizations that have a stake in the technology. Several cases, e.g. videocassette recorders, have shown that technology sponsors can establish a de-facto standard by actively building an ecosystem of followers that support the technology.[128] A large number of firms supporting a technology may encourage customers to adopt it due to enhanced product availability or confidence regarding the future prospects of the technology which, in turn, leads to more firms joining the community. This results in a positive feedback loop, also known as a 'technological bandwagon'.[129]

Research in the field of platforms has generated useful insights regarding the possible modes of collaboration. Before discussing the modes, we first need to clarify the different elements that can be found in the network. Research on 'platform-mediated networks' has identified four different elements:[130]

- Platform sponsors: these firms own or control the technology and determine if and which companies are allowed access to the technology
- Platform providers: those firms that offer the technology to the end-users
- Supply-side users: parties that provide goods that are complementary with the technology (e.g. software)
- Demand-side users: the end users of the technology. If we take the example of consumer electronics, this group is represented by consumers.

Each of these roles can be open or closed to participation by third parties. Figure 17 illustrates this by several examples of platforms. In the case of the Linux operating system, any party can contribute improvements subject to the rules of the open source community that maintains the operating system kernel, any party can bundle Linux with server or personal computer hardware, any party can offer Linux-compatible software applications, and any organization or individual can use Linux. By contrast, in 2008 Apple's iPhone was closed with respect to three of the four roles, and only open for some prospective demand-side users; in the USA, only AT&T Wireless subscribers were able to use an iPhone. Apple is solely responsible for the iPhone's technology, manufacturing and distribution. Although third parties are able to provide software applications for the iPhone, these are only available through Apple's iTunes or App Store and Apple reserves the right to reject third-party applications due to quality or strategic concerns.

| | Linux | Windows | Macintosh | iPhone |
|---|---|---|---|---|
| Platform sponsor (technology owner) | Open | Closed | Closed | Closed |
| Platform provider (offer hardware / operating system bundle) | Open | Open | Closed | Closed |
| Supply-side user (providers of complementary goods) | Open | Open | Open | Semi-Open |
| Demand-side user (end user) | Open | Open | Open | Open |

*Figure 17: Comparison of openness by role in platform-mediated networks (Source: Eisenmann et al, 2009)*

When focusing on platform sponsors and platform providers, there are four models to organize platforms: proprietary, licensing, joint venture, and shared (illustrated by Figure 18).[131] A proprietary platform has a single sponsor who serves as its single provider, for example the Macintosh and the iPhone. With a joint venture model, several firms cooperate in developing the technology, but a single entity serves as the technology provider. With a licensing model, a single company develops a platform's technology and aims to build an ecosystem of followers by providing licenses to other firms. The VHS video recorder is an example of this model. With the model of a shared platform, multiple firms collaborate in developing the technology and then compete with each other in providing differentiated but compatible versions. Examples include DVD and Blu-ray. The development of a shared technology typically occurs in Standard Development Organizations (SDOs) or ad-hoc industry consortia.

There are four scenarios under which parties are allowed to participate in the technology development:[132]

- Fixed group (no new members)
- Members with qualifications (country club): this model is sometimes applied in industry consortia, whereby the existing members decide which firms can become new members, typically using some combination of objective and subjective criteria
- Nondiscretionary membership (fitness club): nearly all firms can become a member upon filing a form and paying membership dues. Many trade associations and industry consortia use this model.
- Nonmember organizations (town meeting): there is no membership required to participate, such as the Internet Engineering Task Force (IETF), which prides itself on its openness to participation

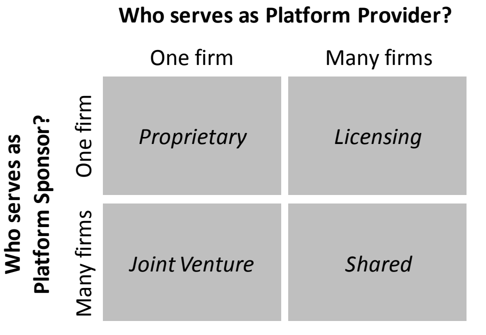


*Figure 18: Models for organizing platforms (Source: Eisenmann, 2008)*

In a technology competition, the different sponsors may select different modes for collaboration as described above, which influences the extent to which they are able to build-up an ecosystem of followers.

*1.2.4. Strategic choice view*

Contrary to the natural-selection view, which states that a de-facto standard can only be identified ex-post at an industry level, company strategists face the issue of how their firm can deliberately shape the odds of their technology emerging as the de-facto standard. This issue has been addressed by scholars advocating the strategic choice view, and their contributions have focused on two aspects: 1) strategic elements and firm resources that can be applied to influence the market adoption of a technology, 2) models combining several elements.

Research on the ability of firms to establish its technology as the de-facto standard started with the identification of a range of elements that firms can use strategically. Over time, many researchers have provided contributions, of which those from Teece,[133] Hill,[134] Shapiro and Varian,[135] Grindley,[136] Schilling,[137] and Eisenmann[138] are most notable. Together, these have identified and thoroughly studied a wide range of strategic elements, including: timing of market entry (first mover advantage), (penetration) pricing, marketing and pre-announcements to create awareness and manage expectations, applying lessons from pattern of adoption of previous technology generations, vertical integration to provide complementary assets, the level to which firms accommodate to the needs / requirements of licensees, efforts to build-up an ecosystem of supporters, level of collaborative platform development, and strategic alliances with complementors. They also identified elements that can be considered inherent to the firm, which include: core capabilities, absorptive capacity (ability to learn and adapt), pre-entry experience, size (market share, turnover), and installed base. Appendix 1 provides an in-depth description of these elements and the contributions from various researchers.

In parallel to the identification of elements, researchers have started to combine these into models in order to obtain a deeper understanding of how firms can influence the emergence of a de-facto standard.

We have identified four models, provided by McGrath et al.,[139] Lee et al.,[140] Gallagher and Park,[141] and Suarez.[142]

McGrath et al. developed a framework showing how corporate executive teams can influence strategic decision making regarding de-facto standards. They draw upon the natural selection view to differentiate three phases of the emergence process of a de-facto standard; variation, selection, and retention. Subsequently, they identify the choices that executive teams need to make regarding their firm's technological trajectory (Figure 19). During the 'variation' phase, the executive team needs to manage the scope and intensity of exploring technological variations. They need to select among competing technology project opportunities, consider if these should be based on technology 'push' or market 'pull', and decide upon the extent to which resources are allocated to the project. During the 'selection' phase, the team can utilize an evolutionary- or a revolutionary strategy. The same holds for the 'retention' phase. Following the variation phase, a firm needs to help its technology overcome the market selection process. They identify several forces that need to be taken into account for technology selection: switching cost for an installed base to move to the new technology, superior technological performance is important but often insufficient in itself, power and influence of the innovator and its competitors over key stakeholders, installed base, marketing capability, reputation, governmental agencies and industry associations, complementary assets, and entry timing. After a firm's technology has been selected it needs to reap the rewards of its investments, which may require the ability to prevent others from copying the technology. If a firm is able to anticipate co-evolutionary requirements, it can appropriate specialized resources. In addition, if an industry has a strong appropriability regime, a firm can protect its intellectual property and prevent others from copying the technology. The strength of the model provided by McGrath et al. is that they identify several phases and list a significant amount of elements that influence the selection of a de-facto standard. However, they provide insufficient guidance on how a firm can utilize these elements strategically to shape the technology selection process.

| Variation | Selection | Retention |
|---|---|---|
| *Scope setting* | *Evolutionary strategies* | *Evolutionary strategies* |
| -Search for opportunities<br>- Screening<br>- Evaluation<br>- Progress reviews | -Building switching costs<br>- Drawing off and reinforcing existing infrastructure<br>- Reinforcing existing standards<br>- Building technology links | -Exploiting organization deliverables<br>- Using specialized assets<br>- Using cospecialized assets |
| *Climate setting* | *Revolutionary strategies* | *Revolutionary strategies* |
| -Expectation setting<br>- Personal demonstration of support<br>- Disproportionate resource allocation<br>- Staffing and restaffing<br>-Managing disappointment and discontinuation<br>-Internal pathclearing (moderating internal conflict, granting dispensation from policy) | -Forging market acceptance<br>- Negotiating coevolution<br>-Demonstrating commitment<br>- Negotiating standards<br>-Negotiated environment<br>-Exploiting clout | -Coevolutionary contracting<br>-Asserting product-class prerogative<br>- Influencing formal standards |

*Figure 19: Executive team influences on the emergence of de-facto standards (Source: McGrath et al., 1992)*

Lee et al.[143] note that according to previous research, the emergence of a de-facto standard can be regarded as the 'black box' between an innovation and 'economic success'. They present a framework of underlying elements and forces that influence a technologically feasible innovation[144] to move on to emerge as de-facto standard (Figure 20). The framework is comprised of 'external conditions' such as an industry's appropriability regime and network effects, a set of technological and non-technological 'driving forces', and complementary assets (distribution channels, service network, etc.) which contribute to successful adoption of a technology. While the framework outlines elements that drive the emergence process, it does not suggest that the process is necessarily linear or sequential; it is a parsimonious description. The variety of elements that may influence the emergence of a de-facto standard precludes the use of simple heuristics for predictive purposes. Lee et al. consider each situation unique, and note that technologies that appear to have similar characteristics may be dissimilar in the manner and forces by which they emerge. They propose that firms can frame the emergence process and systematically manage the elements in the pursuit of competitive advantage from innovation. This framework marks the first attempt to categorize elements that drive the emergence of a de-facto standard, and to note the preclusion of simple heuristics for predictive purposes. However, the framework consists of a limited number of elements, of which several (e.g. organizational and socio-political forces) are abstract and therefore difficult to use strategically by a firm.

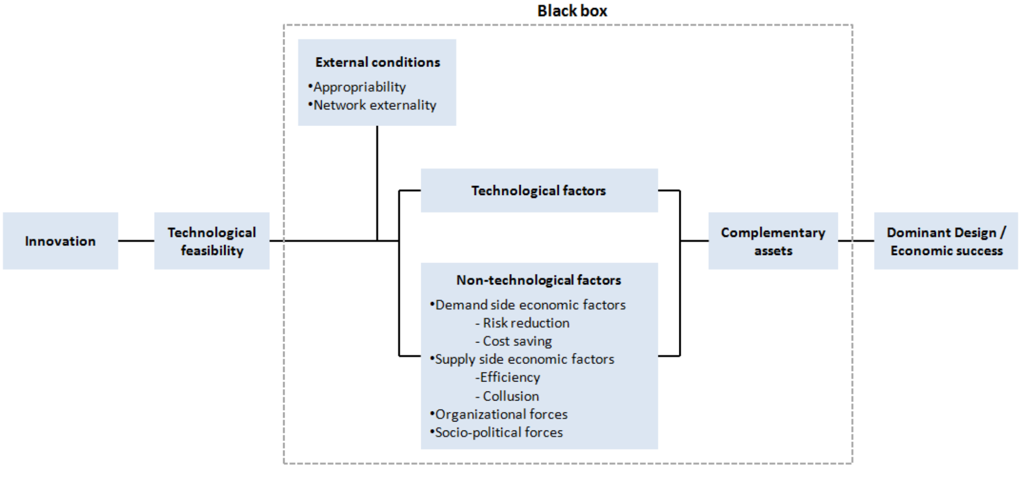


*Figure 20: Framework of de-facto standard emergence process (Source: Lee et al., 1995)*

Gallagher and Park[145] developed a framework to provide insights in the elements influencing a firm's competitive success in markets with network effects (Figure 21). Based on their study on the history of the video game industry, they emphasize the importance of building a network of complementary products and an installed base. They argue that traditional competitive strategies, such as superior technology, early market entry, penetration pricing, brand awareness, channel management and entry barriers, are important to attract independent software vendors into the network of a platform. These competitive strategies lead to higher switching costs and a broader network of complementary products, which increases the installed base. A firm's capabilities and absorptive capacity allows early adoption of a new technology and effective implementation of competitive strategies, leading to higher switching cost. While Gallagher and Park present several elements that influence competitive success and make a suggestion on how these are interrelated, the framework has been deduced from a single case study and further research has not tested its application on other cases.

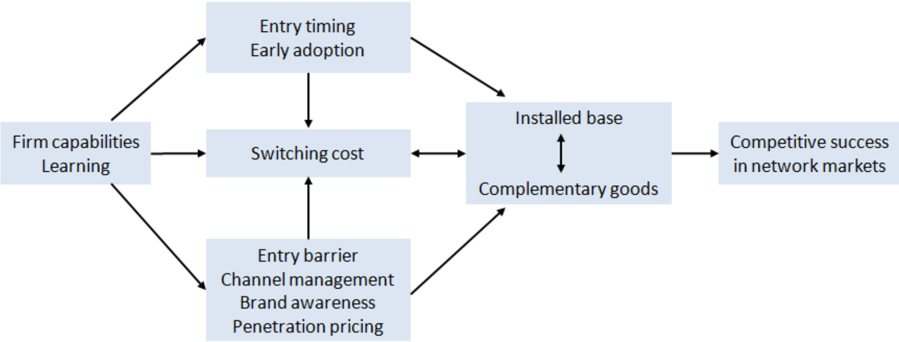


*Figure 21: Integrative framework for success in network based industries (Source: Gallagher and Park, 2002)*

Suarez[146] developed a framework providing insight in the process by which a technology emerges as de-facto standard. First, he identifies elements associated with technological dominance, and proposes two broad groups: firm level elements and environmental elements (shown in Figure 22).

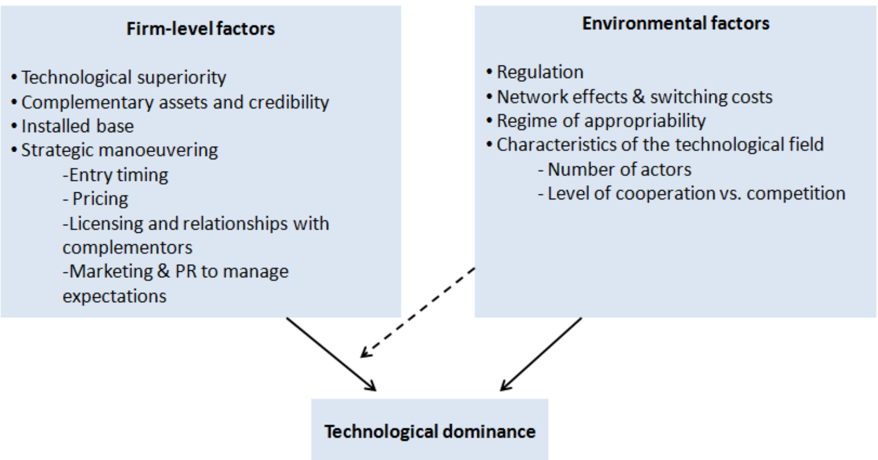


*Figure 22: Framework of elements influencing the dominance process (Source: Suarez, 2004)*

Secondly, Suarez describes the emergence of a de-facto standard in a few key milestones as shown in Figure 23. The beginning of the technological field ($T_0$) can be traced back to the moment when a pioneer firm or research group starts performing applied R&D aimed at the technological innovation. A second milestone ($T_P$) is marked by the appearance of the first working prototype based on the technological innovation. The first working prototype sends a powerful signal to all firms in the race that at least one of the technological trajectories is feasible and has been developed to such a level that there will soon be a product in the market. The third milestone ($T_L$) in the process is the launching of the first commercial product, which for the first time, directly connects a technology coming out of the lab to customers. The first product in the market is often too expensive for the mass market and therefore aimed at the high end of the market. The early market, typically a relatively small one when compared to the mass market, helps a particular design become an early "forerunner". The presence of a clear front runner marks the fourth milestone ($T_F$) in the dominance battle. This front runner has a chance of winning the battle, as its larger installed base tends to create a bias towards the technology with the largest market share. The final outcome will depend on how fast competitors improve on their own designs and how fast the market grows. Finally a specific technological design achieves dominance and marks the last milestone ($T_D$) of the dominance process.

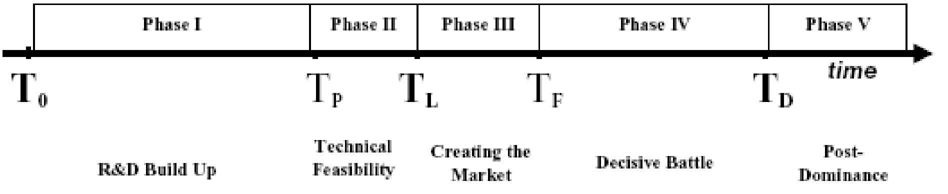


*Figure 23: Milestones in the process of technological dominance (Source: Suarez, 2004)*

Lastly, Suarez combines the milestones and elements into a single model representing the key elements of success at each stage of the dominance process (Figure 24). This model combines a different mix of firm and environmental level elements which according to Suarez have the strongest effect on success in the respective phases of the dominance process. While Suarez's model constitutes a major contribution to the 'strategic choice view', the limitations of this framework are 1) the limited amount of elements, and 2) the abstract description of factor interrelatedness.

| Factor type | Dominance factor | Phase I | Phase II | Phase III | Phase IV | Phase V |
|---|---|---|---|---|---|---|
| Firm level | Technological superiority | | *** | | | |
| | Credibility / complementary assets | *** | | | *** | |
| | Installed base | | | | *** | *** |
| | Strategic manoeuvering | | | *** | | |
| Environmental level | Regulation | | *** | | | |
| | Network effects and switching cost | | | | *** | *** |
| | Regime of appropriability | *** | | | | |
| | Characteristics of the technological field | *** | | | | |

*Figure 24: Key elements of success at each stage of the dominance process (Source: Suarez, 2004)*

## 1.3 Problem description

As the previous sections show, the body of literature on the emergence of de-facto standards covers many aspects. Scholars have found that the emergence can be expressed in patterns representing market adoption or the rate of process and product innovations, they have studied specific market dynamics such as the effects of network externalities and innovators' dilemma, performed in-depth case studies on technology competitions and the drivers for firms to either collaborate or compete, and they identified how firms can utilize specific strategies and resources to influence the technology competition.

However, advocates of the strategic-choice view are still far from a robust clarification on how firms can deliberately shape the odds of their technology emerging as the de-facto standard. We note several limitations regarding the body of literature in this field:

- First, the models take a static approach,[147] providing a single set of measures (a 'recipe' or 'formula') that should lead to success in a technology competition. During my review of extant in-depth case studies on technology competitions, I noticed that the emergence of the de-facto standards displayed case-specific paths, due to the differing constellation of technologies (each technology often has its own characteristics), the firms supporting these technologies, and the environment in which the firms and technologies competed. In addition, technology sponsors applied different strategies, and their competitors responded with their own strategic actions. I therefore believe this field requires a framework that can support the variety and dynamics of technology competitions. This point is confirmed in a recent publication by Narayanan and Chen,[148] which recommends future research on the strategic-choice view to incorporate the action-response perspective from the field of competitive dynamics research. Although no easy answers result from using a framework rather than a 'recipe', it assures that one considers the right questions and criteria;
- Secondly, the various elements of the emergence of a de-facto standard (e.g. market mechanisms, models for creating a technology bandwagon, elements that can be used strategically, and models showing the interrelatedness of several elements) are fragmented over many different publications. Although there are some papers on de-facto standards that provide a synthesis of prior research (i.e. Narayanan & Chen,[149] Van de Kaa et al.[150], Gallagher and West[151]), their contributions do not address the strategic-choice view. The one paper providing a synthesis of prior research whilst addressing the strategic-choice view is from Suarez.[152] Suarez' framework, however, dates from 2004, and therefore lacks insights gained in the past decade (e.g. the more extensive number of elements which were later found by Narayanan & Chen or Van de Kaa et al., and new insights regarding platform technologies). I believe an up-to-date synthesis of prior research, addressing the strategic-choice view, is required to enhance our understanding of the emergence of de-facto standards, leading to better theoretical insights;
- Lastly, the available models have been derived from a very narrow set of cases (often only one). It is therefore unknown if they are robust when applied to other technology competitions.

Strategic decision making to shape the odds of a technology emerging as the de-facto standard is a difficult task, because many different aspects have to be taken into account:
- Opportunity recognition; e.g. innovator's dilemma;
- Development of a technological bandwagon; e.g. open or closed approach to the elements of the technology;
- Strategic and resource related elements; e.g. timing of market entry, pricing;
- Phases and milestones in the emergence of a de-facto standard;
- Interrelatedness of the elements; how does a change in one factor influence other elements of the competition;
- Anticipating and responding to moves of the competing technology sponsors.

This problem is complex from both a practical and a theoretical perspective, but renders opportunities for theoretical advancement.

In addition, advancing the strategic-choice view is becoming increasingly relevant. As described before, many industries display high-stakes 'winner-take-all' games, and the 'rent-seeking' firms in these industries would like to obtain a (near) monopoly position, whereas losing the competition comes at a high cost.[153] I note two trends that will lead to more 'winner-take-all' games, even in industries that have previously not displayed these:

- Due to the increasing use of IT and telecommunications technologies in larger systems, many of tomorrow's products are becoming connected, resulting in stronger network effects. Examples include intelligent lighting, smart grids, personal health, and the "internet-of-things".
- Companies increasingly compete on platform technologies that bring together groups of users in two-sided networks. Examples include smartphones, social networks and internet search engines.

## 1.4 Research objective and research questions

The objective of this study is to contribute to the strategic-choice view by developing a framework that can be used to support strategic decision making to shape the odds of a technology emerging as the de-facto standard. The framework should provide an integrative approach, covering the various aspects identified in the previous sections as relevant for strategic decision making. In addition, it should be able to cater to the variety and dynamics of technology competitions.

In order to develop this framework, I aim to answer the following research questions:

1. What are the various elements of the emergence of a de-facto standard that we would need to incorporate in the framework (e.g. market mechanisms, models for creating a technology bandwagon, elements for shaping the odds of technology selection)?
2. How to integrate these elements in a framework?
    a. Can we differentiate between types of elements (e.g. those that are within or outside a firm's span of control)?
    b. Are some elements more important than others in the decision of an agent to adopt a technology (do they have a direct or indirect influence on the emergence)?
    c. Do the elements affect each other, and how are they interrelated?
3. Which phases and milestones can we identify in the emergence of a de-facto standard?
4. How can the framework be applied to technology competitions
    a. Can the framework really be applied to technology competitions and, when doing so, how robust (scalable) is the framework?
    b. What can we learn from applying it: does it provide comprehensive insight in the dynamics of technology competitions, can it clarify the outcome, can it support strategic decision making to shape the odds of a technology to emerge as de-facto standard?

## 1.5 Methodology and research approach

In order to address my research questions, I adopted a directed content analysis combined with a multiple case study approach.

The objective in research question 1 and 2 is to construct a framework. As this can be considered theory building, rather than theory testing, a qualitative approach was adopted. Section 1.2 has shown the available body of literature consists of a large number of independent studies adopting different perspectives and different concepts of de-facto standards. I decided to use the literature to develop an 'integrative framework' that combines the constructs and variables. The development of an integrative framework is a commonly-used approach when there is a wide, fragmented body of literature. Examples of integrative frameworks can be found in a variety of fields, examples include 'organizational buying behavior'[154], 'collaborative partnerships'[155], and 'persuasive advertisements'[156]. In constructing the integrative framework, I used literature regarding dominant designs, compatibility standards, and platforms, related to the strategic-choice view. In addition, literature from the other three quadrants was reviewed. During this review, I identified literature regarding specific elements from the system-structural view (i.e. regarding market mechanisms such as network externalities), collective-action view (i.e. case studies of technology competitions), and natural-selection view (i.e. regarding types of innovations), which were relevant to complement the literature on the strategic-choice view.

In order to determine the population of literature for my analysis, I started with an initial literature review to contextualize the research within the field of de-facto standards and build an understanding of the key terminology. I searched for publications from different sets of academic journals and scholarly books by searching journal databases on key terminology (e.g. compatibility standards, technology platforms, dominant designs), reviewing the citations of articles and books (backward search), and a forward search using the Web of Science to identify articles citing the key articles and books (indicated by Neuman[157], Rowley et al.[158], and Webster et al.[159], as elements for conducting a comprehensive literature review). I limited my search to English-written sources only. This resulted in a variety of publications and books from different geographic regions (North America, Europe and Asia). Only those of which the object of analysis was in accordance with the emergence of de-facto standards were included. In total 75 sources were found (68 publications, 7 books). Of these, I selected 47 sources based on a combination of their amount of citations, and the number of elements in the publication. The number was determined by diminishing returns of the content analysis. Of the 47 sources, 27 were theoretically oriented and 20 were historical case studies. The theoretical publications study one or more elements that shape (facilitate or delay) the process of de-facto standard emergence, whereas the historical case studies describe technology competitions leading towards de-facto standards.

The constructs and variables for the framework were fragmented over the body of literature, and authors used different labels or narrative descriptions when addressing these. I applied directed content analysis to unify the different elements in a single comprehensive set. Content analysis is a qualitative research technique to interpret meaning from the content of text data. A directed approach to content analysis is aimed at validating or extending a framework or theory.[160] The main strength of a directed approach to content analysis is that it allows to support and extend existing theory. Using prior research, researchers typically begin by identifying concepts or variables as initial coding categories.[161] Next, operational definitions for each category are determined. Lastly, existing research can provide predictions about the variables of interest or about the relationships among variables.

The content analysis was initiated using a process of inductive coding;[162] I performed close readings of the 47 publications and highlighted all text that on first impression appeared to relate to an influence on the emergence of a de-facto standard. As next step, I considered the multiple meanings that were inherent in the texts and created an initial set of labels whereto I could allocate highlighted text segments. Any text that could not be categorized with the initial coding scheme would be given a new label. Subsequently, the highlighted texts were used to develop a description of the elements. As the intended outcome of the process is to create a small number of summary categories that in the researcher's view capture the key aspects of the identified themes, I aimed to group elements together in categories. Lastly, I reviewed the same publications again and identified links between elements, in order to show their relationship in a network and their hierarchy.

In order to address my last research question (i.e. applying the framework to technology competitions in order to explain how a technology became the de-facto standard), I adopted a multiple case study approach. An in-depth case study is a very suitable research method to explore competitive dynamics in the emergence of de-facto standards, because it enables the researcher to capture the details of this complex process. By investigating multiple it is possible to evaluate the merits of the integrative framework in several situations. Regarding the case studies themselves, an explanatory approach was adopted, considering that the goal was to explain the emergence of a de-facto standard. An explanatory case study approach consists of three elements; 1) an accurate rendition of the facts of the case, 2) consideration of alternative explanations of the facts, and 3) a conclusion based on the single explanation that appears most congruent with the facts.[163]

This brings us to the matter of case selection. In total three cases were selected, as this would allow for some measure of generalization through a cross-case analysis. The cases were selected via theoretical sampling, as the aim was to replicate the approach.[164] In selecting the cases, I used the following criteria:

- Cases needed to be technology competitions with a known outcome (either a de-facto standard had emerged or the competing technologies did not manage to displace the extant de-facto standard). In order to understand if the integrative framework can be used to support strategic decision making to shape the odds of a technology emerging as the de-facto standard, ongoing technology competitions would have been ideal. However, this is not feasible since it would require that the researcher would have to be involved in several technology competitions simultaneously and be in a position to influence the technology sponsors to base their strategic actions on a integrative framework.
- Technology competitions from the same industry in order to test the repetitiveness of the constructs, and technologies with similar characteristics (i.e. can be attributed to the four middle sections of Figure 4) in order to test the extent to which the framework can provide insight in the outcomes and to support analytic generalization.[165] The contexts of such cases will have a 'high degree of similarity', and therefore high transferability of the findings of one case to another.[166]
- The market in which the technology competition takes place needs to exhibit strong network externalities
- The competition for market adoption occurred after 1990. The reason for adopting this restriction is because I wanted to perform interviews with key persons from companies involved in the technology competition, and this restriction was necessary to select cases whereby I would be able to find 1) a sufficient number of respondents, and 2) the respondents would still have a reasonably accurate recollection of the events.

After investigating several industries, I focused on the consumer electronics industry because it has many markets that display strong network externalities, market selection is driven by a mass-market of consumers, and the potential cases are often well documented by public announcements. Considering that many existing case studies are based on cases older than 1990 (e.g. video recorders, personal computers, colour television), I selected three new cases: Blu-ray vs. HD-DVD, MP3 vs. WMA, and SuperAudio CD vs. DVD Audio (presented in the order in which they were studied).

Each of these cases was studied in three phases: data gathering, case analysis and case report. Upholding the replication logic[167] in the three cases posed a methodological challenge; how to systematically collect all the relevant details, and obtain the required in-depth insights. In order to tackle this, I developed a data matrix based on the results of the inductive coding of the 47 sources. This data matrix allowed for a structured historic analysis of each case, and enabled me to focus on obtaining the relevant details. Secondly, I collected data by first searching for relevant documents and public announcements and performed content analysis on these. This was complemented by focused interviews with key persons from companies involved in the technology competitions to gain an in-depth understanding of the emergence process. Following completion of the data gathering, the interviewees were asked to verify and moderate the preliminary analysis. Lastly, by aligning the integrative framework with the data matrix, the information collected in the data matrix allows for consistently application of the constructs across the case studies.

Following each case study, the case analysis was used to review the integrative framework and make revisions based on new insights.

Before moving to the cross-case analysis, the limitations and comprehensiveness of the integrative framework were further investigated by 'zooming in' on specific parts. This was done on two different levels; first the relationship between two elements, subsequently one specific (new) element and its position in the framework. When selecting the particular relationship and specific element, I took into account the relevant themes in academia regarding de-facto standards in respectively 2010 and 2012. This resulted in aligning the selection with the topics of special issues of two prominent academic journals, respectively Organization Studies and California Management Review. For the Organization Studies special issue on 'the dynamics of standardization', the relationship between the elements 'collaborative technology development' and 'organizational community of supporters' was investigated. For the special issue of California Management Review on 'Intellectual Property Management', I focused on the element of 'accessibility of intellectual property rights' and its position in the framework.

In the cross-case analysis, the insights from the case studies regarding the emergence of de-facto standards were combined and compared. The transferability of the case findings was investigated through analytic generalization. In analytic generalization the investigator strives to generalize a particular set of results to some broader theory. According to Yin,[168] if two or more cases are shown to support the same theory, replication may be claimed. Analytic generalization may be defined as a two-step process.[169] The first involves a conceptual claim whereby investigators show how their study's findings are likely to form a particular set of concepts, theoretical constructs, or hypothesized sequence of events. The second involves applying the same theory to implicate other similar situations where similar concepts might be relevant. The findings from the analytic generalizations were subsequently used as input for the final framework.

By applying different research methods and information sources I aimed to achieve method and information source triangulation, improving the reliability of the results and a strong theoretical basis.

Figure 25 provides an overview of the research approach, and the corresponding chapters in this dissertation.

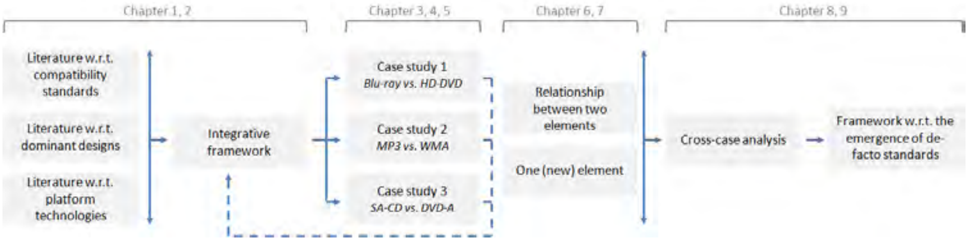


*Figure 25: Overview of research approach and corresponding chapters in dissertation*

## 1.6 Outline of the dissertation

Chapter 1 – Introduction
This chapter starts with a synthesis of several concepts (i.e. compatibility standards, dominant designs and platforms) that represent different facets of the phenomenon of de-facto standards. Subsequently, an overview of the literature on de-facto standards is provided. From this overview, a problem description and research objective are derived. The chapter ends with a clarification of the methodology and research approach.

Chapter 2 – Integrative framework
In Chapter 2, the first three research questions are addressed by constructing an integrative framework from the existing body of literature on de-facto standards.

Chapter 3 – The triumph of Blu-ray over HD-DVD *(published in Business History)*
In order to address the last research question, the integrative framework is applied to three cases, of which the competition between Blu-ray and HD-DVD in the high definition optical disc industry is the first. This chapter starts with an in-depth study of the case, and subsequently the integrative framework is applied for further analysis.

Chapter 4 – The rise of MP3 as the market standard (*published in Journal of IT Standards and Standardization Research*)
This chapter starts with an in-depth study of the emergence of MP3 as the de-facto standard in music formats. Subsequently, the integrative framework is applied to the case.

Chapter 5 – The competition between SA-CD and DVD-A
This chapter starts with an in-depth study of the technology competition between SuperAudio-CD and DVD-Audio in high definition audio storage. Subsequently, the integrative framework is applied to the case.

Chapter 6 – The paradox of standard flexibility *(published in Organization Studies)*
This chapter delves deeper into the effect of two elements that influence the emergence of a de-facto standard: 'collaborative technology development' and 'building an organizational community that supports the technology'.

Chapter 7 – Managing intellectual property using patent pools *(published in California Management Review)*
This chapter focuses on one specific element of the framework: 'accessibility to intellectual property rights'.

Chapter 8 – Cross case analysis
In this chapter the results of the three case studies are compared to investigate if the findings can be generalized, and if generic patterns can be identified. Where applicable, specific insights from the two other papers are included in the analysis.

Chapter 9 – Conclusion
This chapter summarizes the main findings, limitations and suggestions for future research.

Multiple chapters of this dissertation have been published in academic journals, and these were written as 'stand-alone' papers. Where needed, a prologue or epilogue was added to provide context or to add information which was omitted from the paper to adhere to the requirements of the journal (e.g. an overview of the respondents) or relevant for the cross-case analysis.

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# Chapter 2 - Integrative framework for the emergence of de-facto standards

In this Chapter, an integrative framework will be developed by first identifying the various elements that shape the odds of a technology emerging as the de-facto standard. Secondly, we will attempt to categorize the elements (e.g. those that can be utilized strategically vs. those that are outside a firm's span of control). Thirdly, we attempt to differentiate them by level of importance in the decision of an agent to adopt a technology, and investigate the known relationships between the elements. Finally, we will identify the phases and milestones in the emergence of a de-facto standard. Section 2.1, 2.2 and 2.4 were presented at a conference and published in its proceedings,[170] the version in this dissertation was updated by including recent literature.

The following starting points were used in devising the framework:

- Considering that the aim is to add to the strategic-choice perspective, the framework is devised from the perspective of a technology sponsor (i.e. an entity that has property rights to the technology and hence is willing to invest in its adoption)[171]
- As the emergence of de-facto standard is represented by rival incompatible technologies within a single product category competing for market adoption, and the de-facto standard is determined by customers adopting a technology,[172] the customer (and its tendency to adopt a particular technology) is at the center of the framework
- It should encompass de-facto standards in all its facets (platforms, dominant designs, interface standards), on any level in a product hierarchy (complete system, sub-system), and irrespective of a particular market.
- In accordance with Suarez (2004), I presume that no single factor is strong enough to tilt the balance in favour of a particular technology; the final outcome is the result of the interplay of multiple firm-, technology- and environment-level variables
- Elements that are known to facilitate or frustrate the emergence of a de-facto standard will both be included. Technological competitions can have several outcomes (i.e. winner-take-all, market dominance, oligopoly, and failure to replace the old de-facto standard), and the framework should be able to provide insights in such outcomes as well.

## 2.1 Elements influencing odds of technology selection

As described in Section 1.5, 47 sources where analyzed, of which 27 theoretical and 20 empirical. In total, 36 elements were labelled. An overview of these and a short description is presented in Table 1. The elements in the table are ranked on the basis of the frequency of the codes. Appendix 1 presents a more detailed description of the elements. Table 2 shows the elements that were identified per theoretical publication, and Table 3 shows the elements that were identified per empirical publication. Of the 47 sources, I identified the most elements in Cusumano et al (1992) and Shapiro & Varian (1999), which each contained 22 elements. Compared to these two sources combined (which renders 29 individual elements), my analysis provides an additional 7 elements.

Table 1: Overview of elements influencing odds of technology selection

| Element | # of results | Short description |
|---|---|---|
| Technological superiority | 39 | A technology is superior when it has features that allow it to outperform competing alternatives. These features comprise of the pure effect of technology (e.g. picture quality of video storage media), and differentiating features (e.g. amount of video that can be recorded on a video tape) |
| Entry timing | 36 | Point in time when the first product based on a particular technology enters the market. The technology that is first to market can benefit from increasing returns to adoption and a head start in establishing an installed base. |
| Network effects | 33 | The utility of a technology to a customer increases with the number of customers that use the technology |
| Availability of complementary goods | 31 | Products or services that increase the utility of a technology. Goods are complementary to a technology when they adhere to a common compatibility standard. Generally dubbed 'software'. |
| Appropriability | 28 | Ability to protect the innovation from imitation by competitors and capture the profits generated by it. Dependent on solid intellectual property rights, a secure R&D and manufacturing environment, and the efficacy of legal mechanisms |
| Pricing | 27 | Use of a pricing strategy (e.g. penetration pricing) to stimulate market adoption |
| Organizational community of supporters | 27 | Community comprised of competitors and/or complementors that has some degree of hard- and/or software compatibility. Often requires active development by a technology sponsor. Its success is defined by the amount of parties, diversity, and market shares. |
| Government intervention and industry regulation | 27 | The government may act as an early adopter of a particular technology, provide subsidies to promote adoption or erect trade barriers, subject a technology sponsor to antitrust scrutiny, and it may mandate the use of a particular technology. |
| Marketing and pre-announcements | 25 | Creating market awareness regarding the availability of a technology, informing the customer of its strengths, and influencing customer and industry perception regarding its potential success |
| Installed base | 24 | The number of users applying a particular technology at a certain moment in time, the number of users of products of a particular firm, or the number of products in use |
| Firm's complementary assets | 21 | Particular capabilities or resources which support the commercial success of a technology. This relates to the extent to which a firm is vertically or horizontally integrated. |
| Switching and homing cost | 19 | Switching costs are costs that customers incur to move from one technology to another. Homing costs include all the expenses incurred by technology users. If homing costs are low, customers may adopt multiple technologies |
| Reputation and credibility | 19 | A recognized brand name and sponsorship of de-facto standards creates expectations for the potential success of a new technology |
| Strategic partnerships | 18 | Contractual relationship with providers of complementary goods and distributors to more rapidly deploy the technology, or gain access to new technologies |
| Level of competition | 18 | Number of incompatible technological alternatives that are competing in the market for adoption and the strength (financially and in terms of market share) of their supporters |
| Technological knowledge and skill base | 17 | A firm's amount and type of technological skills (e.g. know-how in magnetic recording equipment) |
| Level of collaborative development | 15 | Extent to which a technology sponsor engages into a collaboration with its competitors to develop a shared technology |
| Availability of products | 13 | The extent to which products based on a particular technology are available to the customer |
| Absorptive capacity | 13 | A firm's ability to recognize the value of new information, to assimilate it, and to apply it to commercial ends |
| Increasing returns to adoption | 12 | As a technology is adopted, greater knowledge and understanding accrues as a by-product and enables improvements. Revenues generated by the adoption can be used to further develop and refine the technology |
| Chance | 12 | In technological trajectories with network externalities, random (insignificant) events may become magnified by positive feedback loops and 'tip' the market towards a particular outcome |

| | | |
|---|---|---|
| Market and industry characteristics | 12 | Structure and dynamics of the market and technological field, e.g. excess inertia vs. insufficient friction, rules of engagement and information sharing practices |
| Rate and type of technological change | 12 | The pace of technological change in an industry affects the willingness of suppliers and buyers to invest in a technology and influences the desirability of committing to a specific technology |
| Firm size | 11 | Financial resources, number of industries and geographical markets in which the technology sponsor has a presence and its market share in these |
| Backward compatibility | 10 | A technology is backwards compatible when it is designed to be interoperable with, or accommodate products from, the previous technology generation |
| Powerful rival technology sponsors | 9 | Competing technology sponsors that have the resources required either to imitate a technology, even in the face of high barriers to imitation, or to develop their own, possibly superior, technology |
| Type of technological innovation | 9 | A sponsor can set out to develop an innovation that is either incremental, modular, architectural, or radical. This choice impacts the superiority of the technology, its backward compatibility, appropriability, ability to engage in collaborative development, and ability to build-up an organizational community to support it |
| Adapters and gateways | 8 | Establishes compatibility between non-compatible systems by enabling conversion from one side to the other |
| Availability of imitators | 8 | Companies imitating a technology or its complementary goods. Imitators can increase the amount of products or complements on the market |
| Pre-empting scarce assets | 8 | Anticipating on the path of technological development and preserving future rights to scarce assets (e.g. materials, specific distribution channels or complementary products) and intellectual property |
| Unclear assessment criteria | 8 | Customer ambiguity regarding the features that they value and require in a new technology |
| Technological breakthroughs in subsystems | 7 | Advances and breakthroughs in subsystems that enable a technology to move from prototype to commercially feasible product |
| Technological performance trajectories | 7 | Disruptive technologies, often inferior to existing technologies, open up new (niche) markets. Subsequent sustaining radical and incremental innovations can raise the technology's performance along steep trajectories and enable it to migrate to established (mass) markets |
| Killer application | 7 | Application of the technology that possesses a set of attributes meeting customer demands and stimulates market adoption |
| Hetero- or homogeneity of customer needs | 7 | Markets with homogenic customer needs are prone to 'tipping' under network externalities, whereas markets with heterogenic customer needs are more likely to sustain multiple technologies |
| Product proliferation | 4 | Serving as many niches as feasible by customizing the product offering to appeal to different users |
| | | |

Table 2: Elements identified per theoretical publication

| | **Theoretical research** | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Anderson et. al (1990) | Arthur (1989) | Arthur (1994) | Arthur (1996) | Besen (1994) | Bower et.al (1995) | Clark (1985) | Dosi (1982) | Eisenmann, 2008 | Gallagher & West (2009) | Grindley (2002) | Hill (1997) | Katz and Shapiro (1985) | Katz et. al (1986) | Katz et. al, 1994 | Lee et. al (1995) | Liebowitz et. al, 1996 | McGrath et. al (1992) | Nair and Ahlstrom (2003) | Schilling (1998) | Schilling (2002) | Shapiro et. al (1999) | Srinivasan et. al (2004) | Suarez et. al (1995) | Suarez (2004) | Teece (1986) | Van de Kaa et. al (2011) |
| Technological superiority | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Entry timing | 1 | 1 | 1 | 1 | 1 | 1 | | | 1 | 1 | 1 | 1 | | | | 1 | 1 | 1 | | 1 | 1 | 1 | | 1 | 1 | 1 | 1 |
| Network effects | | | 1 | 1 | 1 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability of complementary goods | 1 | | 1 | 1 | 1 | | | | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | | 1 | | 1 | 1 | 1 | 1 | | | 1 | 1 |
| Appropriability | 1 | | | | 1 | | | | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | | 1 | 1 | | 1 | 1 | 1 |
| Pricing | 1 | 1 | | 1 | 1 | | | | 1 | 1 | 1 | 1 | | 1 | 1 | | 1 | | | 1 | | 1 | | | 1 | 1 | 1 |
| Organizational community of supporters | 1 | | | 1 | 1 | | | | 1 | | 1 | 1 | 1 | | 1 | 1 | | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | | |
| Government intervention and industry regulation | 1 | 1 | 1 | | | | | 1 | 1 | | 1 | | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 |
| Marketing and pre-announcements | | | | 1 | 1 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | | 1 | | 1 | | | 1 | | 1 |
| Installed base | | | 1 | 1 | 1 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | | | 1 | | 1 | 1 | 1 | | | 1 | | 1 |
| Firm's complementary assets | | | | 1 | 1 | | | | | 1 | 1 | 1 | | | | 1 | | 1 | | | | 1 | | 1 | 1 | 1 | 1 |
| Switching and homing cost | 1 | | | 1 | 1 | | | | 1 | 1 | | | | | 1 | 1 | | 1 | 1 | | | 1 | | | 1 | | 1 |
| Reputation and credibility | | | | | 1 | | | | | 1 | 1 | 1 | 1 | | 1 | | | 1 | | | | 1 | | 1 | 1 | 1 | 1 |
| Strategic partnerships | | | | | 1 | | | | | | 1 | 1 | | | 1 | 1 | | | | 1 | 1 | | | | | 1 | 1 |
| Level of competition | | | | | 1 | | 1 | | 1 | | 1 | 1 | | | | | | | | | | | | | 1 | | |
| Technological knowledge and skill base | | | | 1 | | | | 1 | | | | 1 | | | | 1 | | | 1 | 1 | 1 | | | | | 1 | |
| Level of collaborative development | 1 | | | | 1 | | | | 1 | | 1 | 1 | | | | 1 | | | | 1 | | 1 | | | | | |
| Availability of products | | | | | 1 | | | | | 1 | 1 | 1 | 1 | | | | | | | | | | | | | 1 | |
| Absorptive capacity | | | | | | | | | | | | | | | | 1 | | | 1 | 1 | 1 | 1 | | | | | 1 |
| Increasing returns to adoption | 1 | 1 | 1 | | | 1 | 1 | | | | | | | | | | | 1 | | 1 | 1 | | | | | | |
| Chance | | 1 | 1 | 1 | | | | | | | | 1 | | | | | 1 | | 1 | | 1 | 1 | | | | | |
| Market and industry characteristics | | | | | | | | | | | | | | 1 | 1 | | | 1 | 1 | | | | | | 1 | | |
| Rate and type of technological change | 1 | | | | | | | | | | | | | | | 1 | | | 1 | | | | | | | | 1 |
| Firm size | | | | 1 | | | | | 1 | 1 | | | | | | | | | | 1 | | | | 1 | | 1 | 1 |
| Backward compatability | | | | | | | | | | 1 | 1 | 1 | | | | 1 | 1 | | | | | 1 | | | 1 | | 1 |
| Powerful rival technology sponsors | | | | | | | | | 1 | | | 1 | | | | | | | | | | | | | | | |
| Type of technological innovation | 1 | | | | | 1 | | | | | | | | | | | | 1 | | | | 1 | 1 | | | 1 | |
| Adapters and gateways | | | | | 1 | | | | | 1 | 1 | | 1 | | 1 | | | | | | | 1 | | | | | |
| Availability of imitators | | | | | 1 | | | | | | | | | | | | | | | | | 1 | 1 | 1 | | 1 | |
| Pre-empting scarce assets | | | | | | | | | 1 | | | | | | | | | 1 | | | | 1 | | | | 1 | 1 |
| Unclear assessment criteria | | | | | | 1 | 1 | | | | | | | | | | | | 1 | 1 | 1 | | | | | | 1 |
| Technological breakthroughs in subsystems | | | | | | | | | | | | | | | | | | | 1 | | | | | | | | |
| Technological performance trajectories | | | | | | 1 | | 1 | | | | | | | | | | | 1 | | | | | | | | |
| Killer application | | | | | | | | | | 1 | | | | | | | | | | | | 1 | | | | | |
| Hetero- or homogeneity of customer needs | | | | | | 1 | | | | 1 | | | | | 1 | | 1 | 1 | | | | | | | | 1 | |
| Product proliferation | | | | | | | | | 1 | | 1 | 1 | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Number of elements found per publication | 12 | 6 | 8 | 13 | 18 | 7 | 4 | 3 | 16 | 17 | 19 | 21 | 10 | 7 | 15 | 14 | 10 | 16 | 12 | 17 | 13 | 22 | 7 | 9 | 15 | 16 | 19 |

Table 3: Elements identified per empirical publication

| | Empirical research | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Christensen et. al (1998) | Clymer & Asaba (2008) | Cusumano et. al (1992) | David (1985) | David et. al (1988) | Funk (2003) | Gallagher et. al (2002) | Garud et. al (1993) | Garud et. al (2002) | Khazam et. al (1994) | Klepper et.al (2000) | Langlois (1992) | Rosenbloom et. al (1987) | Schilling (2000) | Schilling (2003) | Shankar et al. (2002) | Smit et. al (1998) | Tripsas (1997) | Wade (1995) | Willard et. al (1985) |
| Technological superiority | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | | | 1 | | 1 | 1 | 1 | 1 |
| Entry timing | 1 | | 1 | 1 | 1 | 1 | | | 1 | | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 |
| Network effects | | | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | | 1 | 1 | | 1 | 1 | 1 | | 1 | |
| Availability of complementary goods | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | | | | 1 | |
| Appropriability | | 1 | 1 | | 1 | 1 | | | | 1 | | 1 | | | 1 | | 1 | 1 | 1 | |
| Pricing | | 1 | 1 | 1 | | | | | | | 1 | 1 | | 1 | 1 | 1 | | 1 | | 1 |
| Organizational community of supporters | | 1 | 1 | | | | | 1 | 1 | 1 | 1 | | | 1 | 1 | | | | 1 | |
| Government intervention and industry regulation | | | 1 | | 1 | 1 | 1 | | 1 | 1 | 1 | | 1 | | | | 1 | | | |
| Marketing and pre-announcements | | | 1 | | 1 | | 1 | | 1 | 1 | 1 | | | 1 | 1 | 1 | 1 | | | 1 |
| Installed base | | | | 1 | | 1 | 1 | | | 1 | | | 1 | 1 | 1 | 1 | | | 1 | 1 |
| Firm's complementary assets | | | 1 | | | | 1 | | | 1 | | | | 1 | 1 | | 1 | 1 | | 1 |
| Switching and homing cost | | | | 1 | 1 | | 1 | 1 | | | | | | | 1 | | 1 | | 1 | |
| Reputation and credibility | | | 1 | | | | 1 | | 1 | | | 1 | 1 | | 1 | | 1 | 1 | | 1 |
| Strategic partnerships | | 1 | 1 | 1 | | | | | | 1 | 1 | | 1 | | 1 | | | 1 | | 1 |
| Level of competition | | | 1 | 1 | 1 | | | 1 | 1 | 1 | | 1 | | 1 | | | 1 | | | 1 |
| Technological knowledge and skill base | | 1 | 1 | | | | 1 | 1 | | 1 | 1 | 1 | | | | | | 1 | | 1 |
| Level of collaborative development | | | 1 | | | | | 1 | 1 | 1 | | | | 1 | 1 | | | | | |
| Availability of products | | | 1 | | | | 1 | | | | | 1 | | | | | 1 | | 1 | 1 |
| Absorptive capacity | | | 1 | | | | 1 | 1 | | | | | | | | | 1 | 1 | | 1 |
| Increasing returns to adoption | | | | | | | 1 | | | | | | 1 | 1 | | | 1 | 1 | | |
| Chance | | 1 | | 1 | 1 | | | | | | | | 1 | | | | | | 1 | |
| Market and industry characteristics | | | 1 | | | | 1 | | 1 | | | 1 | | 1 | | | 1 | | 1 | |
| Rate and type of technological change | 1 | | | | | | 1 | 1 | | | 1 | 1 | | | | | 1 | 1 | 1 | |
| Firm size | | | 1 | | | | 1 | | | | 1 | | | | 1 | | | | | 1 |
| Backward compatability | | | | | | | | 1 | | | | | | | 1 | | | | | |
| Powerful rival technology sponsors | | | 1 | | | | 1 | 1 | 1 | 1 | | 1 | | 1 | 1 | | | | | |
| Type of technological innovation | 1 | | | | | | 1 | | | 1 | | | 1 | | | | | | 1 | |
| Adapters and gateways | | | | | 1 | | | | | | | | | | | | | | | |
| Availability of imitators | | | | | | | | 1 | | | | 1 | | | | | | | 1 | |
| Pre-empting scarce assets | | | 1 | | | 1 | 1 | | | | | | | | | | | | | |
| Unclear assessment criteria | | | | | | | 1 | | | | | | 1 | 1 | | | 1 | | | |
| Technological breakthroughs in subsystems | | | | | 1 | | | | | | | 1 | 1 | 1 | 1 | | | | | |
| Technological performance trajectories | 1 | 1 | | | | | 1 | | | | | | | | | | 1 | | | |
| Killer application | | | | | 1 | | 1 | | | | | 1 | | 1 | 1 | | | | | |
| Hetero- or homogeneity of customer needs | | | | | | | | | | | | | | | 1 | | | | | |
| Product proliferation | | 1 | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | |
| Number of elements found per publication | 5 | 10 | 22 | 9 | 13 | 8 | 21 | 13 | 14 | 16 | 9 | 16 | 12 | 15 | 20 | 4 | 17 | 11 | 14 | 13 |

## 2.2 Categorizing the elements

In order to gain a better understanding which elements are within or outside of a firm's scope of influence, and to further pursue the inductive coding process, my next step was to group elements in clusters.

The academic literature on de-facto standards (i.e. Suarez and Utterback[173]; Tushman and Rosenkopf[174]; Lee et al.[175]; Smit and Pistorius[176]; Suarez[177]; Van de Kaa et al.[178]) provides several propositions for grouping elements, however there is no consensus on the best approach. Suarez and Utterback state that the emergence of a de-facto standard is the result of a fortunate combination of technological, economic, and organizational elements. Tushman and Rosenkopf claim that de-facto standards emerge from selection through technological logic, social and organizational dynamics. Lee et al. suggest that the underlying elements and forces influencing the emergence of a de-facto standards consist of certain external conditions, a set of technological and non-technological (amongst which organizational) driving forces, and the concept of assets which are complementary to the commercial viability of a design. Building on the framework of Lee et al., Smit and Pistorius propose a more extensive framework and group the elements in eight categories: technological, market, economic, social and behavioral elements, standards and regulations, political elements, organizational elements and strategic elements. Suarez states that different technological trajectories compete for market dominance through a process where economic, technological and socio-political elements are intertwined, and proposes to cluster these elements in firm-level and environmental elements. He further notes that this broad distinction is consistent with the existing school of thought in management that stresses the importance of firm level capabilities and resources and environmental elements on the performance of different firms in an industry. Finally, Van de Kaa et al. propose an extensive overview of elements for interface format dominance, and divide these over five groups: characteristics of the format supporter, characteristics of the format, format support strategy, other stakeholders, and market characteristics.

As the categories proposed by Suarez are supported by the existing school of thought in management, this distinction was initially followed and the elements were roughly divided into firm and environmental elements. However, while categorizing these elements I encountered some difficulties; following the content analysis I initially grouped the factor of installed base within the category of firm level elements, however I found that several sources instead referred to the installed base of the technology itself as influencing the emergence of the technology as de-facto standard. This occurred for multiple elements.

I also noticed that when the elements were grouped within the firm and environmental level, both levels contained a cluster of technology related elements. These findings, supported by the findings of Lee et al., Smit and Pistorius, and Van de Kaa et al., which all indicate to have found elements related to the specific technology, made me decide to follow the original proposition of Suarez and Utterback that the emergence of a dominant design is a result of technological, economic (environment) and organizational elements. As such I set-out to categorize the overview of elements as listed in the previous section into three categories: firm, technology and market/industry.

### *2.2.1 Allocating elements to categories*

In order to allocate the 36 elements to the three categories, I reviewed the same set of 47 sources again and performed content analysis. For each source, the identified elements were reviewed and the highlighted texts were used to deduct if a source linked an element to a particular category. Before commencing the analysis it was imperative to define the categories, the basis for allocating an element to a category, and to modify the coding process.

The following definitions were used to set the boundaries of the three categories:

- Firm: the technology sponsor, with its assets, resources, customer base, and product range
- Technology: a technology or productized implementation of the technology, as developed by the sponsor and influenced by the market or industry. It can be a system or sub-system, and it can be hardware or software.
- Market / industry: the market or industry in which the technologies compete for adoption. It comprises of customers, competitors, complementors, (potential) collaborators, the existing de-facto standard, rival technologies, and potential substitutes

While reviewing the texts, two points were taken into consideration for allocating the elements to categories; 1) if the element would influence the customer decision to adopt a particular technology from a particular category, and 2) if the customer would consider a particular element inherent to the firm, the technology, market or environment when it is presented with the decision to adopt a technology. As such, the element of 'rate and type of technological change' was categorized under 'market / industry', because it concerns the 'pace of the industry'. Another example is the element of 'backward compatibility'. While the ability of a technology to be backwards compatible depends heavily on choices made by the technology sponsor, it is an element that is inherent to the technology when it is presented to the customer. It requires mentioning that all technology related elements (e.g. technological superiority, adapters and gateways) are heavily influenced by the technology sponsor or the environment.

Lastly, the coding process required a minor modification as this analysis required tracking which elements from which source could be allocated to a particular category. First, the 47 sources were provided with a code (i.e. a number, shown by Table 4). Subsequently a matrix was constructed with the three categories on the horizontal axis, and the 36 elements on the vertical axis. During the content analysis, when an element could be linked to a category, the number of the source was noted in the matrix. The result is shown by Table 5. While categorizing the elements, only a sub-set of the total amount of elements identified per source in the previous section could be allocated, because it was not always possible to deduce from the source to which category an element could be linked.

Table 4: Coding of the sources

| Source | Nr. |
|---|---|
| Anderson et. al (1990) | 1 |
| Arthur (1989) | 2 |
| Arthur (1994) | 3 |
| Arthur (1996) | 4 |
| Besen (1994) | 5 |
| Bower et.al (1995) | 6 |
| Christensen et. al (1998) | 7 |
| Clark (1985) | 8 |
| Clymer & Asaba (2008) | 9 |
| Cusumano et. al (1992) | 10 |
| David (1985) | 11 |
| David et. al (1988) | 12 |
| Dosi (1982) | 13 |
| Eisenmann, 2008 | 14 |
| Funk (2003) | 15 |
| Gallagher & Park (2002) | 16 |
| Gallagher & West (2009) | 17 |
| Garud et. al (1993) | 18 |
| Garud et. al (2002) | 19 |
| Grindley (2002) | 20 |
| Hill (1997) | 21 |
| Katz and Shapiro (1985) | 22 |
| Katz et. al (1986) | 23 |
| Katz et. al, 1994 | 24 |
| Khazam et. al (1994) | 25 |
| Klepper et.al (2000) | 26 |
| Langlois (1992) | 27 |
| Lee et. al (1995) | 28 |
| Liebowitz et. al, 1996 | 29 |
| McGrath et. al (1992) | 30 |
| Nair and Ahlstrom (2003) | 31 |
| Rosenbloom et. al (1987) | 32 |
| Schilling (1998) | 33 |
| Schilling (2000) | 34 |
| Schilling (2002) | 35 |
| Schilling (2003) | 36 |
| Shankar et al. (2002) | 37 |
| Shapiro et. al (1999) | 38 |
| Smit et. al (1998) | 39 |
| Srinivasan et. al (2004) | 40 |
| Suarez et. al (1995) | 41 |
| Suarez (2004) | 42 |
| Teece (1986) | 43 |
| Tripsas (1997) | 44 |
| Van de Kaa et. al (2011) | 45 |
| Wade (1995) | 46 |
| Willard et. al (1985) | 47 |

Table 5: Elements allocated to type of influence

| | **Category** | | |
|---|---|---|---|
| | Firm | Technology | Market / industry |
| Technological superiority | | 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14, 15, 16, 17, 18, 19, 20, 21, 23, 24, 25, 27, 29, 30, 31, 33, 35, 36, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47 | |
| Entry timing | 1, 3, 4, 5, 6, 7, 10, 11, 12, 14, 15, 16, 17, 19, 20, 21, 26, 27, 28, 29, 30, 32, 33, 34, 35, 36, 38, 39, 41, 42, 43, 44, 45, 46, 47 | | |
| Network effects | | 4, 10, 11, 12, 14, 15, 16, 17, 18, 20, 21, 22, 23, 24, 27, 28, 29, 33, 34, 35, 36, 37, 38, 40, 41, 42, 46 | 5, 10, 11, 18, 22, 23, 25, 28, 29, 33, 34, 39, 40, 42, 45, 46 |
| Availability of complementary goods | 4, 5, 9, 10, 12, 14, 16, 17, 18, 21, 25, 30, 33, 34, 35, 36, 38, 45, 46 | | 1, 3, 4, 5, 9, 10, 11, 12, 14, 15, 16, 17, 19, 21, 22, 24, 25, 27, 33, 34, 36, 38, 40, 43 |
| Appropriability | 5, 9, 10, 15, 16, 21, 23, 24, 25, 28, 29, 30, 33, 36, 38, 39, 43, 45 | | 1, 5, 10, 12, 14, 17, 22, 27, 33, 40, 42, 43, 46 |
| Pricing | 1, 2, 4, 5, 9, 10, 11, 14, 16, 17, 20, 21, 23, 24, 27, 29, 33, 34, 36, 37, 38, 42, 43, 44, 45, 47 | | |
| Organizational community of supporters | 1, 4, 5, 9, 10, 14, 16, 18, 19, 20, 21, 22, 24, 25, 26, 28, 30, 32, 33, 34, 35, 36, 38, 40, 41, 42, 46 | | |
| Government intervention and industry regulation | | | 1, 2, 3, 10, 12, 13, 14, 15, 19, 22, 24, 25, 26, 28, 29, 30, 31, 32, 33, 35, 38, 39, 41, 42, 43, 45 |
| Marketing and pre-announcements | 4, 5, 10, 12, 16, 17, 19, 20, 21, 22, 23, 24, 25, 29, 30, 33, 34, 36, 37, 38, 39, 42, 45, 47 | | |
| Installed base | 5, 15, 16, 20, 21, 22, 25, 30, 36, 37, 38, 42, 45, 47 | 3, 4, 5, 11, 15, 17, 20, 23, 24, 33, 34, 35, 46 | |
| Firm's complementary assets | 4, 5, 10, 16, 17, 20, 21, 25, 28, 30, 32, 34, 36, 38, 39, 41, 42, 43, 44, 45, 47 | | |
| Switching and homing cost | | 1, 4, 11, 12, 14, 16, 17, 18, 24, 28, 30, 31, 36, 38, 39, 42, 45, 46 | |
| Reputation and credibility | 5, 10, 17, 19, 20, 22, 24, 27, 30, 36, 38, 39, 41, 42, 43, 44, 45, 47 | | |
| Strategic partnerships | 5, 9, 10, 11, 16, 20, 21, 24, 25, 28, 33, 35, 36, 43, 44, 45, 47 | | |
| Level of competition | | | 5, 8, 10, 11, 12, 14, 16, 18, 19, 20, 21, 25, 27, 32, 34, 39, 42, 45, 47 |
| Technological knowledge and skill base | 4, 9, 10, 13, 18, 21, 25, 26, 27, 28, 31, 32, 33, 35, 43, 44, 47 | | |
| Level of collaborative development | 1, 5, 10, 14, 18, 19, 20, 21, 25, 28, 32, 33, 34, 36, 38 | | |
| Availability of products | 10, 16, 17, 20, 22, 32, 39, 46, 47 | | 5, 10, 17, 21, 22, 27, 32, 43, 46 |
| Absorptive capacity | 10, 16, 17, 18, 28, 31, 32, 33, 35, 38, 39, 44, 45, 47 | | |
| Increasing returns to adoption | | 1, 2, 3, 6, 8, 30, 32, 33, 34, 35, 39, 44 | |

| | | | |
|---|---|---|---|
| Chance | 2, 3, 11 | 2, 3, 10, 29, 35 | 2, 3, 35, 38, 46 |
| Market and industry characteristics | | | 10, 16, 24, 27, 30, 31, 34, 39, 42, 46 |
| Rate and type of technological change | | | 1, 7, 16, 18, 26, 27, 28, 31, 39, 44, 45, 46 |
| Market share and financial resources | 4, 10, 14, 17, 26, 33, 36, 41, 43, 45, 47 | | |
| Backward compatability | | 17, 18, 20, 21, 28, 29, 36, 38, 42, 45 | |
| Powerful rival technology sponsors | | | 10, 14, 18, 19, 21, 25, 27, 34, 36 |
| Type of technological innovation | | 1, 6, 7, 25, 30, 35, 38, 40, 43, 46 | |
| Adapters and gateways | | 5, 12, 16, 17, 20, 22, 24, 38 | |
| Availability of imitators | | | 5, 18, 27, 38, 40, 41, 43, 46 |
| Pre-empting scarce assets | 10, 14, 15, 16, 30, 38, 43, 45 | | |
| Unclear assessment criteria | | | 6, 8, 31, 33, 34, 35, 39, 45 |
| Technological breakthroughs in subsystems | | 12, 16, 27, 31, 32, 34, 36 | |
| Technological performance trajectories | | 6, 7, 9, 13, 31, 32 | |
| Killer application | 16, 17, 34, 36, 38 | | 12, 16, 17, 27, 36 |
| Hetero- or homogeneity of customer needs | | | 6, 17, 24, 29, 30, 36, 43 |
| Product proliferation | 14, 20, 21 | | 9 |

### *2.2.2 Elements allocated to multiple categories*

As Table 5 shows, eight elements were allocated to multiple categories: network effects, availability of complementary goods, appropriability, installed base, availability of products, chance, killer application and product proliferation. The multiple allocation of these elements means that they are able to influence a customer in distinctly different ways, and therefore should be considered as separate elements in the development of the integrative framework. For example, by taking into account that there are two aspects of network effects and two aspects to an installed base which don't necessarily both apply to a situation. In order to indicate the difference between the allocation to one category or another, Table 6 shows the eight elements, their allocation, and a short description of the element per category based on the respective source texts.

Table 6: Allocation of the eight elements to multiple categories including short description

| | Firm | Technology | Market/Environment |
|---|---|---|---|
| Network effects | | Direct network effects; utility of a technology to a customer is dependent on the number of users connected to the same network (e.g. fax machines) | Indirect network effects; utility of a technology to a customer increases with the availability of complementary goods in the market |
| Availability of complementary goods | Complementary goods marketed by the technology sponsor | | Complementary goods marketed by other companies in the industry |
| Appropriability | Firm's intellectual property rights | | Efficacy of legal mechanisms to enforce the property rights |
| Installed base | Installed base of the firm | Installed base of the technology | |
| Availability of products | Products marketed by the technology sponsor | | Products marketed by other companies in the industry |
| Chance | Whim of early developers | Unexpected performance of a prototype | Political circumstances |
| Killer application | Application of the technology that possesses a set of attributes meeting customer demands, marketed by the technology sponsor | | Application of the technology that possesses a set of attributes meeting customer demands, marketed by another company in the industry |
| Product proliferation | Range of products adhering to the needs of a variety of market niches, marketed by the technology sponsor | | Range of products adhering to the needs of a variety of market niches, marketed by other companies in the industry |

### *2.2.3 Elements for strategic decision making*

The elements which are in- or outside the scope of a technology sponsor have now been identified. However, not all elements in the scope of a technology sponsor are subject to strategic decision making, and considering our strategic-choice perspective it is imperative to understand which elements can be influenced by a technology sponsor as part of its strategy. Before commencing the analysis, it was important to define under what conditions an element would be considered to be subject to strategic decision making, and to establish the set of elements that would be reviewed.

The following criteria were used to define which elements were subject to strategic decision making:

- Should be subject to influence by a technology sponsor's executive team during the technological development, market launch and technology competition. In accordance with McGrath et al (1992), I adopt the view that strategic decision making is performed by an executive team that has been tasked by the technology sponsor to optimize its rents on the innovation
- Short time to implementation; upon decision making it should be possible to initiate the change within a short timeframe (although actual results may become apparent as late as a few years thereafter)
- In the view of the customer, the element would not qualify as inherent to the firm

In the analysis, I limited the set of elements to those of Subsection 2.2.1 that were allocated to the 'firm' and 'technology' category, because these are within a firm's scope of influence. I subsequently reviewed each element, and performed content analysis on the respective sources to deduct if the element could be considered as inherent to the technology sponsor or subject to strategic decision making. Table 7 provides an overview of the allocation of the elements; 6 elements were considered to be inherent to the technology sponsor, and 16 elements were considered to be subject to strategic decision making. The technological elements 'switching and homing cost', 'increasing returns to adoption', 'technological performance trajectories' and 'technological breakthroughs in subsystems' were not included in Table 7 since they were not found to be 'inherent to the technology sponsor' or 'subject to strategic decision making'.

Table 7: Overview of elements for strategic decision making

| | Inherent to the technology sponsor | Subject to strategic decision making |
|---|---|---|
| Firm | Reputation and credibility | Pricing |
| | Installed base | Marketing and pre-announcements |
| | Complementary assets | Entry timing |
| | Firm size | Availability of complementary goods |
| | Absorptive capacity | Availability of products |
| | Technological knowledge and skill base | Killer application |
| | | Appropriability |
| | | Product proliferation |
| | | Strategic partnerships |
| | | Organizational community of supporters |
| | | Level of collaborative development |
| | | Pre-empting scarce assets |
| Technology | | |
| | | Technological superiority |
| | | Backward compatibility |
| | | Type of technological innovation |
| | | Adapters and gateways |

## 2.3 Direct or indirect influence

In the previous section, 36 elements were found to influence the emergence of a de-facto standard, but this makes one wonder if all these elements influence a customer's decision to the same extent. As next step, I set out to learn if some elements could be considered to be more important than others in the decision of a customer to adopt a particular technology.

Rather than trying to quantify the measure of influence of each element, I chose to differentiate them on the basis of their direct or indirect influence on the customer's decision. In other words, to determine the first and second order effects on a customer's decision to adopt a technology. My motivation to prefer this approach over a quantifying the influence is twofold: 1) while studying the empirical research on the emergence of de-facto standards it became apparent that the influence of an element differed per technology competition, so a quantifiable approach did not appear promising, and 2) it seemed unlikely that all 36 elements would have a direct influence on the customer's decision and this required further study.

In order to determine which elements have a direct or indirect influence, I took a two stage approach. First, I set-out to identify the elements that have a direct influence (the first order elements). Subsequently I aimed to uncover the inter-element relationships. This second step provided insights which second order elements influenced a particular first order element. In addition, it helped to identify any third order elements (those influencing only second order elements).

### *2.3.1 First order elements*

The first stage was performed by investigating the 36 elements, and a content analysis of the 47 sources to identify which elements directly influenced a customer's decision. One of the leading indicators was for a source to mention that a particular element would stimulate a technology's installed base (i.e. amount of users). The results of the analysis can be found in Table 8. The left side of Table 8 presents the 15 first order elements that were identified, and the right side lists the corresponding sources (using the number coding of Table 4).

Table 8: Overview of the 15 elements with first order influence on a customer's decision

| **Direct influence on customer's decision** | **Sources** |
|---|---|
| Technological superiority | 3, 4, 5, 7, 9, 10, 15, 16, 17, 25, 28, 29, 30, 36, 46 |
| Entry timing | 3, 5, 12, 16, 17, 29, 30, 33, 34, 36, 38, 42 |
| Network effects | 17, 18, 22, 29 |
| Availability of complementary goods | 3, 10, 11, 14, 19, 20, 21, 33, 34, 35, 36, 38, 40, 42 |
| Pricing | 4, 5, 10, 14, 16, 17, 20, 21, 24, 26, 29, 33, 36, 38, 42, 44 |
| Marketing and pre-announcements | 5, 16, 17, 20, 21, 24, 29, 33, 34, 36, 38, 42 |
| Installed base | 22, 23, 25, 28, 29, 33, 35, 36, 37, 42 |
| Switching and homing cost | 1, 12, 16, 17, 24, 42 |
| Reputation and credibility | 20, 22, 24, 36, 42, 44, 46 |
| Level of competition | 5, 12, 16, 21, 39, 46 |
| Availability of products | 10, 16, 21, 22, 36, 40, 46 |
| Market and industry characteristics | 16, 24, 39, 42 |
| Rate and type of technology change | 1, 28, 39 |
| Backward compatibility | 20, 21, 36, 38, 42 |
| Killer application | 12, 16, 36, 38 |

### *2.3.2. Inter-element relationships and second order elements*

In order to gain an overview of the inter-element relationships, a matrix was constructed with the 36 elements on both the horizontal and vertical axis. The elements on the vertical axis were labelled as 'influencing elements' and the ones on the horizontal axis were labelled as 'influenced elements'. The relationships between elements were derived by performing another content analysis of the 47 sources. When a relationship could be deduced from a source, this was noted in the matrix using the code of the source in accordance with Table 4. The element of 'installed base' was omitted as influenced element, because this reflects the elements that directly influence a customer's decision to adopt a technology and therefore has already been addressed in the previous section.

In total, 122 relationships were found. Appendix 2 provides an overview of the results (the overview was divided over two pages due to the size of the 36x36 matrix). The results show that nearly each first order element is influenced by one or more second order elements. Each non-first order element was found to influence a first order element, and therefore I regard all of these as second order elements.

While determining the relationships, the elements 'increasing returns to adoption' and 'network effects' caused some difficulty, because these represent positive feedback mechanisms; increasing returns to adoption refers to the positive feedback loop between an increase in installed base and improving the technology, and network effects refer to the positive feedback loop between an increase in the installed base and the availability of complementary goods. The different nature of these two elements will be taken into account when constructing the integrative framework.

## 2.4 Phases and milestones in the emergence of a de-facto standard

A de-facto standard does not emerge overnight. Technology competitions often go through several phases and span multiple years. It is therefore important to define the phases and milestones in the emergence of a de-facto standard. This area of academic research is, however, relatively underdeveloped. Several scholars have proposed phases and milestones. Utterback and Abernathy (1975) propose that the emergence progresses through three phases: fluid phase, transitional phase, and a mature phase. Tushman and Anderson (1986) propose two phases: era of ferment and an era of incremental changes. The era of ferment is triggered by a technical discontinuity, and selection of a dominant design marks the transition to the era of incremental changes.

Of all frameworks, the phases and milestones as proposed by Suarez (2004) is best suited for studying the emergence of de-facto standards as it is well grounded in academic literature and developed specifically for understanding the process by which a technology emerges as de-facto standard. Suarez states that the emergence of a de-facto standard can be described in terms of a few key milestones as shown by Figure 26. Each milestone marks the start of a new phase in the technology competition. The beginning of the technological field ($T_0$) can be traced back to the moment when a pioneer firm or research group starts doing applied R&D aimed at the technological innovation. A second milestone ($T_P$) is marked by the appearance of the first working prototype based on the technological innovation. The first working prototype sends a powerful signal to all firms in the race that at least one of the technological trajectories is feasible and has been developed to such a level that there will soon be a product in the market. Third milestone ($T_L$) in the process is the launching of the first commercial product, which for the first time, directly connects a technology coming out of the lab to customers. The first product in the market is often too expensive for the mass market and therefore aimed at the high end of the market. The early market, typically a relatively small one when compared to the mass market, helps a particular technology become an early "forerunner". The presence of a clear front runner marks the fourth milestone ($T_F$) in the technology competition. This front runner has a chance of winning the competition, as its larger installed base tends to create a bias towards the technology with the largest market share. The final outcome will depend on how fast competitors improve on their own technologies and how fast the market grows. Finally a specific technology emerges as the de-facto standard and marks the last milestone ($T_D$) of the competition.

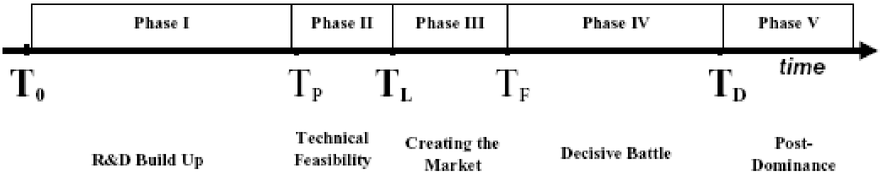


*Figure 26: Milestones in the process of technological dominance (Source: Suarez, 2004)*

The amount of time needed for a technology to go from the beginning of the technological field ($T_0$) to becoming the de-facto standard ($T_D$) depends on the type of technological discontinuity (Anderson et. al, 1990). When a technology builds on a completely new knowledge base, many rival designs appear, and it will take longer for market forces to sort out these variants.

## 2.5 The integrative framework

The previous sections were required to generate the insights necessary for developing a framework that can be used to support strategic decision making to shape the odds of a technology emerging as the de-facto standard. But before progressing to the integrative framework, a data matrix for the structured case study analysis will be presented.

### *2.5.1 Data matrix as case analysis tool*

The concept behind the data matrix is to have a tool which will allow for a structured historic analysis of each case, and enables me to focus on obtaining the relevant details. The matrix was constructed by adopting the phases of Suarez (2004) on the horizontal axis, and combined these with a set of elements on the vertical axis. As elements, I took the 36 as shown in Table 1, divided these into their respective categories in accordance with Table 5. When an element was allocated to multiple categories, these were treated as separate elements and included on the vertical axis in their respective categories. Lastly, per category the elements were ranked on their type of influence on the customer's decision; first order elements were ranked first and the second order elements were placed thereafter. The resulting data matrix is shown by Table 9.

.

Table 9: Case analysis tool

| | | R&D Build-up | Preparing for market entry | Creating the market | Decisive battle | Post-dominance |
|---|---|---|---|---|---|---|
| **Firm** | Reputation and credibility | | | | | |
| | Installed base | | | | | |
| | Pricing | | | | | |
| | Entry timing | | | | | |
| | Marketing and pre-announcements | | | | | |
| | Availability of products | | | | | |
| | Availability of complementary goods | | | | | |
| | Killer application | | | | | |
| | Size | | | | | |
| | Complementary assets | | | | | |
| | Technological knowledge and skill base | | | | | |
| | Absorptive capacity | | | | | |
| | Pre-empting scarce assets | | | | | |
| | Level of collaborative development | | | | | |
| | Organizational community of supporters | | | | | |
| | Strategic partnerships | | | | | |
| | Product proliferation | | | | | |
| | Appropriability | | | | | |
| | Chance | | | | | |
| | | | | | | |
| **Technology** | Technological superiority | | | | | |
| | Installed base | | | | | |
| | Network effects | | | | | |
| | Switching and homing cost | | | | | |
| | Backward compatibility | | | | | |
| | Increasing returns to adoption | | | | | |
| | Technological breakthroughs in subsystems | | | | | |
| | Type of technological innovation | | | | | |
| | Adapters and gateways | | | | | |
| | Technological performance trajectories | | | | | |
| | Chance | | | | | |
| | | | | | | |
| **Market / industry** | Market and industry characteristics | | | | | |
| | Level of competition | | | | | |
| | Rate and type of technological change | | | | | |
| | Network effects | | | | | |
| | Availability of products | | | | | |
| | Availability of complementary goods | | | | | |
| | Killer application | | | | | |
| | Availability of imitators | | | | | |
| | Hetero- or homogeneity of customer needs | | | | | |
| | Unclear assessment criteria | | | | | |
| | Powerful rival technology sponsors | | | | | |
| | Government intervention and industry regulation | | | | | |
| | Product proliferation | | | | | |
| | Appropriability | | | | | |
| | Chance | | | | | |

As Table 9 shows, the data matrix can function as a checklist for the researcher to investigate per phase which elements influenced the emergence of the de-facto standard.

### *2.5.2 Integrative framework of elements that shape the emergence of a de-facto standard*

This chapter began with the goal to devise a integrative framework that integrated the various elements of the emergence of a de-facto standard (e.g. market mechanisms, models for creating a technology bandwagon, elements for shaping the odds of technology selection), differentiated between types of elements (i.e. firm, technology, and market/industry related), their influence on a customer's decision to adopt a technology, influences between elements, and the phases and milestones in the emergence of a de-facto standard.

In accordance with previous frameworks as described in Subsection 1.2.4, I devised a graphic representation of the results of the previous sections. As a starting point, I took the 36 elements that were identified in Section 2.1, and colour coded them based on their allocation to the firm, technology or market/industry category as defined in Section 2.2. The elements that can be utilized for strategic decision making were accentuated by a dotted line. Subsequently the results of Section 2.3 were used to differentiate the first- and second order elements. A circle was used to denote a barrier between the first- and second order elements, and the first order elements were placed inside the circle, whereas the second order elements were placed outside of the circle. Then I moved to draw arrows between the elements, indicating the influences between them. However, the graphic representation could not facilitate the great number of relationships without becoming undecipherable. So for the graphic representation, I decided to prioritize practicality over completeness and included only a few (often one or two) influences per element. The relationships included in the graphic representation were based on a review of Appendix 2, whereby I selected the one or two influences per element that had the highest concentration. I hereby took the assumption that there is a correlation between the number of sources that described a relationship between two elements, and its importance in shaping the odds of the emergence of a de-facto standard. Lastly, I reviewed the integrative framework. A major modification was the decision to omit the element 'chance'. During the analysis on the relationships between elements, it became apparent that the element can randomly influence any particular element. Therefore, one could say that chance is an ever present and uncontrollable event, which makes technology competitions to some extent unpredictable. For this reason it has no place in the framework.

The phases in the emergence of a de-facto standard, as identified in Section 2.4, were not included in the framework to not further complicate it. Instead, I propose to utilize the integrative framework as a summary / snapshot of a phase, whereby the dynamics of a technology competition are captured in five summaries / snapshots wherein multiple firm, technology and market/industry related elements shape the odds of the emergence of a de-facto standard. Applying the integrative framework in the case studies shall have to point out if this allows to adequately capture the process. Figure 27 shows the integrative framework.

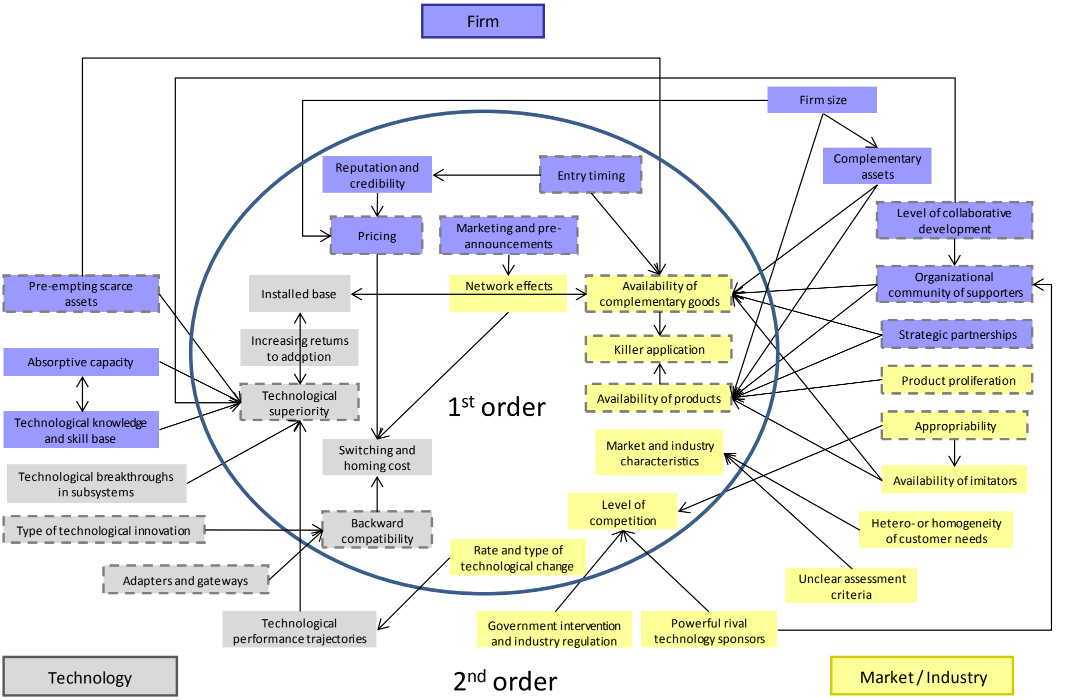


*Figure 27: Integrative framework of elements that shape the odds for the emergence of a de-facto standard*

As can be seen from Figure 27, the elements of 'increasing returns to adoption' and 'network effects' were placed on an arrow between two other elements (as a result the element of 'increasing returns to adoption' has been depicted between the first order elements). This was done to account for their nature as positive feedback mechanism, which is different from the other elements; as mentioned in Subsection 2.3.2., increasing returns to adoption refers to the positive feedback loop between an increase in installed base and improving the technology, and network effects refer to the positive feedback loop between an increase in the installed base and the availability of complementary goods. In Figure 27, we can see that the element of 'installed base' and 'availability of complementary goods' influence each other is moderated by 'network effects'. The same holds for the element of 'installed base' and 'technological superiority' which is moderated by 'increasing returns to adoption'.

### *2.5.3. Assessing the position of the technology sponsor versus its rivals*

While the integrative framework shown by Figure 27 provides insight in the actions that a technology sponsor can take, it does not offer a mechanism to evaluate the position of the technology sponsor versus its rivals during the technology competition. As mentioned in Section 1.3, it is important to include this perspective in order to gain a more thorough understanding of a technology sponsor's ability to shape the odds at a given moment during the technology competition.

Hence, I propose a simple assessment method which can be used in combination with the case analysis tool (Table 9) or the integrative framework (Figure 27) so they can function a as 'dashboard'. First, one needs to identify the elements at play during the respective phase of the technology competition. Then, a score can be attributed on how the technology sponsor's (A) situation compares to that of its rival (B). To this end I propose a simple scoring method whereby the options are shown in Table 10.

Table 10: Scoring options

| | |
|---|---|
| ● | A has a distinct advantage over B |
| ◕ | A has the advantage over B |
| ◑ | There is no apparent advantage for either A or B |
| ◔ | B has the advantage over A |
| ○ | B has a distinct advantage over A |
| Blank | Element is not utilized or not applicable |

Following this, one has an overview of the elements at play and how the technology sponsor scores on these versus its competitor. The resulting overview has the potential to be used as a diagnostic tool, showing where the firm is outperforming its competitor or vice-versa, and which elements are underutilized. In combination with the integrative framework or the tables in Appendix 2, one could even go as far as to determine which second order elements it needs to shape in order to influence a particular first order element.

Besides the case analysis tool and the integrative framework, I will apply the scoring method to the three cases to gain insight if (in retrospect) a technology sponsor could indeed evaluate the situation and identify the relevant elements to shape the odds in its favor.

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# Chapter 3 - Pushing technological progress by strategic manoeuvring: The triumph of Blu-ray over HD-DVD

**Published in Business History, 55 (8), 2013, pp.1361-1384**

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**Abstract**

After the Digital Versatile Disc became the consumer's technology of choice for playing video content in 1996, several consumer electronics companies in parallel initiated the development of the next generation optical discs. This eventually led to a format war between two similar but incompatible high definition optical disc formats: Blu-ray and HD-DVD. The companies behind these formats could not reach consensus on a combined format and either side was unable to impose a dominant technology, therefore they needed to compete for dominance in the marketplace. HD-DVD was first to enter the market with a high definition optical disc player in 2006. In addition, HD-DVD players were significantly cheaper than Blu-ray players. Nevertheless, it did not win the format war due to the strategic manoeuvring of the companies in the Blu-ray Disc Association. Differently from what was experienced in previous format wars, consumers did not determine the outcome. The format war was ultimately decided by tipping the amount of company support for Blu-ray throughout the supply chain and using the technology adoption characteristics of the video game console industry.

**Keywords:** Format wars; Blu-ray, HD-DVD; dominant design, innovation management

## 3.1 Introduction

Since the last quarter of the twentieth century, the 4.7-inch optical disc has been a successful technological format for digital data storage. The success of the 4.7-inch optical disc started in the late 1970s, when Philips and Sony combined their respective technologies to develop the first mass market optical disc for data storage: the audio Compact Disc. The result marked a huge leap in consumer audio by delivering high quality sound on a durable medium with instant playback. In 1991, nine years after introducing the technology to the market, the audio CD had become the dominant format for audio storage, thereby replacing the compact cassette tape. In order to leverage the format to other markets, in June 1985 Sony and Philips introduced the computer-readable CD-ROM, which became a widely applied data storage medium in the computer industry.

Several years before market introduction of the CD, a mass market for video storage was created by the videocassette recorder format war between VHS and Betamax. Sony launched Betamax in 1975, and found support from companies such as Toshiba and Sanyo.[179] VHS was launched by JVC in 1976, and soon thereafter other companies that supported VHS (the most important being Panasonic, then known as Matsushita) also launched products on the market. After VHS had won the format war in the 1980s, Sony managed to recoup some of its losses by receiving license fees from patents that were required for both VHS and Betamax. Although Toshiba also had some patents on a key technology used in both formats, the patents on this invention were close to expiration and it could therefore not recoup the loss by Betamax's failure. This caused Toshiba to hold a grudge against Sony.

Aiming to repeat the success of the CD format, in December 1994 Sony and Philips announced the development of a new optical disc format for digital video storage, called the MultiMedia Compact Disc (MMCD). However, one month later a consortium of several companies including Panasonic (wanting to uphold its position in video storage), Toshiba and Warner announced that they were developing an alternative format: the SuperDensity (SD) disc. In September 1995, pressured by the computer industry, the two factions agreed to combine their technologies into a new format: the Digital Versatile Disc (DVD). The DVD format was much closer to the SD disc format than the MMCD format. Little of MMCD's fundamental technology was transferred into the DVD format. The groups united to form the DVD Consortium (which was renamed 'DVD-Forum' in 1997), to help the DVD format to rapidly gain adoption. The market transition from video cassettes to optical discs took six years (from 1997 to 2003), faster than any other technology transition in consumer electronics (Peek et al., 2009). Following the outcome, Sony and Philips wanted a more equal distribution of the license income, but this was not accepted by the other members of the DVD Consortium. Sony and Philips subsequently left the DVD Consortium patent pool (DVD6C) and established a separate patent pool (DVD3C). In effect, companies that wanted to manufacture DVDs required a license from both patent pools. This move by Sony and Philips worsened the relationship with Toshiba. After becoming the dominant format in the video recording industry, the DVD format also became dominant in the video game console industry and a widely applied data storage medium in the computer industry. Due to the success of CD and DVD, the optical disc has become a widely applied digital data storage format with a dominant market share in several large markets, some of which are listed in Table 11.

Table 11: Market penetration of the 4.7-inch optical disc format

| | 1980 | 1991 | 1998 | 2003 |
|---|---|---|---|---|
| Music players | Compact Cassette tapes | CD | CD | CD |
| Computer software | Floppy discs | Floppy discs | CD | DVD |
| Video players | VHS | VHS | VHS | DVD |
| Video game consoles | Tapes | Cartridges | Cartridges | DVD |

While the DVD was becoming the consumer's technology of choice for playing video content at the end of the 1990s, several companies in parallel started developing the next generation optical discs. By 2007, seven high-definition optical disc formats competed for consumer adoption; Blu-ray, HD-DVD, Versatile Multilayer Disc, CH-DVD, EVD, AOSRA, and Forward Versatile Disc. [180] The two most serious competitors were Blu-ray and HD-DVD, which attracted the most industry support and the largest consumer base. In their struggle for market dominance, the two formats faced a more complex environment than their predecessors. As shown in Table 1, the four product categories using the 4.7-inch optical disc format in 2003 all used different storage media in 1980. Whereas these products each had a single function in 1980, in 2003 a video player could be used both for playing video and audio, and video game consoles could be used for playing video games, videos and audio. With the success of the optical disc format in these product categories and the convergence of product functionalities, it had become more difficult to introduce a new optical disc format due to the necessity for building larger and more diverse networks of companies supporting the innovation.

From the early years of the optical disc industry, innovation was always led by a group of large-scale, integrated firms of the sort that Alfred D. Chandler Jr. observed in his studies of several of the world's largest industries.[181] The increasing convergence of product functionalities and the increased difficulty to introduce a new optical disc format retained the necessity of large-scale, integrated firms as an engine of progress in this industry. The optical disc industry also illustrates Schumpeter's notion of 'creative destruction'[182]; CD, DVD and Blu-ray were all based on new intellectual property portfolios because these formats were radical rather than incremental innovations. Format wars, such as the competition between the high-definition optical disc formats, demonstrate different competitive dynamics than markets in which competitors can coexist relatively peacefully, as they often have a single tipping point which shifts the balance to one side.[183] Tipping of the market towards one technology is often driven by network effects[184]; the phenomenon that the value of a product to an individual customer depends on the number of other users of that product.[185] Different from previous format wars in videocassette recorders[186], microcomputers and operating systems[187] and internet browsers[188] which suggest that 'the market decides', in the format war of Blu-ray versus HD-DVD, consumers did not play a decisive role. The outcome of this format war was determined by the amount of company support for the formats, which was influenced by strategic manoeuvring. Therefore, the events in the high definition optical disc format war add new insights to what is currently known on strategies and tactics in format wars[189] which focus on customer adoption of new technologies. With the technology being a platform used in multiple product categories, it connects different supplier and distribution networks. Therefore, the more parties an alliance manages to attract, the stronger its position in the format war. Due to the on-going integration of technologies and markets, we expect to see such format wars unfold more often.

## 3.2 Initial development of Blu-ray and HD-DVD: the R&D build-up (1986-2000)

*3.2.1 Enabling the technological development with blue laser diodes*

In 1998, commercial high definition television (HDTV) sets began to appear in the US and Japanese consumer market. But there was no commonly accepted, inexpensive way to record or play high definition content. The CD and DVD format were based on red laser diodes, and due to their wavelength these optical disc systems were not able to store the amount of data required for HDTV recording. A new format had to be developed, using shorter-wavelength lasers.

In 1986, the Japanese company Toyoda Gosei started developing blue laser diodes under the guidance of Professor Isamu Akasaki.[190] However, the required technological breakthrough was achieved by a team of scientists led by Shuji Nakamura at Nichia Corporation that produced the first commercial blue laser diodes in 1993.[191] Blue light has the shortest wavelength of visible light. With a blue laser diode the amount of data that could be read and stored on a 4.7 inch optical storage disc could be quadrupled, enabling high density optical media capable of recording HDTV. Although the blue lasers became commercially available in 2001, it took another two to three years[192] before the price was low enough for mass market consumer products. A legal battle between several companies (e.g. Nichia, Toyoda Gosei and Cree[193]) from 1996 to 2002[194] led to limited availability and high prices for the blue laser diodes ($5000 for a sample), and made companies reluctant to license technology from either company.

The invention of blue-laser diodes was a first step in creating a high definition optical disc format. To create a disc that could store the required amount of data, one had to choose between two technical approaches:

- Compressing the digital information to a lower data rate (use less digital data) to data capacity levels supported by DVD based technology. This lower bit rate would, however, degrade the high definition picture quality.
- Recording the data at the higher data rate required by HDTV, but use new technology that would support the higher data rate and higher data capacity. This approach allowed the high definition signal to pass without excessive compression, preserving the detail of the original high definition picture.

*3.2.2 Developing the DVR-Blue format*

Due to their long relationship, at the end of 1997, Sony and Philips decided to collaborate on a high definition optical disc format. Concerning the technological approach, an executive at one of these consumer electronics companies stated: "It was a strategic choice to work on a technology with five times more storage capacity than DVD because we believed that in the future, motion picture studios would have the need for more disc capacity (to include more interactivity features, etc.) and because consumers require a substantial improvement in order to switch to a new system". As such, Sony and Philips chose to support the higher data rate and data capacity required to record HDTV. This required new technologies, leading to a new intellectual property base. They combined their new high-numerical aperture lens, advanced tilt servo system and phase change material[195] and started developing DVR-Blue, the technology which would eventually become Blu-ray.[196] With a data storage capacity of 25GB (gigabytes), about four hours of HD video, on a single layer disc the technology was far more advanced than DVD technology (4.7GB for single layer disc).[197] Due to the importance of video recorders in Japan (which accounted for 60% of DVD player/recorder shipments in 2005), the DVR-Blue format was set-up as a video recorder and the development started with a rewritable disc.

The most important technological difference between DVR-Blue and its predecessors was its disc structure. As Figure 28 shows, the data layer of the CD was located at the bottom of a substrate and the data area of the DVD was placed in the middle of a disc. To create room for extra data layers, and as such the potential to store more data, the DVR-Blue discs were designed to keep the data layer close to the surface; they were composed of a single substrate instead of two halves,[198] placing the data layer 0.1mm from the surface. Because the data layer was so close to the laser, the design had little allowance to scratches and the discs required a caddy. The design called for a more complex lens, which had to be made of glass rather than the less expensive plastic used for other types of optical players.

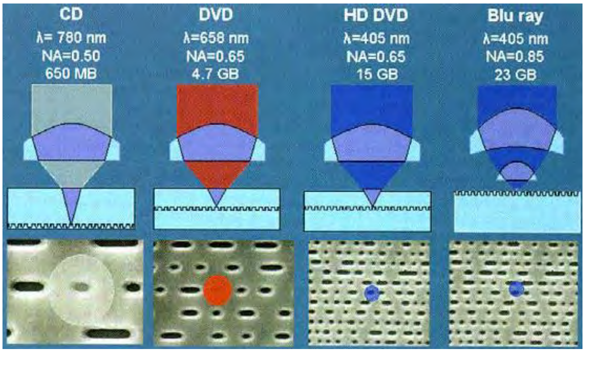


*Figure 28: Optical disc technology roadmap*[199]

The technology base of DVR-Blue was also used to target other markets. In November 2000, Plasmon and Sony jointly announced the development of the Ultra Density Optical technology as a high capacity storage solution for data servers.[200]

## 3.3 Preparing for market entry: Building business networks, shifting allegiances and efforts to merge the formats (2000-2006)

In October 2000, Sony and Philips presented the first DVR-Blue prototype.[201] It was based on an intermediate version of the format (version 0.5), leaving sufficient room for other parties to provide suggestions for modifications. Half a year later, Matsushita (Panasonic) presented a prototype of their high definition optical disc format.[202] Sony and Philips, having learnt the importance of building a network of consumer electronics companies supporting a technology from the format war between VHS and Betamax[203] and wanting to prevent another costly format war, invited Panasonic to join their partnership. Panasonic evaluated both formats and decided to support DVR-Blue because of its superior storage capacity. Panasonic contributed valuable aspects of their own format, including its dual layer technology which enabled the discs to double their storage capacity to 50GB. Involving Panasonic was a very important move for Sony and Philips due to Panasonic's abilities and reputation. An executive at one of the consumer electronics companies stated: *"Throughout history, when Panasonic supported a technology, that technology won the format war. Therefore Panasonic was an obvious key player that we wanted to attract in the development of DVR-Blue"*. Together, the three companies developed the standard to version 0.9.

In order to fully prevent a format war and increase the support behind DVR-Blue, the three parties aimed at involving eight other large consumer electronics manufacturers. Each contacted those companies they had the closest relationship with. Toshiba and Mitsubishi Electric declined the offer. Due to their stake in the intellectual property of DVD, Toshiba decided to pursue its own technological development, thereby moving towards a format war. A former Japanese government official stated: "*Toshiba's decision to develop their own format was also motivated by their grudge towards Sony from previous format wars*". Mitsubishi Electric did not want to adhere to the stringent non-disclosure demands for evaluating DVR-Blue. A few years later, in 2003, Mitsubishi Electric reconsidered and decided to support the format; the arguments from a business perspective prevailed over those from the intellectual property perspective. Mitsubishi's decision to choose DVR-Blue over Toshiba's format was based on the larger alliance size and larger disc capacity.

On 19 February 2002, nine large consumer electronics companies (Sony, Philips, Hitachi, LG, Panasonic, Pioneer, Samsung, Sharp and Thomson) formed the Blu-ray Disc Founders (BDF) and DVR-Blue was renamed to Blu-ray. These nine companies developed the format to version 1.0, which was completed in June 2002. Licensing of version 1.0 started in February 2003.

In August 2002, Toshiba and NEC publicly announced their competing format Advanced Optical Disc (AOD was later renamed to HD-DVD).[204] AOD was built upon the intellectual property of the DVD format, while adding new intellectual property for the HD application. In developing AOD, Toshiba and NEC chose to reduce the data rate in order to record HDTV. The surface layer of AOD discs was similar to DVD (0.6mm). This technology was more evolutionary than revolutionary, with a data storage capacity of 15 GB of data, or about 2.5 hours of HD video, on a single layer disc. In October 2002, Toshiba gave the first public demonstration of an AOD prototype.[205]

The different disc designs influenced the lens pickup apertures (0.65 for AOD vs. 0.85 for Blu-ray), which made the two formats technically incompatible despite using the same type of blue laser diodes. The companies behind both formats understood the importance of low switching cost to enable consumers to migrate to the new format. To achieve this, both groups made their formats backwards compatible, enabling them to play CD and DVD discs. AOD used a single plastic lens that could operate with both blue and red lasers, but the Blu-ray systems required a separate lens for a red laser besides the glass lens for the blue laser,[206] increasing its manufacturing cost. Due to the different technological choices in developing the formats, Blu-ray and AOD were positioned differently. AOD discs were cheaper to manufacture, because they used the same manufacturing equipment as DVDs (existing DVD-Video fabrication plants could be retrofitted to produce AOD discs and the projected cost for retooling a plant for AOD was $150,000, versus $3,000,000 for Blu-ray). Blu-ray had a higher data capacity of 25GB versus 15GB for AOD on a single layer disc, and a theoretical limit of 200GB versus 60GB.

Shortly after founding the BDF, the focus of the Blu-ray development changed. Several of the new network members made clear that pre-recorded discs and content were required to make the technology successful. Their experience with DVD had taught them that consumers were not really interested in a new format for recording, but adopted the new format for playing pre-recorded discs. Therefore, the companies started to work on a read-only disc for motion pictures. With this change in course, they saw the importance of gaining commitment from content providers (the major film studios) and the IT industry. In order to obtain support from the major film studios, in 2002-2003 Sony, Philips and Panasonic organized a series of meetings between their engineers and the major film studios. This led to a decision by 20th Century Fox and the Walt Disney Company in the autumn of 2004 to pledge support for Blu-ray. To obtain support from these film studios, the BDF agreed to include a three layer content protection (AACS, ROM mark and BD+[207]), region coding, additional video codecs (providing content providers more flexibility to pack more content on a disc)[208] and a new video application format. According to an executive at a consumer electronics company "*20th Century Fox and Walt Disney have fewer, but very strong titles in comparison to other major film studios, and due to their size it is more difficult to launch movies world-wide on the same date. Therefore, content protection and region coding are especially important to these two studios*". The importance of the copy protection is also reflected in its ownership; BD+ was developed and licensed in a collaborative effort by Sony, Panasonic and 20th Century Fox. AOD also used AACS content protection, but that was its single form of content protection. Region codes denote the areas of the world in which distribution and playback of the discs are intended, and allow studios to control various aspects of a release, such as date and price, per region. AOD did not have region codes in their technical specifications. The companies in the BDF were initially divided over the issue of including region coding. Around 2003-2004 the European Commission was investigating the region coding of DVD due to an anti-trust issue (Neuwirth, 2009) but because 20th Century Fox and Walt Disney required region coding, the BDF decided in 2004 to include it in the format. They limited the amount of regions to three, half the number used for DVD. A key requirement for the new video application format was advanced interactivity and web connectivity, for which a new programmable environment needed to be created. After long consideration, in September 2003 the BDF agreed to proceed with the development of a Java-based programmable platform.

With Blu-ray gaining momentum, the DVD-Forum (initially known as the DVD Consortium), chaired by Toshiba, was divided on whether to support the blue lasers (9 of the 17 members of the DVD-Forum Steering Committee were also the founders of the BDF, thereby uniting outside the Forum). The technical decisions made during the development of Blu-ray resulted in a more expensive medium and physically different from DVDs. In order to avoid what would be a costly shift to blue-laser technology, only a week after the creation of the BDF, the DVD-Forum approved a proposal endorsed by Warner Bros. and other major film studios that involved compressing HD content onto dual-layer DVD-9 discs. Six of the 17 companies in the Steering Committee, including Panasonic, Sony and Philips, abstained. In spite of this decision, in June 2002 the DVD-Forum's Steering Committee decided to form two subgroups to study the best technical approach based on blue laser optical disc applications,[209] in order to adopt a successor for the DVD format. The first of the two subgroups was formed in the same month and immediately started studying a disc format with a 0.6mm surface layer. The Blu-ray format was never formally proposed to the DVD-Forum, although some of the parties in the BDF lobbied in the Steering Committee for acceptance. On 29 August 2002, Toshiba and NEC proposed the AOD format to the DVD-Forum,[210] but were thwarted twice when Blu-ray members of the Steering Committee either abstained or voted against.[211] Political tactics and rhetoric from both sides were in play. Toshiba pointed at the immaturity of Blu-ray; the discs used a caddy, along with the higher cost required for retooling by disc manufacturers. The Blu-ray camp countered with continuing efforts and historical precedence to placate those concerns along with their future capacity and higher bit stream rates. But the biggest issue was the future revenue from licensing and royalties. Blu-ray was based on new intellectual property, whereas AOD was based on the intellectual property base of DVD. By accepting AOD, the intellectual property base of DVD would still generate revenues. In order to break the stand still, Toshiba managed to get the Steering Committee to accept a proposal changing the voting rules to allow absentee votes not to count in the final tally while also accepting the addition of three new members to the Steering Committee. This resulted in AOD winning final approval in November 2003 without a majority. Subsequently the AOD format was renamed to HD-DVD.

DVD-Forum’s support for HD-DVD provided additional momentum. Many disc replicators and smaller companies relied on the DVD-Forum to indicate where the industry would be headed and decided to support the HD-DVD format. However, with the DVD-Forum being a mere means of collaboration, it could not impose industry regulation. As Blu-ray was based on new intellectual property, the BDF could continue the development of the format without requiring licenses from the DVD-Forum.

An important aspect in a format war is to be first to launch a product on the market; whoever is first to market can build-up an installed base of users. On 10 April 2003, Sony introduced the first commercially available high definition disc recorder, the BDZ-S77.[212] This product targeted the niche market of recording the HD image of the digital satellite broadcasting (launched in Japan in December 2000) and the terrestrial digital broadcasting (launched in Tokyo, Nagoya and Osaka in December 2003). Due to the importance of recorders in Japan and the shift of focus in the technological development, the BDZ-S77 was only made available in Japan and the recommended price was ¥450,000 (US$3,815). The Sony BDZ-S77 was based on version 1.0 Blu-ray Disc Rewritable format, using Sony proprietary BDFS as logical format and 23GB discs with a caddy. Sony wanted to be the first to market a Blu-ray device to show that they were the main party behind Blu-ray. However, the timing of market entry was too early. Consumer adoption of the BDZ-77 and a later model from Panasonic was not very successful due to the price (which was much higher compared to the hard disc drive recorders which had entered the market at the end of 2001 and satisfied the same consumer need) and because the products experienced technical problems. Nevertheless, the device did enable the companies in the BDF to learn about the consumer requirements for the new format.

In order to gain commitment from the IT industry, in 2003 the BDF decided to modify version 1.0 to their requirements by replacing Sony's logical format with the non-proprietary logical format UDF. They also committed to find an alternative solution for the caddy. As a result, in January 2004 the world's two largest PC manufacturers, Hewlett Packard and Dell, joined the BDF. Two months later the BDF announced the addition of TDK, a leading manufacturer of optical discs, which had developed a new hard-coat polymer. The hard-coating enabled the cost-efficient production of robust, bare Blu-ray discs. By eliminating the caddy, the cost of the discs was reduced.

Following its collaboration with Sony in 2000, Plasmon announced the global debut of their UDO drive for data archival storage based on DVR-Blue in March 2003. Later that year, the first products entered the market. On 7 April 2003, Sony announced its own format for data archiving applications,[213] ProData, which was based on Blu-ray. Sony's first products based on the ProData format were shipped in June 2004. Next to ProData, Sony also developed XDCAM HD which targeted yet another market; broadcasters and AV studios.[214] The first XDCAM HD entered the market in April 2006. This prolific approach in leveraging the DVR-Blue and Blu-ray technology to other markets increased market demand for e.g. Blu-ray discs.

By 2004 the market for DVD began to saturate, creating a sense of urgency with the major film studios to cooperate in developing a new format. Because of the success of the optical disc format in multiple product categories, the supporters of both formats vied for support from companies in various industries (e.g. major film studios, video game studios, optical disc manufacturers, disc replicator and authoring companies, providers of disc production, replication and authoring equipment, consumer electronics manufacturers, computer manufacturers, game console manufacturers, and retailers). Although the process to diversify the business network supporting the formats started in 2003, this got a significant boost in 2004. Appendix 1 provides a timeline containing the major events in the development of the respective business networks.

On 18 May 2004, the 13 members of the BDF announced to be re-incorporated into the Blu-ray Disc Association (BDA). Companies wishing to participate in the future development of Blu-ray and support the format were welcomed into the BDA. Three months later, more than 70 companies from the consumer electronics, information technology, media and software industry had joined.

In September 2004 Sony, owner of the film studios Sony and Columbia Pictures, acquired Metro Goldwyn Mayer (MGM), expanding its complementary assets and enlisting its support for Blu-ray. In the same month, Sony announced that their game console PlayStation 3 (PS3) would use Blu-ray discs.[215] The practical reason for integrating a Blu-ray player in the PS3 was that Blu-ray could support the increasing amount of data required for the graphics of its games. A strategic reason was that Sony realized the PS3 could function as a 'killer app', just as their PlayStation2 had been for the DVD format. Several studies have shown the importance of a 'killer app'. Shapiro & Varian (1999) note that Walt Disney's Wonderful World of Color was the 'killer app' for colour television sets, and Oshri, De Vries & De Vries (2010) report the Mosaic browser was the 'killer application' for the Internet. Another strategic reason was to show the industry, and primarily the major film studios, that Sony was fully committed to making Blu-ray a success.

In addition of the DVD-Forum's support, Toshiba, Sanyo, NEC and Memory-Tech established the HD-DVD Promotion Group in December 2004. This entity was created to provide additional momentum behind promoting the HD-DVD format and to enhance the development of content and hardware made in compliance with the format.

Back in 2002, Microsoft had announced plans to deliver HD-enhanced new DVD content using an interactive menu system called HDi (initially known as iHD). In order to run HDi, new players would need to incorporate a small computer. Intel supported Microsoft's plans, having an interest that such a small computer would be based on its microprocessors. Microsoft hoped to get both Blu-ray and HD-DVD to adopt HDi.  Hewlett Packard in turn invited Microsoft to support Blu-ray for playback under Windows, which HP would need for its Blu-ray-equipped PCs. Microsoft demanded that the Blu-ray group would adopt HDi in order for its support. In 2005, the BDA performed a three-month evaluation of BD-J and HDi. By the end of June 2005, Sun announced that the BDA had chosen the Java-based BD-J interactivity layer instead of Microsoft's HDi. The BDA Board of Directors voted 10 to 4 in favour of BD-J, despite an earlier 7 to 5 vote by the technical committee in favour of HDi. The choice for BD-J instead of HDi was one of the most difficult and important decisions in the development of the Blu-ray format because it concerned the intelligence of the player. Several of the IT companies and major film studios had a strategic alliance with Microsoft and therefore had a preference for HDi. However, some BDA members strongly preferred BD-J because of its interoperability with other products, and the interactivity and broadband-ready new functions. Adopting HDi would also allow Microsoft to enter the consumer electronics market and gain an influential role in the Blu-ray disc format. In addition, the manufacturers of Blu-ray players would need to integrate Intel products. Both were not in the interest of the consumer electronics companies supporting Blu-ray.

The Japanese Ministry of Economy, Trade and Industry (METI) wanted to avoid the impeding format war. In April 2005, METI urged Toshiba, Sony and Panasonic to initiate negotiations for unifying their formats. Panasonic and Sony proposed the combination of the Blu-ray disc physical format and HD-DVD application (video) format, however Toshiba insisted on the HD-DVD physical format because it believed low cost was very important. For all companies it was important to come to a consensus whereby none would lose face. Both sides regarded that the 'winner' of the negotiations would be the one that had its optical disc substrate thickness selected. Both sides could not find a resolution for this, and on 22 August 2005, the BDA and DVD-Forum announced that the negotiations to unify their formats had failed.

As a result of the BDA's decision to select BD-J and the negotiations not altering this, in September 2005 Microsoft and Intel announced their exclusive support for HD-DVD (which had already included HDi as a mandatory part of the specification). HP made a last attempt to broker an agreement between the BDA and Microsoft. It demanded that the BDA would adopt Microsoft's HDi and a mandatory managed copy feature, otherwise it would support HD-DVD. Eventually, the BDA did not comply with HP's requests and in December 2005, HP announced it would support both formats.

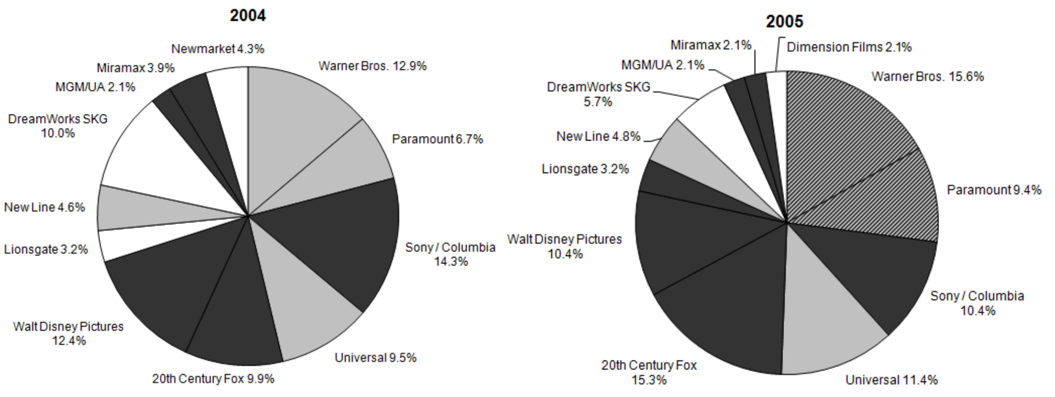


*Figure 29: Major film studios committed to Blu-ray (black), HD-DVD (grey), and not committed (white) end of 2004 and 2005, including studio market shares.*[216]

Figure 29 shows that at the end of 2004 each format had the exclusive support of three of the big six film studios. But in October 2005, Warner Bros. and Paramount decided to also support Blu-ray. Warner's decision to withdraw its exclusive support for HD-DVD was the first time it diverged from its commitment to Toshiba and put a strain on their long relationship. The reason behind Warner's decision was that they wanted to sell their products regardless of the format, and at that point it was clear that Blu-ray would be launched. Moreover, Panasonic had established a pilot production line of Blu-ray discs earlier that year[217] with new (inexpensive) manufacturing technology that reduced the price of the Blu-ray discs.[218]

In November 2005 Sony and NEC agreed to merge their optical disc storage groups,[219] which was later fully acquired by Sony. This weakened NEC's support for the HD-DVD format.

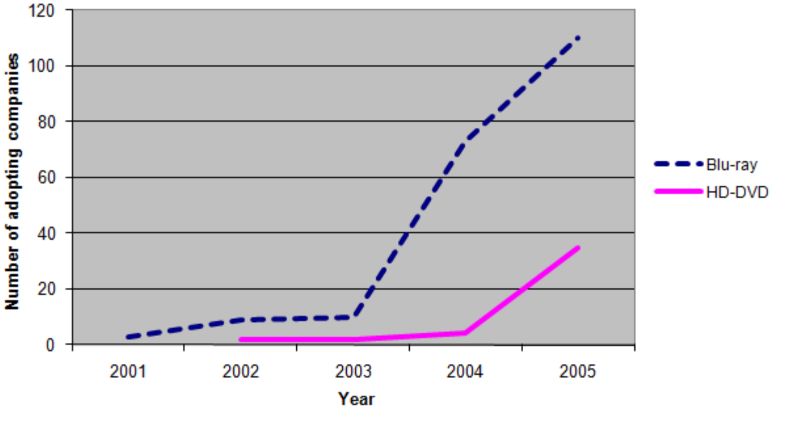


*Figure 30: Number of companies in the alliances of Blu-ray and HD-DVD*

Figure 30 shows that by the end of 2005 the Blu-ray format had gathered a greater number of companies that supported the format. Table 12 shows that the Blu-ray format managed to achieve a large accumulated market share through its supporters in consumer electronics, personal computer, game console and film studio industry.

Table 12: Accumulated market share (% of total market) of the companies supporting Blu-ray and/or HD-DVD in their respective industries, through the years[220]

| | 2002 | | 2003 | | 2004 | | 2005 | |
|---|---|---|---|---|---|---|---|---|
| | Blu-ray | HD-DVD | Blu-ray | HD-DVD | Blu-ray | HD-DVD | Blu-ray | HD-DVD |
| Consumer electronics manufacturers (in US DVD hardware) | 50 | 10 | 47 | 11 | 51 | 10 | 43 | 9 |
| PC manufacturers (based on worldwide shipments) | | | | | 27 | | 27 | 16 |
| 128-bit video game console manufacturers (installed base, worldwide) | | | | | 62 | | 63 | 17 |
| Top 12 major film studios (worldwide) | | | | | 43 | 34 | 66[221] | 41 |

Because the film studios required copy protection to securely distribute movies to consumers, an agreement on a new copy protection standard, AACS, was required before movies in either format could be released. AACS LA, a consortium founded in 2004 by e.g. Toshiba, Microsoft, Sony and Panasonic, had been developing the AACS copy protection. However, the final AACS standard was delayed several times. At the request of the consumer electronics manufacturers, an incomplete interim standard was published early 2006. At the same time, DVD sales started to decrease. With the last technical details solved, both formats were on the brink of market entry.

## 3.4 Creating the market (2006-2007)

In the race to have the first high-definition optical disc player on the market, the HD-DVD format won. On 31 March 2006, Toshiba released their first HD-DVD player in Japan, the HD-A1, at ¥110,000 ($934).[222] HD-DVD was subsequently released in United States on 18 April 2006, with players priced at $499 and $799. The first HD-DVD titles were released on the same date by Warner and Universal.

Only three months after the launch of the first HD-DVD player, Samsung launched the first Blu-ray disc player, the BD-P1000, based on version 2.0 of the Blu-ray format at a suggested retail price of $999. Because the time window between the market entry of the two formats was small and both formats were launched in the US before Black Friday (the first Friday after Thanksgiving which marks the beginning of the Christmas shopping season in the US), being first to market did not give HD-DVD a strong advantage. However, with HD-DVD players on the market it was difficult for Blu-ray disc players to build-up an initial installed base. The original proposition of offering a technology that was four to five times better than any other commercially available product was cancelled out. In addition, the first Blu-ray disc players were perceived as expensive and buggy, and only few titles were available.

The market for both high definition optical disc formats was limited, as their adoption was dependent on the sales of HDTV sets. Worldwide an estimated 48 million households had a HD television at the end of 2006.[223] The United States accounted for 58% of HD homes, Japan for 20%, with Britain, Canada and China also high on the list.

On 11 November 2006, Sony launched its PS3 game console with integrated Blu-ray disc player in Japan and the week thereafter in the United States. The video game console market has a tradition of switching to a new console every few years and its users are very willing to adopt the latest technology, whereas users in the movie player and recorder industry are more conservative. The characteristics of the video game console industry were therefore very suited for building-up an installed base for a high definition optical disc format.

A few weeks after Sony launched its PS3, Microsoft began offering an optional HD-DVD player designed for its Xbox360 game console for $200. The Xbox360 itself had been launched in November 2005 and contained a DVD drive. The external HD-DVD drive was restricted to HD-DVD playback to prevent fragmentation of the installed base for Xbox games publishers and to ensure that all Xbox games were playable on all machines. For this reason, it was clear that Microsoft would not launch a second generation Xbox360 with a built-in HD-DVD drive. Microsoft wanted to leave its options open and not get locked into a particular information storage technology.

At the end of 2006, both formats competed for consumer adoption through multiple stand alone high definition players and video game consoles. Figure 31 shows that in the first year after both formats were on the market, consumer adoption of the stand alone players was only marginal, and the PS3 primarily fuelled the installed base of the Blu-ray format. Fewer than 2% of the Xbox users opted to buy the optional HD-DVD drive, but those that did would subsequently also purchase HD-DVD discs. Only a small percentage of the consumers purchasing a PS3 actually purchased Blu-ray movies.

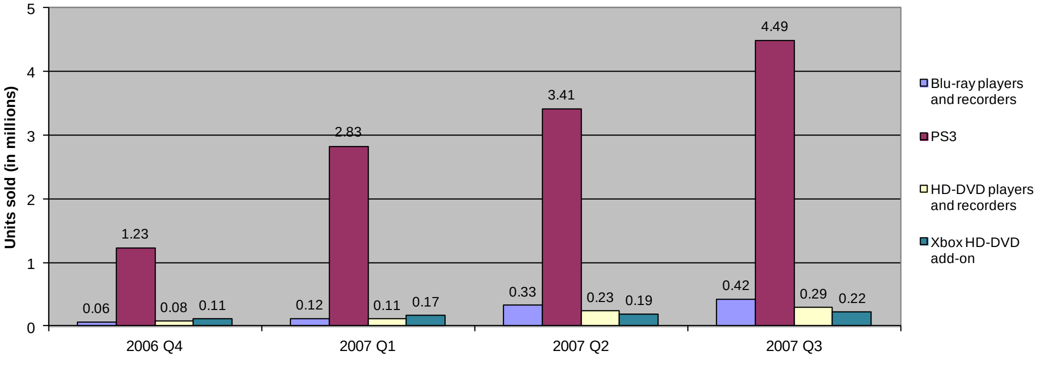


*Figure 31: Worldwide Blu-ray and HD-DVD hardware sold to consumers, 4th quarter 2006 – 3rd quarter 2007.*[224]

A known strategy in format wars is the use of marketing to manage expectations.[225] In February 2007, the BDA launched their "The War is over" marketing campaign, already pronouncing Blu-ray as the winner.[226] The BDA emphasized that many more consumers had a Blu-ray player than a HD-DVD player. The goal of the campaign was to increase consumer trust that Blu-ray would become the next standard and in effect boost confidence to invest in a Blu-ray player. On the other hand, the HD-DVD Promotion Group emphasized that the HD-DVD format sold more dedicated HD-DVD players; consumers purchasing a HD-DVD add-on for the Xbox360 did so solely for watching HD-DVD movies and therefore those sales numbers could be added up to the stand alone HD-DVD players. They used a marketing campaign pushing the slogan "The Look and Sound of Perfect" in efforts to raise awareness of their format.[227]

The leading companies behind the formats used different pricing tactics.[228] Sony initially sold its PS3 at an estimated loss of more than $200 per unit, so that it cost less than an Xbox 360 with the optional HD-DVD player ($499 vs. $599). Toshiba sold its HD-DVD players for around $500, whereas a parts breakdown revealed that the components alone cost around $674 (in order to run Microsoft's HDi menus and render HD video, the players incorporated several sophisticated components), even without manufacturing costs, packaging, and other expenses. Toshiba sold the players at a loss to encourage uptake of HD-DVD prior to the release of the first Blu-ray players. Because Sony earned a license fee per game title sold for the PS3, it could recoup most of the discount, whereas Toshiba could not recoup its discount on the players.

On 10 March 2006, Blu-ray supporter LG Electronics surprised the industry with news that it was developing a dual HD-DVD/Blu-ray player. Nearly a year later, in January 2007, they released their dual format player, the LG BH100 "Super Multi Blue Player".[229] In the same month, Warner Bros. showed a prototype disc with both an HD-DVD and Blu-ray disc layer, and announced that their Total HD disc would become available later that year. In previous format wars[230] such 'gateway technologies', were applied to resolve the incompatibility of two formats. However, in this case the adoption of the LG BH100 player was limited due to its price (which was higher than the price of a player of either of the formats) and on 13 November 2007, Warner announced to delay the introduction of the Total HD disc (during 2007, Warner had tried to gain support from other film studios, however this had failed because the other film studios were too entrenched in their support for either Blu-ray or HD-DVD). As such, these technologies did not resolve the format war.

Although a significant amount of time and effort had been spent to create adequate copy protection for both formats, on 26 December 2006 a hacker managed to break part of the AACS copy protection. In the following months, more such cases occurred, cracking additional parts of the AACS copy protection. With AACS being the only copy protection on HD-DVD,[231] this could impact the adoption of the HD-DVD format. However, implementing these hacks required some degree of technical savvy and due to adequate actions of AACS LA to restrict and prohibit the availability of the hacks through the Internet, the impact of cracking AACS on the adoption of the HD-DVD was very limited.

In June 2007, Blockbuster, the largest U.S. movie rental company, moved to Blu-ray exclusively in 1450 stores after test-marketing both formats at 250 stores and finding that more than 70% of high definition rentals were Blu-ray discs. A month later, in July 2007, Target Corporation began carrying only Blu-ray players in its stores.

## 3.5 The decisive battle (2007-2008)

At the end of July 2007, the two formats had been competing for consumer adoption for a year. Blu-ray had an advantage in installed base, amount of companies providing players and amount of support from content providers (as shown by Figure 32, the film studios supporting Blu-ray had 78% market share, while those supporting HD-DVD had 47% market share), but because of the reluctance of the market to adopt high definition players, the balance in the format war was only slowly tipping towards Blu-ray. Both formats were in a virtual stalemate. Blu-ray players were technologically superior but more expensive. HD-DVD had sold more players on the high definition player market, but this was overshadowed by the number of sales of PS3s with the integrated Blu-ray player. Meanwhile, the market was speculating that the platform war might be futile as technological alternatives such as internet downloads were advancing.

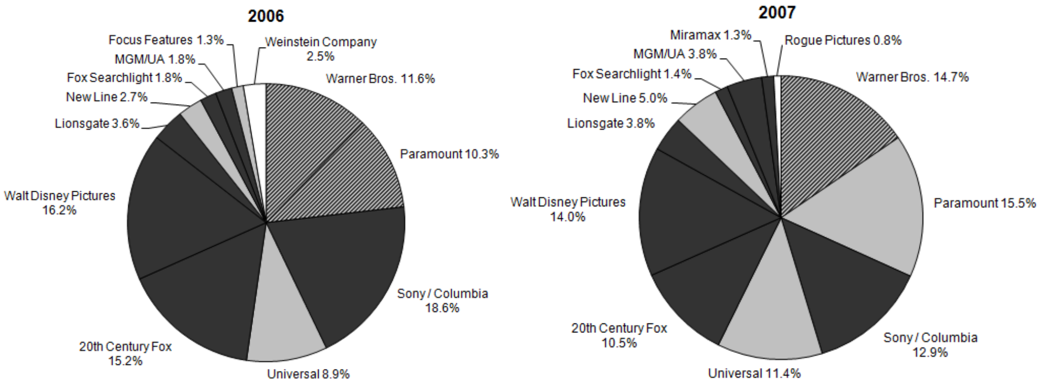


*Figure 32: Major film studios committed to Blu-ray (black), HD-DVD (grey), and not committed (white) end of 2006 and 2007, including studio market shares.*[232]

In order to counteract the momentum behind Blu-ray and try to tip the market in its favour, the HD-DVD camp increased its efforts to win exclusive support from major film studios; the format with most complementary goods is the most attractive to customers. In August 2007, after having supported both HD-DVD and Blu-ray for over a year, Paramount announced it would release all high-definition content (except titles directed by Steven Spielberg) exclusively on HD-DVD.[233] At the same time, DreamWorks Animation SKG, which had not released any high-definition discs, announced it would release exclusively on HD-DVD. The companies cited perceived advantages of HD-DVD's technology and lower manufacturing costs. However, rumours suggest the companies together received about $150 million in cash and promotional guarantees. Viacom (owner of Paramount) reported receipt of $29 million in cash[234] for Paramount's exclusive support for HD-DVD. By providing financial incentives to increase support for a format and improve its position regarding the availability of complementary goods, Toshiba used a tactic never seen before in a platform war. With two of the big six film studios exclusively supporting HD-DVD, the HD-DVD camp still needed to convince Warner (the movie studio with the largest market share of DVDs and the only major studio still releasing movies in both HD-DVD and Blu-ray), to get on even ground with Blu-ray.[235]

By the end of 2007, as the holiday shopping season began, supporters of HD-DVD initiated a price war including $100 Toshiba HD-DVD players, discounted movies and increased player features. Microsoft cut the price of its HD-DVD player for the Xbox360 from $199 to $179 and offered five free movies.

The tipping point came on 4 January 2008, a day before the Consumer Electronics Show (CES) 2008 in Las Vegas, when Warner Brothers announced it would release only in Blu-ray after May 2008. This effectively included other studios under the Warner umbrella, such as New Line Cinema and HBO. At the CES 2008, some HD-DVD-related events and private meetings with analysts and retailers were cancelled. Toshiba management expressed disappointment over Warner's decision, but said it would continue to promote its format. The following Monday, Toshiba reduced the price of its HD-DVD players by 40%-50%, with the HD-A3 selling at a retail price of $150.

Towards the end of 2007, Warner realized the market was not tipping towards a single format and its Total HD format would not be a means to resolve it. With the DVD market becoming saturated and retailers becoming concerned about the cost of their shelf space (including Wall-Mart which was responsible for 40% of the optical disc sales in the USA, and other retailers with whom Warner had a vendor managed inventory relationship[236]), Warner wanted to speed up the emergence of a dominant high definition optical disc format. This implied choosing between the two formats. In the second half of 2007, Warner closely monitored the consumer disc sales of both formats. By the end of 2007, Blu-ray discs were outselling HD-DVD discs by about three to one, and Blu-ray had a larger installed base of disc players due to the PS3. Warner concluded that consumer adoption of Blu-ray discs was more successful and decided to exclusively support Blu-ray. As the decision for Blu-ray implied sourcing the disc replication in a single format, Warner negotiated a business arrangement[237] with Sony which included a discount on fees for patent rights, reproduction rights, etc. totaling a rumored amount of between $400 and $500 million.[238]

Warner's move caused a chain reaction in the industry. Wal-Mart and other major US retailers dropped HD-DVD from their stores. A major European retailer, Woolworths, dropped HD-DVD from its inventory. Netflix, the major online DVD rental site, would no longer stock new HD-DVDs. Best Buy decided to recommend Blu-ray over HD-DVD in its retail locations and removed all HD-DVD players.

Following these developments, on 19 February 2008, Toshiba announced plans to cease the development, marketing and manufacturing of HD-DVD players and recorders. The company cited "recent major changes in the market".[239] On that same day, Universal Studios announced it would release its titles in Blu-ray, following two years of exclusive HD-DVD support. On 20 February 2008, Paramount Pictures announced it would back Blu-ray, becoming the last of the big six film studios to do so. Paramount Picture's sister DreamWorks Animation followed suit by cancelling its only remaining HD-DVD release. The HD-DVD Promotion Group was dissolved on 28 March 2008.

Sony's decision to integrate a Blu-ray Disc player in the PlayStation 3 video game console helped the format's triumph. As Figure 33 shows, by the time Toshiba ceded the market, about 800,000 standalone Blu-ray players and 10.5 million PS3s had been sold versus almost 500,000 stand alone HD-DVD players and almost 400,000 add-on players for Microsoft's Xbox 360 console. Sony's strategy came at a cost: their decision to sell the PS3 at a loss resulted in a total estimated loss of more than $3 billion.[240]

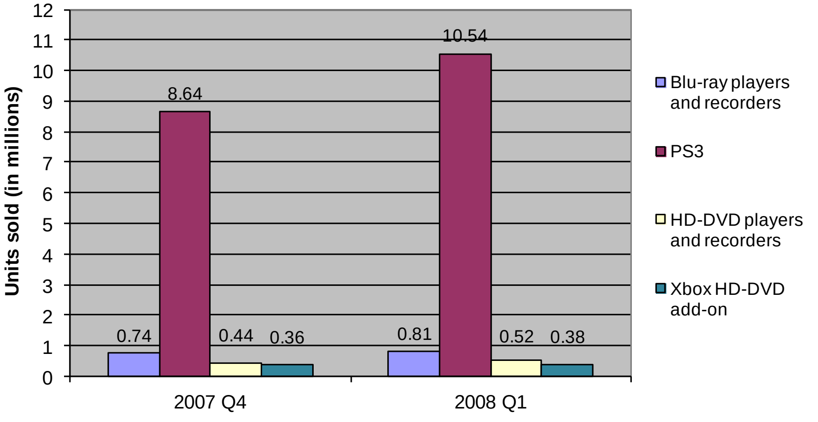


*Figure 33: Worldwide Blu-ray and HD-DVD hardware sold to consumers, 4th quarter 2007 – 1st quarter 2008.*[241]

## 3.6 The format war aftermath: Post-dominance (2008-onward)

Although the format war in high density optical discs had been won by Blu-ray, it still needed to replace DVD as the dominant format for optical discs. Figure 34 shows that from 2008 to 2011, the sales of Blu-ray discs were only a fraction of DVD sales. It took the CD nine years to replace the compact cassette tape, and DVD only needed six years to replace VHS video tapes, but it remains to be seen whether Blu-ray can break this record. Figure 7 indicates this will be challenging. Since 2007, the overall sales of optical discs have declined due to the impact of the 2007 credit crunch and the increasing popularity of substitutes such as Video on Demand services and illegal film downloads. The overall reduction in optical disc sales has affected the adoption of Blu-ray, being a new and more expensive technology. It remains to be seen how the adoption of Blu-ray will actually develop over the upcoming years, but with a clear winner in the format war, there is less uncertainty for the consumer. This might increase Blu-ray's market share faster than projected.

After its victory, the BDA continued its campaign to support Blu-ray. Prices of Blu-ray players and discs were further reduced and more companies joined the BDA, thereby increasing the momentum behind the technology. Meanwhile, in August 2008, Toshiba tried to extend the lifetime of the DVD format by introducing a device that upscaled the output of a DVD player to more closely match the resolution of an HDTV screen.[242] Despite this last effort, market adoption of Blu-ray quickly progressed and in August 2009 Toshiba applied for membership of the BDA.[243] With even its main adversary on board, little stands in the way for Blu-ray to become the dominant technology for optical discs. It remains to be seen how long Blu-ray can sustain its position of up and coming technology. The fast progress of alternate technologies is imposing a threat; downloading digital content from the Internet is becoming increasingly popular and can become a serious contender in the near future.

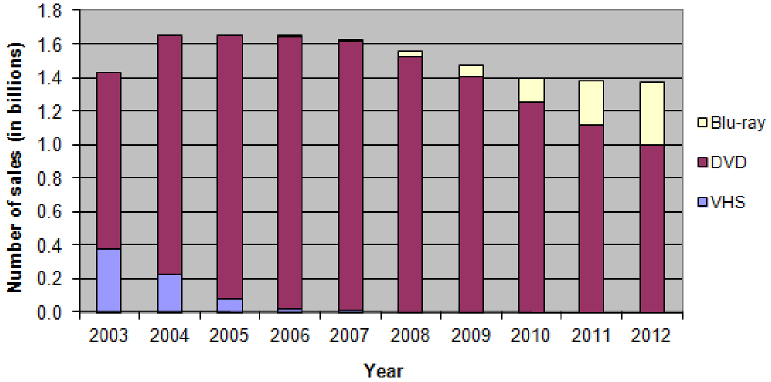


*Figure 34: Worldwide recorded and estimated sales of CD, DVD and Blu-ray discs.*[244]

## 3.7 Conclusions

The description of the format war between Blu-ray and HD-DVD shows the strategic measures a company can take to push the adoption of its superior technology when facing a limited market and a cheaper alternative that entered the market earlier. The story of Blu-ray versus HD-DVD shows the importance of building alliances and using the technology adoption characteristics of a particular industry to gain worldwide technological market dominance.

Two elements proved decisive for Blu-ray's victory: the 'killer app' PS3 and the exclusive support from Warner Bros. However, other elements such as the short time window between the market entries of the two formats were important as well. The development of HD-DVD proceeded significantly faster than the development of Blu-ray because the group of companies sponsoring HD-DVD was considerably smaller. When HD-DVD entered the market, it started to build-up an installed base. The installed base did not grow fast due to the limited number of HD television sets in households. However, the initial installed base combined with the low pricing and a technological superiority which was 'good enough' for consumers provided HD-DVD with an advantage over Blu-ray. Previous format wars have shown that network effects can reinforce such a slight advantage to the point that a market will tip towards one technology.[245] When Blu-ray entered the market, it was difficult to create a beachhead. This brings us to the PS3 which proved to be the 'killer app' for Blu-ray. The PS3 quickly increased Blu-ray's installed base, which became an important advantage. If the PS3 had only offered an optional Blu-ray player, just as Xbox360 for HD-DVD, it is questionable whether Blu-ray had been able to recoup its arrears. Warner's exclusive support for Blu-ray was the fatal blow for HD-DVD. It set in motion a chain reaction of multiple companies announcing exclusive support for the Blu-ray format, which settled the format war.

The companies behind the Blu-ray and HD-DVD format used different strategies. Blu-ray established a broad alliance, and developed the technology to meet the criteria of the alliance partners. Building on this, the alliance supporting Blu-ray focused on gaining an advantage in the availability of products, complementary goods (content for the discs) and establishing a 'killer app'. After Blu-ray obtained an advantage in installed base, its supporters used marketing and PR to manage expectations and stimulate tipping the market. HD-DVD, on the other hand, primarily relied on its technological positioning by offering acceptable quality for a lower price and being first to market. This was difficult for Blu-ray to counter, but after it overcame its initial arrear, the HD-DVD camp needed to come up with something new. In its efforts to react to Blu-ray's manoeuvres to tip the market, the HD-DVD supporters identified the most important factor to tip the market; the availability of content for the discs. However, HD-DVD failed in the execution of gaining a decisive advantage. Although it started successfully by gaining exclusivity from Paramount and DreamWorks, support from Warner Bros. was essential to tip the scales. By first attracting Paramount and DreamWorks, the companies supporting Blu-ray were alarmed and could act to obtain exclusive commitment from Warner.

At the end of the format war, the parties sponsoring HD-DVD incurred huge losses. Toshiba reported an approximate loss of $1 billion on the HD-DVD endeavour.[246] The parties behind Blu-ray have invested large amounts of capital in the format while it remains to be seen if they will recoup their losses. Would joining forces been a better alternative? If Toshiba had joined Philips, Sony and Panasonic in 2003, or if they had agreed on a unified format in 2005, they would not only have prevented the format war and its related costs, it would have also enabled all consumer electronics manufacturers and film studios to fully focus on the unified format. This would have resulted in much faster market adoption, generating more income, but these proceeds would have also been divided over more parties.

Appendix 1. High definition optical disc format war and business network build-up chronology, 1986-2009.

| Phase | Year | Month | Blu-ray | HD-DVD |
|---|---|---|---|---|
| R&D build-up | 1986 | | Start of development of blue laser diodes by Toyoda Gosei and Professor Akasaki of the Nagoya University | |
| | 1993 | Nov. | First commercial production of blue laser diodes at Nichia | |
| | 1996 | | Sony presents lens for higher density optical recording | |
| | 1997 | | Sony and Philips combine developments for a high definition optical disc format: DVR Blue | |
| Preparing for market entry | 2000 | Oct. | Sony and Philips present the first DVR Blue prototypes | |
| | 2001 | Apr. | Sony, Philips and Matsushita combine their separate developments | |
| | 2002 | Feb. | DVR Blue project is announced as Blu-ray and 9 consumer electronics manufacturers found the Blu-ray Disc Founders (BDF) | |
| | | June | DVD-Forum's Steering Committee decides to form two Subgroups of the Forum's Working Group 11 to study the best technical approach for blue laser optical disc applications | |
| | | July | Legal battle concerning blue laser diodes settled, ending uncertainty of blue laser diode IPR ownership | |
| | | Aug. | | Toshiba and NEC announce their competing format: Advanced Optical Disc |
| | | Oct. | | Toshiba presents a AOD prototype |
| | 2003 | Feb. | Licensing of version 1.0 of the Blu-ray format (disc recorder and rewritable discs) begins | |
| | | Apr. | The first Blu-ray product, the Sony BDZ-S77, becomes commercially available in Japan only | |
| | | May 28 | Mitsubishi Electric joins the BDF | |
| | | Nov. | | AOD gains support from the DVD-Forum and is renamed to HD-DVD |
| | 2004 | Jan. 12 | Hewlett-Packard and Dell join the BDF, adding support from the world's two largest PC manufacturers | |
| | | Mar. 18 | TDK, a leading manufacturer of optical discs joins the BDF | |
| | | May 18 | The 13 members of the Blu-ray Disc Founders announce plans to be re-incorporated into the Blu-ray Disc Association | |
| | | Sep. 13 | Sony acquires US film company MGM | |
| | | Sep. 21 | Sony announces the PlayStation 3 game console will use Blu-ray | |
| | | Oct. 4 | 20th Century Fox joins BDA | |
| | | Oct. 11 | JVC joins BDA | |
| | | Nov. | Sony starts cooperation with Singulus to commercialize the manufacturing line for Blu-Ray discs[247] | |
| | | Nov. 29 | | Paramount Pictures, Universal Pictures, Warner Bros. Pictures, HBO and New Line Cinema announce support for HD-DVD |
| | | Dec. 8 | The Walt Disney Company and Buena Vista Home Entertainment (BVHE) announce their support for the Blu-ray Disc format | Toshiba, Sanyo, NEC and Memory-Tech establish the HD-DVD Promotion Group |
| | 2005 | Jan. | TDK develops a special hard coating polymer for the recording surface of the Blu-ray discs, cartridges are no longer necessary | |
| | | Mar. 14 | Apple joins the BDA | |

| | | | | |
|---|---|---|---|---|
| | | Apr. | Start of negotiations to come to a unified format | |
| | | May 3 | Panasonic starts pilot production line for Blu-ray disc replication based on inexpensive spin-coating technology (developed with Origin Electric) | |
| | | June | Sun announces BDA to choose BDj codec | |
| | | Aug. | Blu-ray Disc Association and DVD-Forum announce that the negotiations to unify their standards have failed | |
| | | Aug. 18 | Lions Gate Home Entertainment and Universal Music Group decide to support Blu-ray format | |
| | | Sep. 27 | | Microsoft and Intel announce support for HD-DVD |
| | | Oct. 3 | Paramount Home Entertainment drops exclusive support for HD-DVD and says it will offer movies on both formats | |
| | | Oct. 20 | Warner Brothers drops exclusive support for HD-DVD and says it will offer movies on both formats | |
| | | Nov. | NEC optical disc storage group sold to Sony | |
| | | Dec. 16 | Hewlett-Packard decides to drop exclusive support for Blu-ray Disc and backs both formats | |
| | 2006 | Jan. 4 | | Microsoft announces it will offer an add-on HD-DVD drive for the Xbox 360 game console |
| Creating the market | | Mar. 31 | | Toshiba releases the first consumer-based HD-DVD player in Japan |
| | | Apr. | | First HD-DVD players released in the United States |
| | | June 25 | Samsung releases the first consumer-based Blu-ray player | |
| | | Nov. 11 | Sony releases its PS3 game console in Japan, on 17 November in the United States | |
| | | Nov. | | Microsoft offers optional HD-DVD player for X-Box360 |
| | 2007 | Jan. | LG launches its dual format player | |
| | | Feb. | Launch of 'The War is Over' marketing campaign | |
| Decisive battle | | Aug. | | Paramount and Dreamworks Animation announce to exclusively release in HD-DVD |
| | 2008 | Jan. 4th | Warner Bros. announces to exclusively release in Blu-ray | |
| | | Feb. 11 | | Netflix and Bestbuy announce to phase out HD-DVD |
| | | Feb. 15 | | Wall-Mart announces to phase out HD-DVD |
| Post dominance | | Feb. 19 | | Toshiba announces to cease development, marketing and manufacturing of HD-DVD players and recorders |
| | | Apr. | | Toshiba starts sampling of SpursEngine™ processor which upgrades standard DVD video content to high definition quality |
| | 2009 | Aug. | Toshiba applies for BDA membership | |

## 3.8 Epilogue

In order to create consistency between the cases, this epilogue is added in order to complement the published paper with additional information. In this epilogue, some information is included on the research methodology and the frameworks of Section 2.5 are applied to the case.

### *3.8.1 Research methodology*

Data for the case study stem from several sources. First, written documents and public announcements were used to gain a general insight in the technology competition between the Blu-ray and HD-DVD. Based on this initial desk research I performed a preliminary analysis. To complement and triangulate the data from the literature and gain an in-depth understanding of the technology competition, I conducted focused interviews with key persons from companies involved in the technology competition. I interviewed twelve respondents, of which an overview is provided in Table 13. The interviews were conducted from 2007 to 2010 and the length of the interviews varied from 0.5-2.5 hours. To ensure consistency and reliability, interview guidelines were used for all interviews. The findings from archival sources were compared to the findings from the interviews and the results were communicated to the interviewees for verification. The data were complemented by sales data and market intelligence reports from an independent market research firm and a few documents which were sent by or studied at the offices of the interviewees.

Table 13: Overview of interviewees in the case of high density optical discs

| Company | Name | Relevance to case |
|---|---|---|
| Panasonic Corporation | Masayuki Kozuka | General Manager Storage Devices Business Strategy Office, BoD member of Blu-ray Disc Association |
| | Nobuo Akahira | Senior Engineer, Storage Devices Business Strategy Office |
| Sony | Tadashi Ezaki | Director at Standards and Intellectual Property Department |
| Philips | Maurice Maes | Senior Director, Standardization BG Consumer Lifestyle, BoD member of Blu-ray Disc Association |
| | Jaap Nijboer | Standardization Officer, Intellectual Property and Standards Department |
| Mitsubishi Electric Corporation | Masaharu Ogawa | In charge of standards promotion, former BoD member of Blu-ray Disc Association |
| Blu-ray Disc Association | Roel Kramer | President of the Blu-ray Disc Association |
| Warner Bros. Home Entertainment Group | Jim Noonan | Senior VP Worldwide Strategic Promotions & Communications |
| Walt Disney Studios | Benn Carr | VP Studio New Technology, BoD member of Blu-ray Disc Association |
| Microsoft | David Rudin | Senior Attorney, Interoperability Group |
| METI | Manabu Eto | Director of METI's Japanese Industry Standard Research Office |
| Screen Digest | Richard Cooper | Senior Analyst, Video |

*3.8.2 Applying the frameworks*

Case analysis tool

Table 14 shows the result of using the case analysis tool on the technology competition of the high definition optical discs. While gathering data, this tool was used to (abstractly) note if a particular element influenced the technology competition in a particular phase. In addition, it helped to identify gaps in the analysis and provided guidance to the focused interviews. Each phase of the detailed case description, as presented in sections 3.2-3.5, is based in essence on the elements that were identified in a particular phase, and therefore these sections can be considered as the result of Table 14.

Table 14: Case analysis tool for the case of high density optical discs

| | | **R&D Build-up** | **Preparing for market entry** | **Creating the market** | **Decisive battle** | **Post-dominance** |
|---|---|---|---|---|---|---|
| | | 1986-2000 | 2000-2006 | 2006-2007 | 2007-2008 | 2008-onward |
| **Firm** | Reputation and credibility | | X | X | | |
| | Installed base | | | | | |
| | Pricing | X | X | X | X | X |
| | Entry timing | | X | X | | |
| | Marketing and pre-announcements | | X | X | | |
| | Availability of products | | | X | X | |
| | Availability of complementary goods | | | X | X | |
| | Killer application | | | X | X | X |
| | Size | | X | X | X | |
| | Complementary assets | | X | X | X | |
| | Technological knowledge and skill base | X | | | | |
| | Absorptive capacity | | | | | |
| | Pre-empting scarce assets | | X | | X | |
| | Level of collaborative development | X | X | | | |
| | Organizational community of supporters | | X | X | X | X |
| | Strategic partnerships | | X | | X | |
| | Product proliferation | | X | X | X | |
| | Appropriability | X | | | | |
| | Chance | | | | | |
| | | | | | | |
| **Technology** | Technological superiority | X | X | X | X | X |
| | Installed base | | | X | X | X |
| | Network effects | | | | | |
| | Switching and homing cost | | X | X | X | |
| | Backward compatibility | X | X | X | X | |
| | Increasing returns to adoption | | X | | | |
| | Technological breakthroughs in subsystems | X | X | | | |
| | Type of technological innovation | X | X | | | |
| | Adapters and gateways | | | X | | |
| | Technological performance trajectories | | | | | |
| | Chance | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Market / industry** | Market and industry characteristics | X | X | X | X | |
| | Level of competition | | X | X | X | |
| | Rate and type of technological change | | | | X | X |
| | Network effects | | | X | X | X |
| | Availability of products | | | X | X | X |
| | Availability of complementary goods | | | X | X | X |
| | Killer application | | | | | |
| | Availability of imitators | | | | | |
| | Hetero- or homogeneity of customer needs | X | X | | | |
| | Unclear assessment criteria | | | | | |
| | Powerful rival technology sponsors | | X | X | X | |
| | Government intervention and industry regulation | | X | | | |
| | Product proliferation | | | | | |
| | Appropriability | | X | X | | |
| | Chance | | | | | |

Following the first application of the case analysis tool, the following things became apparent:

- The five phases fit well with the technology competition. However, in the phase of post-dominance Blu-ray still had to overcome DVD as de-facto standard.
- By using the tool I found 35 elements influenced the technology competition between Blu-ray and HD-DVD. It appears that by using this tool, due to its combination of an extensive set of elements with the five phases, I was able to render a more detailed recollection of historic technology competitions.
- Some elements became apparent to influence the technology competition, which were not included in the case analysis tool:
    - Subsidizing providers of complementary goods, in order to obtain their commitment to join the organizational community of supporters
    - History of the industry; events in previous technology competitions affect the new technology competition, especially with regard to the level of collaborative development; some technology sponsors may hold a grudge to each other and rather compete in the market than collaborate on a shared technology
    - Accommodating the needs and requirements of providers of complementary products, in order to obtain their commitment to join the organizational community of supporters. This aspect should be taken into account in the element of 'level of collaborative development', for example by modifying the description as follows: extent to which a technology sponsor engages into a collaboration with its competitors and complementors to develop a shared technology

Based on the above mentioned insights regarding the use of the case analysis tool, I decided to not modify the tool and reserve actions regarding the findings for the cross-case analysis (Chapter 8).

Applying the integrative framework

Based on the data gathered in Table 14, for each phase of the technology competition a snapshot was made by applying the integrative framework (Figure 35 - Figure 39). Each Figure shows only those elements that were at play during the respective phase. The relationships between the elements were reconstructed based on the written documents, public announcements and interviews. When the relationships were the same as presented in the integrative framework, these were marked in black. Relationships that were not presented in the integrative framework, were marked in blue.

Considering that Blu-ray and HD-DVD were in direct competition during multiple phases, I also attempted to apply the scoring method in accordance with Subsection 2.5.3 (an overview of the scoring options can be found in Table 10). I based the scores on the insights from the written documents, public announcements and interviews. Although this approach seems rather subjective, the scores were often based on solid data (sales data, product pricing, size of the organizational community of supporters, their market shares, etc). I did not attribute scores to the elements in the first and the last phase of the technology competition; the first phase was omitted because the rival technology (HD-DVD) was announced during the second phase and little is known about the technology before its announcement, and the phase of post-dominance was omitted since it was redundant (the scores are meant to compare a technology versus its rival and during the phase of post-dominance one technology has prevailed over its rival).

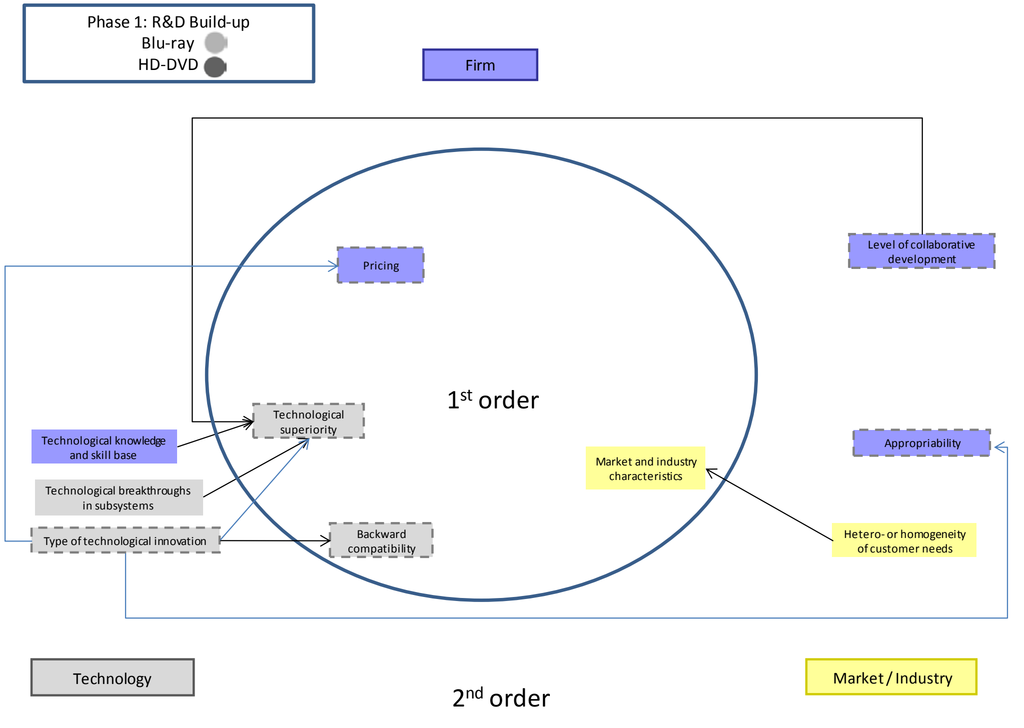


*Figure 35: Integrative framework applied to Phase 1 of the case of high density optical discs*

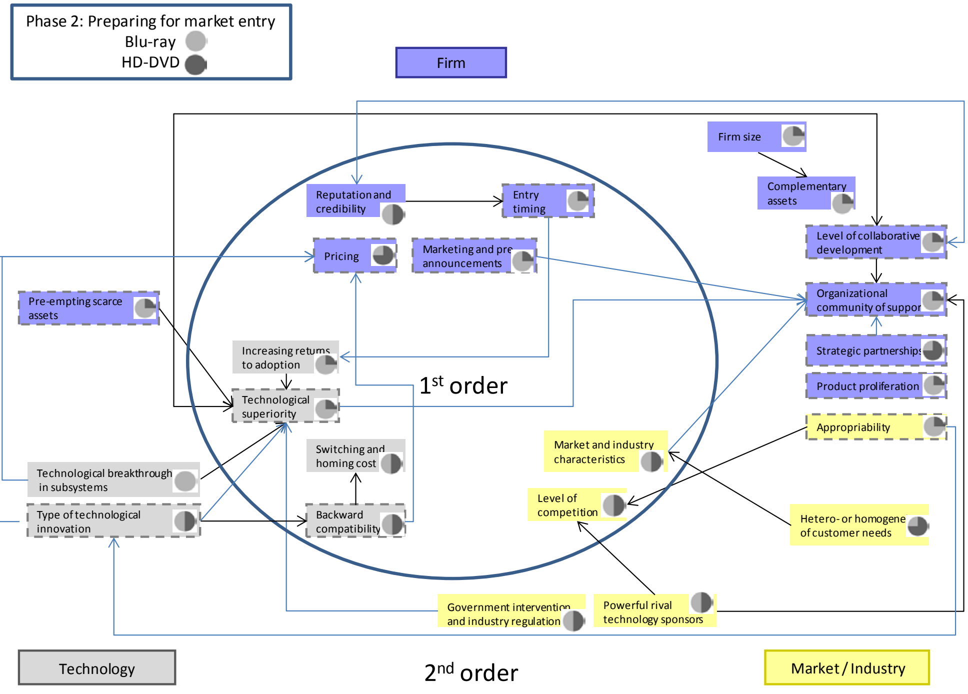


*Figure 36: Integrative framework applied to Phase 2 of the case of high density optical discs*

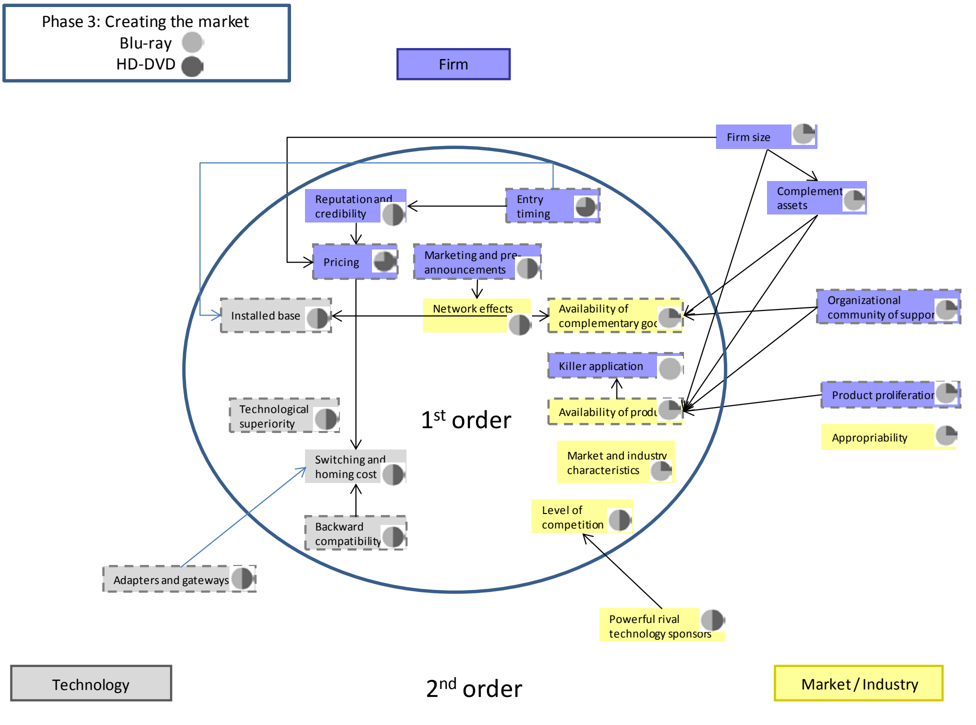


*Figure 37: Integrative framework applied to Phase 3 of the case of high density optical discs*

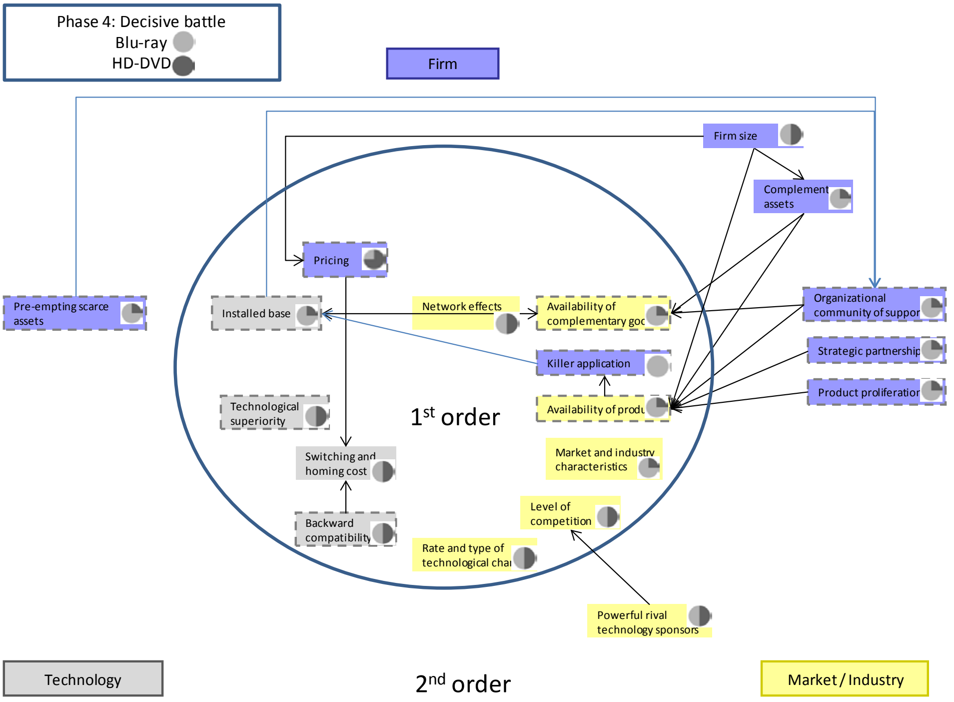


*Figure 38: Integrative framework applied to Phase 4 of the case of high density optical discs*

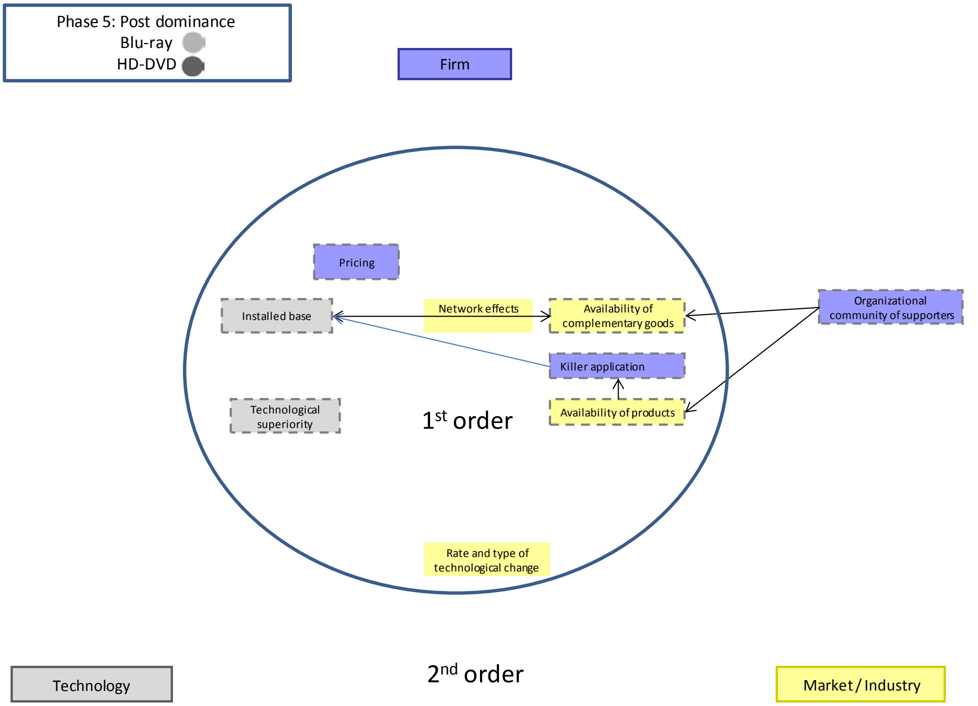


*Figure 39: Integrative framework applied to Phase 5 of the case of high density optical discs*

The methodological approach and the application of the integrative framework allows an analysis of the dynamics of each phase of the technology competition. When reviewing Figure 35, I note that the dynamics in the first phase are mostly related to the technology. This is in accordance with what one can expect during the phase of R&D build-up. The elements in this phase are mostly related to the Blu-ray technology, and shows that its original sponsors, Sony and Philips, made a strategic decision on the type of innovation, which influenced its technological superiority, backward compatibility, pricing and appropriability. During the phase of preparing for market entry, a rapid increase in the number of elements is clearly visible. The elements of the previous phase are still in play, and 13 additional elements have come into play. In this phase many firm-related elements come into play, because the activities of the technology sponsors are strongly focused on creating an organizational community of supporters, comprised of competitors and complementors. As shown in Figure 36, the organizational community of supporters for both technologies is influenced by the level of collaborative development, strategic partnerships, pre-announcements, technological superiority, industry characteristics, and that both technologies have powerful sponsors (due of this last point, some supporters join both communities). It is interesting to note that before entering the market of high definition disc players, Sony and Panasonic entered a 'niche' market (video recorders for Japan) and thereby gained experience in manufacturing products based on the new technology and obtained insights in customer requirements (i.e. increasing returns to adoption). In the phase of creating the market, there is a small increase in the number of elements. The point that is most striking, and shown by Figure 37, is the shift from technology-related elements to firm- and market/industry- related elements. Both sides were focused on jump-starting the positive feedback loop of network effects by besting the rival technology in terms of entry timing, the availability of products and complementary goods in the market, penetration pricing, and marketing and pre-announcements. In the phase of the decisive battle, there is a small decrease in the number of elements; five elements go out of play and are replaced by three new ones. As can be seen from Figure 38, the ratio of firm-, technology-, and market/industry-related elements is similar to the previous phase. In this phase we see the focus of the technology sponsors shift again to the organizational community of supporters. The major film studios can be considered as scarce assets, and during this phase the rival technology sponsors set out to obtain exclusive support from the major film studios. In making their decision, these film studio's take the installed base of the rival technologies into account. In the last phase, post-dominance, there is a rapid decrease of elements in play. Of the 20 elements in play during the decisive battle, only 10 are remaining in the post-dominance phase (as shown in Figure 39). In this phase there are no new elements, and the remaining elements are mainly firm-related.

While reviewing Figure 35 to Figure 38, I noted that Blu-ray and HD-DVD used different strategies. The technology sponsors of Blu-ray relied heavily on strategic elements; in order to deal with the uncertainty of who would be first to market and the effect of the technological positioning, before entering the market the Blu-ray sponsors focused on gaining an advantage in the availability of products and complementary goods through collaborative technology development and pro-actively building an organizational community of supporters, and one of them prepared a potential killer application. During the decisive battle they used marketing and PR to manage expectations to stimulate tipping the market. The HD-DVD camp primarily relied on the technological positioning (offering acceptable quality for a lower price) and being first to market. Although this was difficult to counter for the Blu-ray sponsors, when they did the HD-DVD camp had to come up with a countermove. They identified an important element for tipping the market: the availability of complementary goods. However, they failed in gaining an advantage on that element as the Blu-ray sponsors managed to obtain exclusive support from Warner Brothers.

Contrary to what was encountered in previous technology competitions in the consumer electronics industry, the market did not 'tip' towards one technology due to consumer selection, but because the industry (consumer electronics manufacturers, film studios, retailers, movie rental outlets, etc.) tipped towards Blu-ray. The integrative framework is based on the premise that customer selection drives the emergence of a de-facto standard, so this raises the question if the integrative model requires modification / adequately captures this. Considering that this is the first time that the industry rather than the customers has tipped to one technology, I have decided to not modify the integrative framework. The framework seems to have adequately captured this dynamic, and it should be noted for future work that a market can tip not only due to a bandwagon of customer support, but also due to a bandwagon of industry supporters.

Does this first application of the scoring method indeed provide insight if a technology sponsor could evaluate the situation and identify the relevant elements to shape the odds in its favor? In retrospect, the scores show three clear signs that the main sponsor of HD-DVD, Toshiba, could have used to shape the odds in its favor. As Figure 36 shows, Sony and Philips were very successful in building an organizational community of supporters during the phase of preparing for market entry. Before Panasonic joined Sony and Philips, Toshiba had already learned about the development by Sony and Philips. They could have anticipated upon the plans of Sony and Philips and pre-empt their efforts to build-up an organizational community of supporters. The second sign occurred during the phase of 'preparing for market entry' wherein Warner Bros. and Paramount decided to shift from exclusively supporting HD-DVD to also supporting Blu-ray. This showed that the Blu-ray sponsors were making an effort to actively recruit support from Hollywood movie studios, increasing the availability of complementary goods. While Figure 36 and Figure 37 clearly show that the Blu-ray sponsors had the upper hand in terms of the organizational community of supporters, which led to a better availability of products and of complementary goods, it took till the phase of 'the decisive battle' until Toshiba won back some support of the Hollywood movie studios. This was clearly much too late; based on their previous experience in DVD, they should have realized that the film studios are scarce assets which should be pre-empted, and therefore it was key to attract more supporters during the phase of 'preparing for market entry'. Lastly, on the 16$^{th}$ of May 2005 Sony issued the news that they would integrate a Blu-ray player in their PlayStation3 game console. Toshiba could have anticipated on its effect and potential success, and counter it by going to great lengths to ensure a HD-DVD player would be integrated in one of the other game consoles with a major market share (either that of Microsoft or Nintendo). What happened in practice, that Microsoft offered a separate HD-DVD player for an X-Box360, had too little effect to counter the effect of the PS3.

A few years after I finalized my research on the case of the high definition optical discs, Gallagher[248] published a paper on the same case. In his paper, Gallagher uses a model with 13 elements (of which most coincide with the first order elements in my integrative framework), but no phases. When comparing my results with those of Gallagher, I find that we both identify the same decisive elements in this technology competition; Sony's PlayStation3 as killer application, and tipping the industry by obtaining substantial exclusive support from film studio's. However, as Gallagher lacks most of the second order elements and the phases, his case reconstruction lacks clarification on how the first order elements developed over time and reached the point that they tipped the market in favour of the Blu-ray technology. As Gallagher's paper shows, with the current state of the academic field, one can analyse a case, identify a range of elements (in this case 13) and determine which of these were decisive. My approach complements this by adding insight how these elements were influenced and shaped over time.

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# Chapter 4 - The Rise of MP3 as the Market Standard: How Compressed Audio Files Became the Dominant Music Format

**Published in International Journal of IT Standards and Standardization Research, 11(1), 1-26, January-June 2013**

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## 4.1 Introduction

The recent downfall of the iconic photography company Kodak, caused by the paradigm shift from analog to digital photography, is a clear example of an innovative market leader that was among the first to identify a radical innovation but chose to bypass the opportunity because it cannibalized its existing market. Clayton Christensen first described this 'innovator's dilemma' in his bestselling book.[249] He showed that an excessive customer focus may prevent firms from creating new markets and finding new customers for the products of the future. As they unwittingly bypass opportunities, such firms clear the way for entrepreneurial companies to catch the next wave of industry growth.

In the last two decades, we have witnessed how audio codecs, in particular the MP3 audio compression format (also known as the MPEG-1 Layer 3 standard), changed the music industry. In 1995, when a representative of one of the organizations behind MP3 presented the idea of compressed audio distribution using the Internet and copy protection to the music industry, they replied "It all sounds very interesting, but what does this have to do with us?". Not only did the music industry fail to embrace the opportunity for music distribution over the Internet, but so did the market leaders in consumer audio equipment which were involved in audio compression.

This paper examines the rise of the MP3 audio compression technology, from its inception to when it became the dominant music format. It shows how a disruptive technology can change an industry and offer opportunities to new entrants. In the following sections, we will summarize previous research on platforms and platform competitions, and describe our research methodology. This is followed by a detailed case description, case analysis and our conclusions.

## 4.2 Theoretical overview

The body of literature on management of technology and innovation, labels compressed audio formats as platform technologies. Platforms are products, technologies or services consisting of core components which remain stable, and interfaces which allow the core components to operate with complements as one system (Baldwin & Woodard[250]). Interfaces are often codified into standards. Platforms may occur on multiple levels of a product's architecture: a personal computer is a platform, and its operating system as well. Platforms may enable 'platform-mediated networks', facilitating the interaction between two groups of users, the supply network (which provides complementary products) and the demand network (Eisenmann et al.[251]). For example, in the case of the Compact Disc platform, the record labels constitute the supply network and the consumers constitute the demand network. Other well-known examples where content providers and consumers interact through platforms can be found in the video (e.g. VHS and DVD) and videogame industry (e.g. PlayStation). The platform's value to a user depends on the size of the network on the other side, and the two networks attract each other (Rysman[252]). This phenomenon whereby the functionality for a user increases, i.e. complementary goods become more plentiful and lower in price, if more users join is known as cross-side or indirect network externalities (Arthur[253]; Arthur[254]; Eisenmann et al.[255]; Liebowitz & Margolis[256]). Platforms can also experience same-side or direct network externalities, whereby an increase in the number of users on one side of the network makes the platform either more or less valuable to users in that network. Since platform mediated networks are prone to externalities, industries governed by platform technologies often have a single platform that has a dominant market share, or in other words, can be regarded as the market standard.

The field of innovation management includes a significant collection of academic papers and books on platforms competing to become the market standard, including VHS versus Betamax (Cusumano et al.[257]; Rosenbloom & Cusumano[258]), Blu-ray versus HD-DVD (Gallagher[259]), color television versus black and white television (Willard & Cooper[260]), and various generations of video game consoles (Gallagher & Park[261]; Schilling[262]; Shankar & Bayus[263]). Organizations that obtain technological market dominance can potentially earn near-monopoly rents (Schilling[264]), whereas those that are unsuccessful forfeit most of the investment in their technology. These 'winner-take-all' markets demonstrate very different competitive dynamics than markets where competitors coexist relatively peacefully, as they often have a single tipping point which shifts the balance to one side.

Eisenmann[265] has shown that there are roughly four different models for organizing platforms: proprietary, licensing, joint venture and shared. As Figure 40 shows, these models differ by the number of platform sponsors (parties that control the technology and participation rights) and platform providers (parties mediating interactions between users in two-sided networks). The platform sponsors of competing platforms often choose different models. The specific situation dictates which model works best. During a platform competition, a model may evolve towards a hybrid form by implementing aspects of another model.

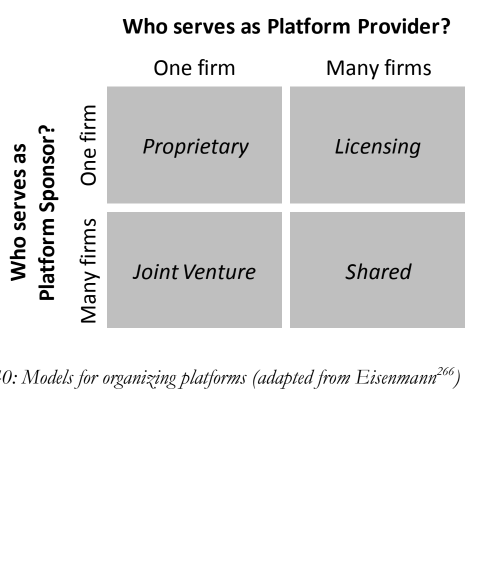

*Figure 40: Models for organizing platforms (adapted from Eisenmann[266])*

Previous research by Suarez[267] provides a framework which links eight elements (technological superiority, complementary assets and credibility, installed base, strategic maneuvering, regulation, network effects and switching cost, regime of appropriability, and characteristics of the technological field) to a five-phase division of a platform competition: R&D build-up, technical feasibility, creating the market, decisive battle, and post dominance. Suarez posits that a platform competition can be described in terms of a few key milestones, and each marks the start of a new phase in the competition. The start of the R&D build up can be traced back to the moment when a pioneer firm or research group starts applied R&D aimed at the technological innovation. The second milestone is the appearance of a first working prototype based on the technological innovation. This marks the start of the 'technical feasibility' phase during which platform sponsors start to prepare for market entry. The phase of creating the market is triggered by the market introduction of a first commercial product of the new technology. After the platform competition has commenced, a particular design can become a front-runner. The presence of this front-runner is the fourth milestone and marks the start of the decisive battle. The front-runner has the best chance of winning the competition, as its larger installed base tends to create a bias towards the technology with the largest market share. Finally, a specific technological design achieves dominance and the competition moves into the last phase: post dominance.

## 4.3 Research methodology

In order to study the rise of MP3 as the market standard, we have refined Suarez's phase division of a platform competition, and combined these with elements known to influence the decision of users in two-sided networks to adopt a particular technology.

In the emergence of a market standard, a new technology needs to compete against alternatives, displace the existing de-facto standard, and be cautious not to be leapfrogged by a substitute. While studying platform competitions, we found that a platform first becomes dominant in a specific market niche, and then competes for dominance in a product category. An example of this is the video industry where Blu-ray first competed against HD-DVD and became the dominant platform for high-definition video storage and distribution, but is currently competing with DVD for dominance in the product category. We modified Suarez's model accordingly by adding the phase 'Winning the mass market' and renaming some of the other phases to better fit our ideas. An overview of the phases is shown by Figure 41.

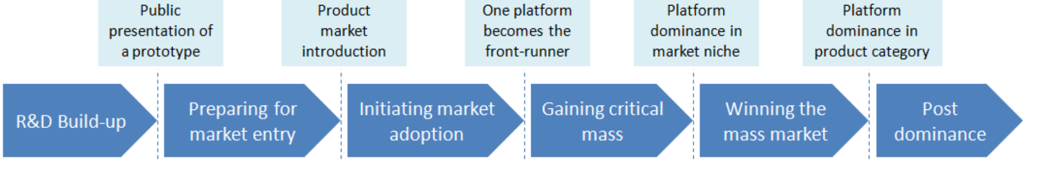


*Figure 41: Six phases of platform competition (adapted from Suarez[268])*

To determine which elements influence the adoption of a particular technology by users in two-sided networks, we examined 40 papers in academic journals on the emergence of market standards, and identified and consolidated the elements which influence users to adopt a particular technology. The resulting overview provided 46 elements (Den Uijl & De Vries[269]). By combining these elements with the six phases in a data matrix, we created a framework for identifying which elements influenced the rise of MP3. The elements in the data matrix function as a checklist in each phase of the platform competition.

We used the same list of elements to determine the number of elements found in previous case studies (Christensen[270]; Cusumano et al.[271]; David[272]; David & Bunn[273]; Gallagher & Park[274]; Garud & Kumaraswamy[275]; Garud et al.[276]; Khazam & Mowery[277]; Rosenbloom & Cusumano[278]; Shankar & Bayus[279]; Smit & Pistorius[280]; Tripsas[281]; Wade[282]; Willard & Cooper[283]) and identified up to 22 elements per case.

To analyze the MP3 case, we first collected data and made a chronological case description. Then we defined the phases of the platform competition by determining when the milestones occurred. Subsequently we identified which elements influenced the platform competition at each phase. Data was collected from several sources. Written documents such as academic papers (Denegri-Knott & Tadajewski, 2010) and market intelligence reports from independent market research firms, and public announcements were used to gain a general insight. Based on the initial desk research, a preliminary case study analysis was performed. To complement and triangulate the data from the literature and gain an in-depth understanding of the platform competition, we conducted eleven focused interviews with key people from parties involved in the platform competition (e.g. Fraunhofer, Philips, AT&T, Thomson). These interviews were conducted during 2011-2012. Each interview lasted between hand an hour and three hours. To ensure consistency and reliability, interview guidelines were used. We compared the findings from archival sources to the findings of the interviews, and the results were communicated to the interviewees for verification. The data were complemented by documents which were sent by the interviewees, or studied at their offices. In the subsequent sections, the case will be described using the results in the data matrix.

## 4.4 The evolution of audio formats and the origins of MP3

The first time sound was mechanically reproduced, was in 1877 when Thomas Edison invented the phonograph. The device used a tinfoil wrapped cylinder or wax-coated cardboard cylinder on which the music was stored. This invention created a market for prerecorded music. The wax phonograph cylinder dominated the recorded sound market during the early 20$^{th}$ century. During the 1910s phonographs using flat double-sided records became the dominant audio technology and 78 revolutions per minute became the standardized speed in 1925. As technology improved, consumers became interested in better recording quality. This led to the market introduction of the 33-rpm and 45-rpm records in 1932 and 1949 (Langlois & Robertson[284]). Sales of the 45-rpm format took off with the emergence of rock and roll music (Spanias et al.[285]), and the 33-rpm and 45-rpm records became the dominant format for albums and singles respectively. In 1963, the compact cassette tape format was introduced and became an instant success with accessories for home, portable, and car use (Musmann[286]). Nevertheless, it took twenty years to replace the 33-rpm and 45-rpm records as the dominant format (as shown by Figure 42). In 1982 the introduction of the Compact Disc Digital Audio (CD), marked the transfer of analog to digital audio storage. The CD took over the dominant position in 1991, thereby becoming one of the fastest technologies to obtain market dominance.

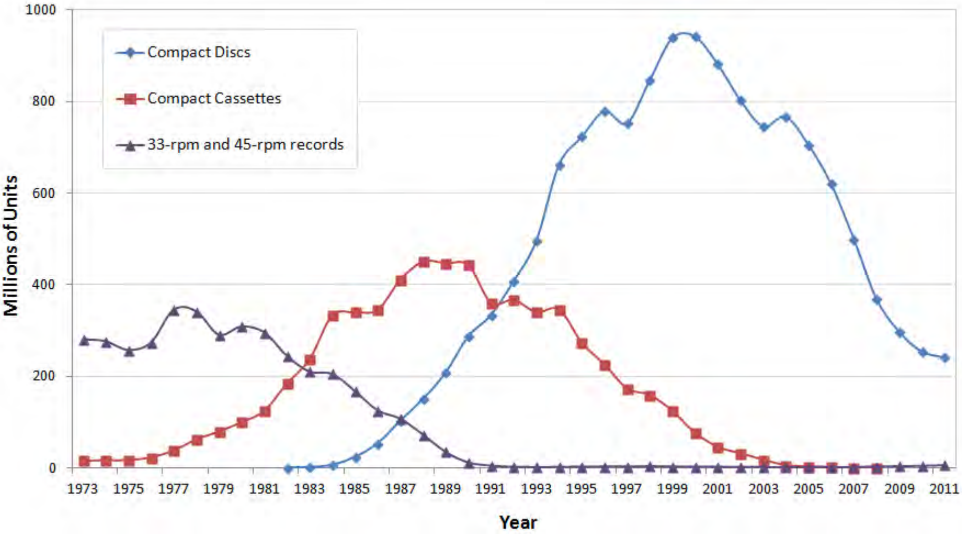


*Figure 42: Volume of recorded music products sold in the United States by format*[287]

Shortly after the compact cassette tape format had been introduced and the 33-rpm and 45-rpm records dominated the market of recorded music, some academic and corporate (e.g. Bell Labs) visionaries recognized that audio and video transmission over telephone lines could result in new products and services. However, this required digitalized data and high data rate transmission. One of these visionaries was Professor Musmann of the University of Hannover (Germany), who focused on data reduction by encoding the amplitudes. In 1977, he managed to reduce the bit rate of moving images by a factor of three thousand to 64 kbit/s, which brought transmission via telephone lines and satellites within reach. In the early 1970s, another visionary, Professor Seitzer of the University of Erlangen (Germany), had the idea to compress and transmit audio data in high quality over telephone lines. As improvements were made to telecommunications infrastructure, he shifted his focus to transmitting music. This shift in focus was necessary to justify his research on data reduction. The industry was losing its interest in data reduction, due to the advances in optical transmission using optical fibers. Seitzer wondered what could be promoted as a step forward when using a digital phone line of 64 kbit/s, so he came with the idea of transmitting music over the telephone network from a central music database. He applied for a patent in 1977, which was granted in December 1982. The patent was subsequently offered to the industry (e.g. Bosch, Telefunken, Grundig, Philips and Siemens), however no-one believed that there would be a need for the invention and it was discontinued in 1988. In 1979, Prof. Seitzer's team developed the first digital signal processor capable of audio compression, creating the basis for developing audio compression schemes.

## 4.5 The rise of MP3 as the market standard

The following sections describe the subsequent phases in the rise of MP3, and identify the relevant elements and tactics that influenced the platform competition.

### *4.5.1 R&D build-up (1982-1986)*

The first steps towards MP3 started with the development of ATC (Adaptive Transform Coding), which started in 1982 when a young German Engineer named Karlheinz Brandenburg was hired as a PhD student by Professor Seitzer at the University of Erlangen. He set out to work on digital audio coding for music transfer over a phone line, and to show the practical feasibility of Professor Seitzer's patented idea. To devise a functional algorithm for digital audio encoding, Brandenburg required a cross-disciplinary approach, combining knowledge from various fields such as psychoacoustics and quantization. The University of Erlangen had a broad knowledge base, and by consulting many of his colleagues, Brandenburg managed to learn about these disciplines. The difficulty was in combining these into a working algorithm.

In 1986, Brandenburg achieved a major breakthrough when he read an article in a scientific journal, which proposed to combine several concepts in a different sequence. Brandenburg had also experimented with these concepts, and decided to develop a new algorithm based on the different sequence, and aimed at speech encoding. The tests of the new algorithm showed that the idea worked properly, compressing speech much more than before without a noticeable decline in quality. The result was a 'proof of concept' of the algorithm and something new compared to what other people were working on. In the folloing year, he further revised and improved the algorithm in iterative steps. During this period he needed computer capacity to perform the tests, which was provided by Deutsche Thomson. The result was the ATC algorithm for speech encoding. After Brandenburg reached his breakthrough, he presented his findings at international conferences and learnt about other parties (e.g. Institut fur Rundfunktechnik and Bell Labs) that were working on a solution to the same problem.

### *4.5.2 Preparing for market entry: reducing the level of competition (1987-1992)*

In 1987, the European Union funded EUREKA project for Digital Audio Broadcasting (DAB) started. The aim was to deliver near-CD quality audio programmes in digital form to domestic receivers. A powerful algorithm was required that would allow audio compression so that it could be transferred via the Integrated Services Digital Network (ISDN). The project embraced research institutes and industries from 29 European countries including electronic equipment manufacturers (e.g. Philips and Thomson), public and private broadcasters (e.g. IRT, CCETT and France Telecom), and regulatory bodies. The Fraunhofer Institute for Integrated Circuits (set up in 1985 as a department of the Fraunhofer Gesellschaft[288]) and the University of Erlangen participated with the ATC algorithm and a large team (including Brandenburg). Although ATC was suitable for speech encoding, encoding music was more difficult. So the team worked on overcoming the problems of encoding music signals with ATC. They named the resulting algorithm Optimum Coding in the Frequency domain (OCF). Fraunhofer compiled this on signal processors, made dedicated hardware, and managed to build the first real-time OCF encoding/decoding device in the same year they started. Before this development, it would take several hours to encode or decode seconds of music.

At the International Conference on Acoustics, Speech, and Signal Processing in 1987, Brandenburg attended a presentation of an Australian university. Brandenburg managed to reproduce their ideas and use this to make significant progress in the encoding efficiency and audio quality of OCF. At the same conference Fraunhofer and AT&T Bell Labs presented their work on music encoding and discovered they had independently developed a similar algorithm. Just like the University of Erlangen, AT&T Bell Labs had the required core competences: the underlying technologies for audio compression were conceived at AT&T in the 1920s and 1930s (Spanias et al.[289]). Since the two approaches were similar, this offered a good basis to collaborate on developing the algorithm. So after Brandenburg finished his PhD in 1989, he went to AT&T Bell Labs to perform Postdoctoral research till 1991. In return, the collaboration gave AT&T access to Fraunhofer's hardware expertise, which they were lacking. However, AT&T was not focused on music, but on speech encoding, and consequently research on music encoding was not really valued An interviewee mentioned AT&T's attitude was "we're not going to make any money on this". As a result, AT&T gave Fraunhofer co-ownership of e.g. the intellectual property rights and code during their collaboration.

In 1988, the Japanese telecommunications company NTT took a leading role in establishing a standard for digital video and audio encoding. The head of NTT's research laboratory, Hiroshi Yasuda, realized that market adoption of encoding required a worldwide standard. His approach was to make a standard for computer networks, whereby the data would be stored in the computer. At that time, the CD was the only means to play and store video and audio real time, and its short access time made it suitable for interactive communications. So it was important to include the CD in the standard as storage medium. To facilitate the standard development process, Yasuda approached a prominent standard development organization, the International Organization for Standardization (ISO). As a result of Yasuda's efforts, the ISO established the Motion Picture Expert Group (MPEG) in 1988 to develop a digital coding standard for video and audio signals. Two experts were appointed to lead the efforts (audio and video) in the MPEG: Didier LeGall (AT&T Bell Labs) for video and Prof. Musmann (University of Hannover) for audio. Since the CD had a bit rate of 1.5Mbit/s, Yasuda, Musmann and LeGall decided to split up the available data rate: 1.24 Mbit/s for video, and the rest (256 kbit/s) for audio while keeping the sound quality intact. The parties issued a document describing the goals for the technical specifications. In the same year ISO posted a call, inviting interested parties to join the MPEG. NTT, AT&T Bell Labs, University of Hannover, and Deutsche Thomson were the first parties that joined. Subsequently, the first working group meeting was planned, and an invitation – open to all interested parties – was widely distributed.

At the same time, the EUREKA project struggled to select an audio encoding format. During a EUREKA project meeting, the Chair proposed that the parties would work towards a single solution in the MPEG-1 audio working group, and the result would be adopted for DAB. The members agreed and submitted their DAB proposals to the MPEG-1 working group.

The first meeting of the MPEG-1 audio working group was organized by Deutsche Thomson in Hannover (Germany) in December 1988 and was attended by approximately 20 company representatives. They appointed Professor Musmann as chair of the audio working group. They also defined the system requirements and selected applications (CD-ROM for audio and video, Digital Audio Tape Recorder, and Digital Audio Broadcasting). As part of the standardization process, task forces were formed to set commercial and technical requirements (aspects on which the compression algorithms would be tested and their measure of importance), and define objective test criteria.

After the first meeting, Professor Musmann issued a call for proposals. He received fourteen proposals before the deadline of June 1989. Professor Musmann subsequently had to conceive a process that would lead to a single solution supported by all participants. From June to October 1989, he studied the proposals, and found they could be divided in four groups (see Figure 43). His suggestion to work towards a solution in four groups was accepted by all parties. As a result, Fraunhofer, AT&T, Thomson and France Telecom started to work together and each made their contribution: Fraunhofer's OCF filterbank, AT&T's PXFM perceptual model, Thomson's window and block switching, and France Telecom's entropy coding. The four clusters set up research groups which had six months to develop hardware that combined the ideas of the members in the group. Since most of the companies in the MUSICAM and ASPEC clusters had already worked together in the DAB project, they had an important advantage over the other two clusters.

| Company | Country | Coding Concept |
|---|---|---|
| CCETT | France | MUSICAM Subband coding with more than 8 subbands |
| IRT | Germany | |
| Matsushita | Japan | |
| Philips | Netherlands | |
| AT&T | USA | ASPEC Transform coding with overlapping blocks |
| France Telecom | France | |
| Fraunhofer Gesellschaft | Germany | |
| Deutsche Thomson-Brandt | Germany | |
| Fujitsu | Japan | ATAC Transform coding with non-overlapping blocks |
| JVC | Japan | |
| NEC | Japan | |
| Sony | Japan | |
| BTRL | Great Britain | SB/ADPCM Subband coding with less than 8 subbands |
| NTT | Japan | |

*Figure 43: Coding concepts and members of the four groups (adapted from Musmann[290])*

In July 1990, during the 4th meeting of the working group, the progress of the clusters was tested. It became apparent that the ATAC and SB/ADPCM cluster could not get their hardware for real time processing functioning properly (at that time the hardware for the real time processing was difficult to develop, and the required signal processors were developed not long before). As a result, it was not possible to complete the full range of tests, and much additional work was required to reach the level of the other two proposals. Since the MPEG audio standard had a strict deadline to be completed by the end of 1991, there was no time for the two clusters to catch up, so Professor Musmann suggested that the companies in ATAC and SB/ADPCM to join the MUSICAM and ASPEC clusters. Only few companies actually did, and the others remained involved in the working group as neutral parties.

During the next meeting in September, the tests results were discussed. These showed MUSICAM had achieved the best overall results. The outcome was based on an agreed formula that took into account audio quality, complexity (which translates into cost of the integrated circuit for the decoder and encoder), delay and some other parameters. Although ASPEC and MUSICAM scored similarly on most tests, the difference in complexity was 10:1. However, ASPEC showed better audio quality at low bit rates, and several parties (including AT&T and two parties involved in testing the codecs: BBC and Swedish Radio) were dissatisfied with the idea that a codec with better results on the low bit rate would not be included in the standard. As a result, the MPEG-1 audio working group feared that the national standards bodies would vote down the outcome (especially the US standards body, ANSI, due to the influential role of AT&T). Since MUSICAM inherently consisted of two layers (Layer 1 was aimed at the Digital Compact Cassette application, and Layer 2 was aimed at the DAB application), the working group managed to reach consensus by agreeing to add a third layer for lower data rate applications that would be backwards compatible to Layer 1 and 2. Layer 1 had a data rate of 192kbit/s, Layer 2 had a data rate of 128kbit/s, and Layer 3 was set at 64kbit/s (reducing the original sound data from a CD by a factor of 12). The latter was selected to enable data transfer over ISDN. Brandenburg became responsible for writing the Layer 3 specification, under the review of two people from MUSICAM. While writing the Layer 3 specification, Brandenburg had to mix the different technologies in order to maintain the good performance of ASPEC at low data rate, while maintaining compability with Layer 1 and 2.

During an intermediate test event in Paris in June 1991, the results showed that Layer 1 and 2 were nearly completed. But the working group found there were problems in meeting the requirements for Layer 3. After this test, one of Professor Musmann's PhD students discovered a mistake had been made while combining ASPEC and MUSICAM. He came up with a solution on how to reduce the efficiency impairment of the combined technologies and improve the sound quality. But due to the lack of interest from the University of Hannover, this idea was patented by Fraunhofer. The day before the Layer 3 team had to deliver their equipment for the final test, the Fraunhofer team managed to solve a software bug which greatly increased the audio quality and resulted in meeting the quality requirements.

The last test before completing the specification was conducted in October 1991 in Hannover. The group concluded that most of the problems that had been found at the intermediate meeting in June were solved. Since the deviations from CD sound quality were minor and there was little time before the deadline, they agreed to include Layer 3 in the MPEG-1 audio standard. MPEG-1 audio was finalized in November 1991. The complete MPEG-1 standard, which comprised both audio and video, was approved as ISO/IEC IS 11172 in November 1992. The standard was published several months later.

The MPEG-1 standardization process and the willingness of its participants to collaborate greatly reduced the amount of competition among compressed audio formats. Nevertheless, next to Layer 2 (which became the audio compression format for DAB), there were several other audio compression formats that competed for market adoption. Sony renamed the ATAC technology to ATRAC and implemented this in their products such the portable music player MiniDisc which was launched in 1992. Dolby was very active with a proprietary format, AC-1, which they introduced in 1987 at the beginning of the High Definition Television (HDTV) standardization process (Todd et al.[291]). In 1989, they introduced AC-2 which had better audio quality and a reduced bit-rate. Finally, in 1991 AC-3 (also known as Dolby Digital) was introduced, which was implemented in a commercial cinema product and later also in HDTV and DVD.

#### *4.5.3 Initiating market adoption: finding the first applications (1993-1996)*

After the MPEG-1 audio standard was published, it became clear that this was no guarantee for Layer 3 to be utilized in an application. Unlike the MUSICAM supporters, the ASPEC supporters were not strongly positioned to implement the MPEG-1 audio standard. Fraunhofer focused on applied science, AT&T and France Telecom offered telecom services whereby music compression was out of scope, so this left Thomson (which was active in the consumer electronics field) as the only ASPEC supporter able to implement Layer 3 in products. To overcome this problem, the Fraunhofer team took it upon themselves to find applications for Layer 3. They made an effort to promote the application of Layer 3 by attending many conferences, giving demonstrations, and by creating a website to inform interested parties about the technology. They also searched for applications they could service themselves. Due to the relatively high complexity of Layer 3, the implementation required a market which was not sensitive to the price of the integrated circuit. This led them to the radio broadcasting market. Between 1989 and 1992, Fraunhofer had sold a small series of equipment that was able to encode music (first using OCF and later

ASPEC) and could be distributed via low-cost ISDN telephone lines, and in 1993 these were converted to MPEG-1 Layer 3. These systems were used by, for example the Christian Science Publishing Society and the U.S. Army Research Laboratory. They also did contract research for professional ISDN broadcasting systems and speech announcements for buses to customers such as Philips Kommunikations Industrie (PKI), Dialog4, NSM Löwen and Meister Electronic. These parties were interested to use high quality low bitrate audio coding because this allowed them to save cost by using fewer cables or less data storage. These were small initial markets for the technology and showed its advantages. In that same year, Telos Systems (at that time a small US based firm) was the first to buy a MPEG-1 Layer 3 license and the equipment to encode and distribute MPEG-1 Layer 3 for newscasting of sport matches. Telos was successful with the system, and afterwards purchased additional equipment. This increased the visibility of MPEG-1 Layer 3 in the industry. In addition, Telos introduced Fraunhofer to other companies. One of these was one of the first internet service providers, and the respective contact person later switched to Microsoft. The resulting relationship with Microsoft later became important to the market adoption of Layer 3.

In 1993, Fraunhofer established a partnership with Thomson for their essential patents on Layer 3. Since Thomson was experienced in licensing negotiations, they agreed that Thomson would focus on the consumer market and provide licenses on the combined patent portfolio (approximately 18 patent families) while Fraunhofer would service the professional market with equipment. Although Thomson actively licensed the combined patent portfolio to all commercial enterprises interested in using Layer 3, a license from them alone was not sufficient since it did not include the MUSICAM patents. In order to obtain access to these, companies had to negotiate a license with the Italian company SISVEL, which Philips, IRT and CCETT appointed as the licensing agent for their combined MPEG-1 patent portfolio in 1996.

After the ISO MPEG audio standard was finalized, several companies started developing chipsets for Layer 2, a prerequisite for implementing the technology in mass-produced devices. To enable this for Layer 3, the Fraunhofer team entered into discussion with the German company Intermetall. The two companies got acquainted during the EUREKA project. Intermetall had just developed a new chip, and were looking for a complex task to showcase its capabilities. Layer 3 was ideal for this due to its complexity. Intermetall was also interested to provide receiver chips for the DAB digital radio. Although DAB was based on Layer 2, Intermetall was hoping that DAB would eventually move toward Layer 3.This led to the development of the Layer 3 decoder chip prototype, which became available in 1994. The Fraunhofer team used this chip to develop a prototype of a portable Layer 3 player. The device was battery powered, used an EEPROM decoder chip to store and play music, and had 1MB memory. At that time, memory was expensive. A portable player with sufficient memory to store one hour of music would have cost several thousands of US Dollars. Using Moore's law (Moore[292]) which states that the number of transistors per semiconductor (and thereby the amount of bits that can be stored on a chip) doubles roughly every two years, they calculated that solid state memory would become attractively priced for the mass market around 2000. The prototype was shown publicly for the first time at an academic conference in fall 1994. Even though the idea of storing music on solid state memory was not new, it attracted substantial academic interest.

In the same year, the Fraunhofer team held an internal meeting about the commercialization strategy. They identified a rapid increase in the adoption of the World Wide Web and the interest of its users to share music through this new means of communication as an important opportunity, and realized there was a limited window of opportunity to establish Layer 3 as dominant audio distribution format in this niche. Fraunhofer was aware of the development of the World Wide Web because Brandenburg had used Usenet (a hybrid between e-mail and web discussion forums) during his postdoc at AT&T to exchange research results with the University of Erlangen. The interest to share music via the Internet became apparent in 1993, when the Internet Underground Music Archive (IUMA) started sharing music of independent artists over File Transfer Protocol (FTP) and Gopher sites in Layer 3 format. The IUMA was founded by a group of Californian engineers that had attended the MPEG-1 audio working group meetings. Their intention was to develop a new distribution method for music of independent bands, eliminating the need for record companies. At that time, it was commonly known that a CD-ROM drive (which was introduced in the personal computer market in 1985) could be used to "rip" the music (which was stored using Pulse Code Modulation which digitally represented sampled analog signals, and this signal had no copy protection mechanism) from an audio CD. The IUMA used a software program to grab songs as WAV files and an encoder (based on the source code which was published in part 4 of the MPEG-1 audio standard) to convert and compress the files to Layer 3 format for storage, computer playback and Internet distribution. The IUMA showed that the Internet was a suitable means to exchange music. The Layer 3 format was used because it had several important advantages compared to its alternatives. It was one of the few formats that was fully developed, it required a low data rate (while maintaining good quality) which matched well with the requirements for music transfer over the Internet (the vast majority of Internet users accessed it through a 56 kilobit per second dial-up modem), and it had shown to provide high quality audio at low bitrates in the radio station market. The interest for music distribution over the Internet was enabled by the developments in personal computers, which became capable of playing good quality audio due to the implementation of sound cards. In order to capitalize on the limited window of opportunity and facilitate the use of Layer 3 on the Internet, in July 1994 Fraunhofer released the first software MP3 encoder called L3enc on their web site for US$250[17]. These developments enabled Layer 3 to cross over from the professional market to the consumer market.

In July 1995, the Fraunhofer team renamed MPEG Layer 3 to MP3 because it was shorter and easier to utilize, and changed the file extension to .mp3. They released a media player named WinPlay3 later that year. WinPlay3 was the first real-time MP3 audio player for PCs running Microsoft's Windows[293], and could be downloaded from the Internet. Previous to the release of the application, audio compressed with MP3 technology had to be manually decompressed by the users prior to listening.

In the same year, Fraunhofer started selling and licensing encoder hardware boards for the PC domain. In addition, the software company Macromedia obtained a license on MP3 and integrated the encoder and decoder in their Shockwave media (audio and video) player. Soon thereafter Xing Technology and RealNetworks introduced their streaming media players: Streamwork and RealAudio. The RealAudio media player could play MP3 but also used a propietary format called RealAudio which was based on Dolby's AC3. According to statistics from International Webcasting Association in September 1997, the web broadcasting (e.g. radio stations transmissions) market share of RealAudio almost reached 90%. Although the RealAudio player was popular during the early years of the Internet, it was surpassed in market share by Microsoft's media player in 2000.

In 1996, another competitor, Liquid Audio, entered the stage. The company had developed a website where customers could purchase, download and play music using its own software player, encoded in a proprietary, secure format. In order to create the compression format, the company had worked with Dolby. By 1999, Liquid Audio had enlisted over 200 partners and affiliates that agreed to sell or distribute music in the Liquid format (Hause, 2000). Major labels EMI and BMG and several hundreds of small labels were using the Liquid format and another major label, Warner Music, was utilizing Liquid's server software. However, the format was hindered by its PC-only playback capabilities, since there was little support from integrated circuit vendors and therefore could not be implemented in portable compressed audio players.

MP3's lack of copy protection spurred its popularity for illegal music distribution, but this feature was unintentional. Fraunhofer was able to offer copy protection, but they also wanted to agree upon a standard with the record labels. However, at that time the record labels did not recognize the increasing popularity of the Internet and the potential impact on their business model. In 1995, the Fraunhofer team participated in a European project: Music on Demand. Only the small record labels participated in the project. Fraunhofer held a presentation about digital rights management, however the record labels failed to recognize the urgent need to discuss the topic. Fraunhofer also contacted the project leader of a European project on real time audio encoding on PCs. This project included participants from the computer and music industry, and it was the first time Fraunhofer established contact with the major record labels in the music industry. During a meeting at BMG Ariola in Munchen, the major record labels said "it all sounds very interesting, but what does this have to do with us?".

#### *4.5.4 Gaining critical mass in the Internet music distribution market: the rise of complementary assets (1997-1999)*

Several years after the Internet music distribution market started, several compressed audio formats were competing for market adoption and MP3 was in the lead. In 1997, AAC, a technologically superior audio compression format joined the competition. The initial idea to start with the development of AAC can be traced back to the end of 1992. At that time, the MPEG-1 audio working group finalized the first MPEG audio standard, and MPEG continued with the development of the next standard by starting the MPEG-2 audio working group. This working group focused on developing an audio compression format that could be used for low data rates, enable multichannel sound, and would be compatible with the MPEG-1 audio standard. However, during this development there were concerns that the backwards compatibility requirement put too many restrictions on the capabilities of the new format. In 1993, the MPEG-2 audio working group decided to compare the new format to two codecs that were not compatible with MPEG-1: Dolby's AC-3 and AT&T's new Perceptual Audio Coder (PAC). In January 1994, the test results became available, showing that AC-3 and PAC were better than the newly developed backwards compatible codecs. Subsequenty, the MPEG-2 audio working group started a new work item on 'non backwards compatible coding'. Several parties submitted proposals. After testing these, the working group decided to move forward by combining the proposals of Fraunhofer, AT&T, Dolby and Sony. Their respective proposals showed good results and were technically similar. The parties together created the AAC codec, which was finalized in April 1997. After the AAC standard was finalized, industry insiders expected the market would switch to the new format. An interviewee reported: "From a technical perspective MP3 had lost its right to exist after AAC became available". However, market adoption was hindered due to two reasons. First, after the AAC codec became available, the standard developers wanted to put different licensing constraints on AAC, making it difficult to obtain a license on the 'standard-essential' patents. This issue was solved when the parties agreed on a collaborative patent licensing program in 1998. As result, the first implementations of AAC entered the market in 1999. By this time, MP3 had an extensive installed base and a large number of complementary products. Secondly, Dolby was appointed by the patent holders to act as the licensing agent (in 2003 this role was appointed to VIA Licensing, a Dolby subsidiary), while the company was simultaneously marketing its proprietary AC-3 codec, causing a conflict of interest.

In 1997, two important events boosted the market adoption of MP3. Firstly, the MP3 decoder software was hacked by an Australian student and published on-line as freeware. Due to the lack of a regime of appropriability, this could not be counteracted and Fraunhofer and Thomson decided to support the distribution of unrestricted MP3 media players. Secondly, Microsoft obtained a license from Thomson[294], and included MP3 in their Windows Media Player (WMP) 6.1. This media player was the multimedia platform that came with Windows 98 as the default front end for playing audio and video files, and since Windows was the dominant personal computer operating system, many consumers had access to WMP. Microsoft included MP3 rather than AAC in WMP 6.1 mainly because it was already a popular codec with much available audio content, but also because AAC was not finalized in time to be included in WMP 6.1.

In the same year, the type of complementary assets for MP3 broadened with the launch of the world‘s first commercially available portable players that could store and play MP3 files and websites for MP3 file sharing. The portable MP3 player was introduced by Audio Highway and contained software for uploading MP3 audio content to a personal computer and then downloading it onto the portable MP3 player. The device had no moving parts, therefore (unlike the compact disc) the music did not skip when consumers were exercising or driving. The portable MP3 player used Intermetall's first commercial Layer 3 decoder chipset which had become available the previous year. About half a year later, the South Korean company SaeHan introduced the MPMan, which was the first mass produced portable MP3 player. The first dedicated website for sharing MP3 files was MP3.com. It quickly became one of the most popular websites on the Internet that offered the possibility to stream, play and store MP3 encoded music.

A media player called Winamp, introduced in 1997 as MP3 playback engine, was distributed as shareware and quickly became a success (Paxton[295]) due to the expanding penetration of multimedia computers and high-speed Internet connections. Within months of its first release, Winamp was consistently topping the download list at shareware sites, new media players were entering the market, and the user base quickly expanded. At the same time, new websites started offering MP3 songs for free download, and other sites allowed people to upload music, creating a virtual market for free music. In addition, most people did not notice or care that this trading of music was illegal.

In 1998, the Recording Industry Association of America (RIAA) began to take notice and started to actively shut down these websites. However, the number of sites that were started significantly outnumbered those that were shut down. Since people could only listen to the music on their computer, the problem for the recording industry was limited. Later that year, Diamond Multimedia, a large company with retail distribution capabilities, entered the market with its own portable MP3 player: the Rio PMP300 (Paxton[296]). This became the first commercially successful portable MP3 player. With the prospect of MP3 moving off the PC and into the mainstream, the RIAA filed a lawsuit against Diamond for encouraging illegal music copying. This lawsuit attracted much press coverage, ironically bringing MP3 under the attention of the mainstream, creating mass-market awareness and increasing demand for portable MP3 players and MP3 files.

In October 1998, Diamond Multimedia, GoodNoise, MP3.com, MusicMatch, and Xing Technology founded the MP3 Association to promote MP3 technology as the standard for downloadable music, thereby increasing both the visibility and use of the technology. In addition, the organization pooled together legal resources to strengthen its lobbying efforts, while attempting to improve the relationship with the recording industry.

In June 1999, the user-friendly peer-to-peer music sharing site Napster was launched. Although there were already websites which facilitated file sharing (e.g. IRC and Hotline), Napster specialized exclusively in MP3 files and presented an interface that made it easy to find the audio file of interest. The result was a system whose popularity generated an enormous selection of downloadable MP3 files. By the end of the first week, Napster had 15,000 users, and this number had grown to over 25 million by 2001. Due to Napster's popularity, the RIAA filed a lawsuit against the website end of 1999, based on the Digital Millennium Copyright Act (DMCA). The DMCA had been passed in the United States at the end of 1998, and criminalized services that controlled access to copyrighted works. This legislation gave the RIAA a strong legal basis to strike against the rising popularity of websites that facilitated sharing MP3 files.

Although Microsoft had a license on the MP3 technology, in 1999 they introduced a proprietary format named Windows Media Audio (WMA) with copy protection. This new format became a serious competitor to MP3. Microsoft, as a strong market player, aggressively pushed WMA as the market standard. They bundled WMA with the release of the fourth version of Windows Media Player in 1999, and licensed their codec to other software providers so users would not be tied to WMP. They embedded support for WMA in other products using Windows, such as set-top boxes, and used marketing slogans to manage industry expectations. At the CES conference in 2000, Microsoft requested its licensees to mention that WMA was 'twice as good as MP3' on their booths. However, the technological superiority of WMA over MP3 was not evident. There were tests that showed both codecs gave similar results. Microsoft had two reasons to introduce WMA. First, they wanted to be free of license payments, and secondly they believed an alternative audio compression format with adequate copy protection could win the support of the music industry and gain significant market traction. By the time WMA entered the market, MP3 had gathered significant momentum and held a large advantage over other compressed audio formats due to its significant installed base, availability of songs in the MP3 format, and complementary assets (software and hardware players). Strong direct and indirect network externalities helped to increase this momentum. By 1999, MP3 was regarded as the market standard for Internet distribution of music, and the Internet had become a fast growing medium for information, communication and entertainment exchange (see Figure 44), reaching 35% penetration among U.S. households, at a 49% consumer PC penetration[5].

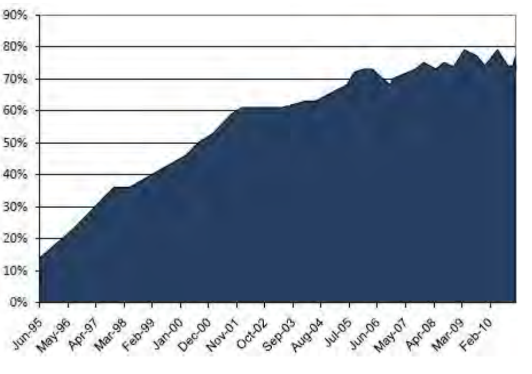


*Figure 44: Percentage of American adults using the Internet*[297]

### *4.5.6 Winning the mass market: the power of network effects (2000-2009)*

Although by 2000, MP3 was regarded as the market standard for music distribution over the Internet, it still needed to replace the Compact Disc as the dominant format for music storage and distribution.

Simultaneously there were several physical formats (of which MiniDisc was the most prominent) on the market that aimed to replace the CD. MPEG-1 Layer 2, one of MP3's first competitors, was no longer an important contender. DAB did not achieve the commercial success that was expected and the format resided in several very successful applications for video distribution (Video CD and Digital Video Broadcasting).

In 2000, several major consumer electronics players (e.g. Philips, Sony, Sanyo, Sharp, Samsung and LG) entered the market for portable MP3 players. The major consumer electronics company Panasonic and the personal computer company Apple (with its first generation iPod) joined the competition in 2001, and in the same year MP3 file sharing websites KaZaa and Bittorrent were launched. In 2004, KaZaa's popularity peaked, and the same happened for Bittorrent in 2006. The combination of an increase in availability of portable MP3 players and websites providing MP3 files created strong network effects and reinforced the market adoption of MP3. Between 2000 and 2007, the market adoption of portable MP3 players grew rapidly (see Figure 45). The first boost (between 2000 and 2002) resulted from the large number of companies entering the portable MP3 player market, especially the major consumer electronics players. The second boost (between 2003 and 2006) was caused by the network effects and the market tipping towards the MP3 format. This was also driven by the popularity of Apple's portable compressed audio player, the iPod, which turned out to be the ´killer application´ of the compressed audio players. iPod sales were a significant part of the MP3 player sales (see Figure 45).

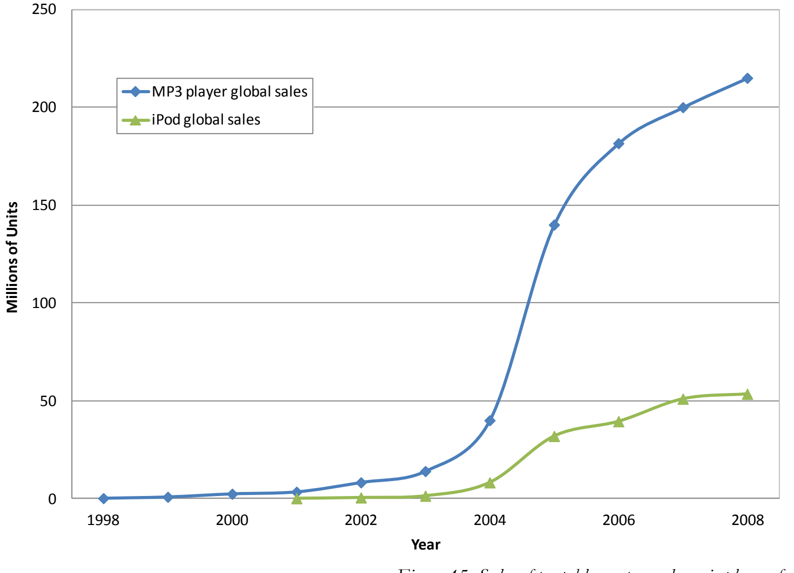


*Figure 45: Sales of portable compressed music players from 1998-2008*[298]

In 2000, the major record labels BMG, Sony, EMI and Warner (which had been working with Liquid Audio and RealNetworks) decided to use Microsoft's WMA format for online music downloads because of its copy protection and its tie-in to Windows Media Player[299]. This significant increase in content support boosted WMA's market traction and made it the major up-and-coming competitor in the audio codec domain. However, the additional support from the music industry hardly resulted in compressed audio players supporting the format, limiting the use of WMA to the computer. When the market adoption for portable MP3 players accelerated, and Apple's iPod (which supported several audio codecs, amongst which MP3, but not WMA) became successful, the window of opportunity for WMA in the portable compressed audio market closed. In an attempt to boost compressed audio player support, Microsoft launched the Zune in 2006. However, this did not become successful.

Up to 2001, MiniDisc players, which could be used to record and play music in Sony's proprietary ATRAC codec, had the highest market adoption in the compressed audio player segment. MiniDisc was launched by Sony in 1992, taking a proprietary approach and focusing on the portable music player market after the ATAC audio compression format was removed from the MPEG-1 audio standardization process. MiniDisc players quickly became popular in Japan, accounting for most of the worldwide sales. Although Sony was the major sponsor behind MiniDisc, they also licensed it to others (in 2001 Sony's player shipments constituted 25% of the MiniDisc market). Despite MiniDisc's early entry in the portable compressed audio player market, the format failed to gain critical mass outside Japan.

After 2001, sales of portable MP3 players exceeded those of MiniDisc players. Sales of MiniDiscs peaked in 2001 and then decreased sharply (see Figure 46).

In February 2001, the US Ninth Circuit Court of Appeal ruled that Napster should stop allowing music fans to share copyrighted material (Smith & Wingfield[300]). However, not all attempts of the RIAA were successful. In April 2003, the court ruled that Grokster and Streamcast Networks could continue to distribute Internet file-sharing software, forcing the music industry to intensify the legal pursuit of individuals who distributed copyrighted works online. By July 2003, the RIAA had issued hundreds of federal subpoenas demanding Internet service providers and some universities to turn over names of users suspected of illegally sharing music. Several months later, the RIAA filed 261 lawsuits against individuals who allegedly illegally used file-sharing software to distribute copyrighted music online.

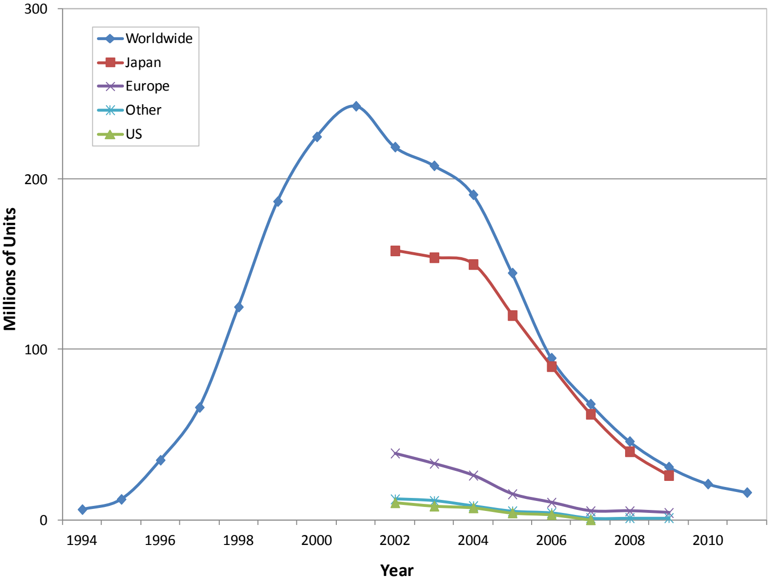


*Figure 46: Volume of MiniDiscs sold from 1994-2011*[301]

Amidst all this turmoil, in 2003 Apple launched iTunes 4.0 (version 1.0 was introduced in January 2001 as an MP3 media player for Apple's Mac operating system) which contained a new feature: the iTunes Store. The iTunes Store was a proprietary software-based online digital media store where consumers could purchase music files in the AAC format including Apple's Fairplay data rights management. The use of a strong data rights management system was a prerequisite from the record labels to make their music catalogues available for iTunes (Jobs[302]). The AAC codec was very suitable to Apple's needs, because it provided high audio quality at low bitrates and its design allowed an extension with a DRM implementation. Apple's Fairplay software restricted purchased song playback to Apple products. When the iTunes Store was launched, it had content support from the five major record labels (EMI, Universal, Warner, Sony Music Entertainment, and BMG). During this time, the iPod was becoming increasingly popular, and the iTunes Store allowed iPod users easy access to a broad selection of music and to download songs legally. Consumers were thrilled, and the iTunes Store quickly became a success. The store sold about 275,000 tracks in its first 18 hours in business and more than one million in its first 5 days. In August 2004, Apple announced that the iTunes Store was the world's number one online music service. It had over one million songs available for download in the US, more than 100 million songs had been downloaded and the store had more than 70 percent market share of legal downloads for singles and albums[303]. The success of the iPod and the iTunes Store proved to be a potent combination and reinforced the market adoption of both products.

Table 15: Market share of music acquisition by US consumers[304]

| | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** |
|---|---|---|---|---|---|---|
| **Physical CDs** | 51% | n.a. | 41% | 32% | 27% | 22% |
| **Digital** | 49% | n.a. | 59% | 68% | 73% | 78% |
| Paid downloads | | | 7% | 10% | 13% | 15% |
| *iTunes* | | | | 69% | 68% | 69% |
| *Amazon MP3* | | | | | 5% | 8% |
| *Rhapsody* | | | | 2% | 3% | 4% |
| *Zune* | | | | 1% | 2% | 3% |
| *Napster* | | | | 4% | 2% | 2% |
| *Other* | | | | 24% | 20% | 14% |
| Un-paid music acquisition | | | 52% | 58% | 61% | 63% |
| P2P | | | 27% | 33% | n/a | 29% |
| Burned from others | | | 40% | 33% | n/a | 17% |
| Ripped from others | | | 33% | 33% | n/a | 19% |
| Music transferred from external hard drive | | | | | | 29% |
| Music downloaded from digital storage locker | | | | | | 5% |
| | | | | | | |
| **Market share per compressed audio format** | | | | | | |
| MP3 | 72% | | | 64.3%[305] | 62.5% | 60.9% |
| WMA | 19.6% | | | 17.5% | 17% | 16.6% |
| iTunes (AAC) | 4.3% | | | 10.1% | 11.6% | 13.3% |
| Other | 3.9% | | | 8% | 8.9% | 9.3% |
| **Market share of music formats** | | | | | | |
| MP3 | | | | 43.7% | 46.2% | 48.7% |
| WMA | | | | 11.9% | 12.4% | 12.9% |
| AAC | | | | 6.9% | 8.5% | 10.4% |
| CD | | | | 32% | 27% | 22% |
| Other | | | | 5.5% | 5.9% | 6% |

With the introduction of portable MP3 players, compressed audio formats competed more directly with CDs. This initiated the decline of CD sales. In 2004, the share of physical CDs and digital music acquired by US customers was almost equal (Josephson, 2005). The market started to reach a tipping point, whereby MP3 was taking over the dominant position from the CD (see Table 15). MP3's market share in the music industry is difficult to measure since its use is largely based on unpaid music acquisition. Based on CD sales data and paid downloads (see Figure 47) and the market share of the different ways of music acquisition (see Table 15), we calculated the volume of unpaid music acquisition between 2006 and 2009 (see Figure 8). The volume of unpaid music acquisition surpassed the CD sales in 2006. While much of the unpaid music acquisition was based on the MP3 format, alternate formats were also. In addition, some paid downloads used MP3 files (for example, from the Amazon MP3 store). With the drop in CD sales, and the rise of compressed audio formats, MP3 became the dominant audio format. However, in order to pinpoint when this actually occurred, we need an indication of the market share of the audio compression formats that were used for music distribution. The last available research on this was conducted in 2004 by the NPD Group, and provided the following results: 72% market share for MP3, 19.6% for WMA, 4.3% for AAC, and 3.9% for other formats[306].

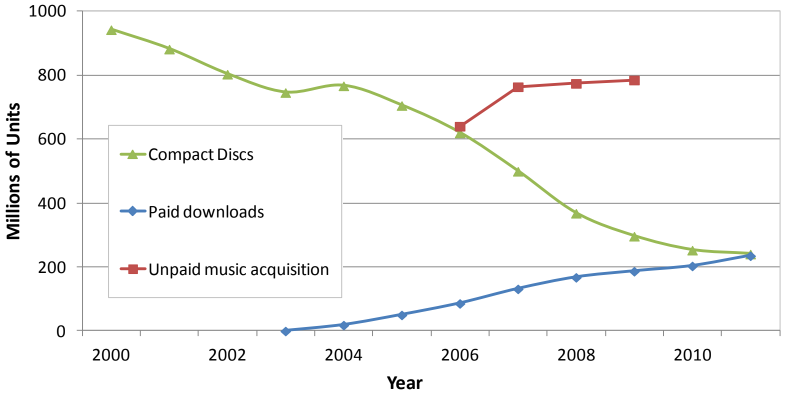


*Figure 47: Volume of music products sold in US from 2000-2011*[307]

When we cross reference these figures with the actual market development of paid and unpaid music acquisition, and extrapolate the figures for MP3, we find that by 2009 the MP3 format had nearly obtained 50% market share of of music acquisition by US customers.

However, the extrapolation does not account for the positive effect that the rapid market adoption of portable MP3 players had on the market share of MP3. This suggests it likely exceeded 50% by 2009 (perhaps already in 2008) and can therefore be regarded as the dominant music format in the US.

*4.5.7 Post dominance (2010-ongoing)*

As we have seen from Figure 47 and Table 15, the market share of paid downloads is increasing fast. This is largely driven by Apple's iTunes store which uses the AAC format. As Table 15 shows, the market share of AAC in terms of the overall music formats has grown relatively fast, but its absolute growth is similar to that of MP3. With the introduction of the iPhone in 2007 and the iPad in 2010, Apple leveraged its iTunes store to cellphones and tablet computers. The rapid market adoption of the iPhone and iPad boosted the adoption of AAC. As the MP3 standard was finalized in 1993, most essential patents will be expired by 2013, lowering the cost for a MP3 license and making the format more commercially attractive. Both MP3 and AAC will benefit from the steady decrease of the CD, and although AAC could take over the dominant position from MP3 at some time, this is not likely to happen any time soon.

## 4.6 Case analysis

It took MP3 17 years from the start of its development to become the market standard for music on the Internet (see Figure 48). At that time, it was still far from becoming the dominant music format. While competing against the CD as incumbent dominant format, the adoption of MP3 experienced a period of rapid growth and within nine years it had become the overall dominant music format. By modeling an S-curve (Foster[308]) on the market adoption of MP3, we can see the importance of the phases from a market adoption perspective. It was useful to add the phase of 'winning the mass market' to our scope of analysis, because during this period MP3's market adoption increased the most (see Figure 9). At present, MP3 is in a phase where the market is mature and saturated. This is often the time when a new platform emerges to compete for the position of dominant platform (Anderson & Tushman[309]; Clark[310]; Dosi[311]; Foster[312]). As noted in the previous section, the market share of paid downloads (which is mainly driven by the AAC codec) is steadily increasing and could challenge MP3 for market dominance.

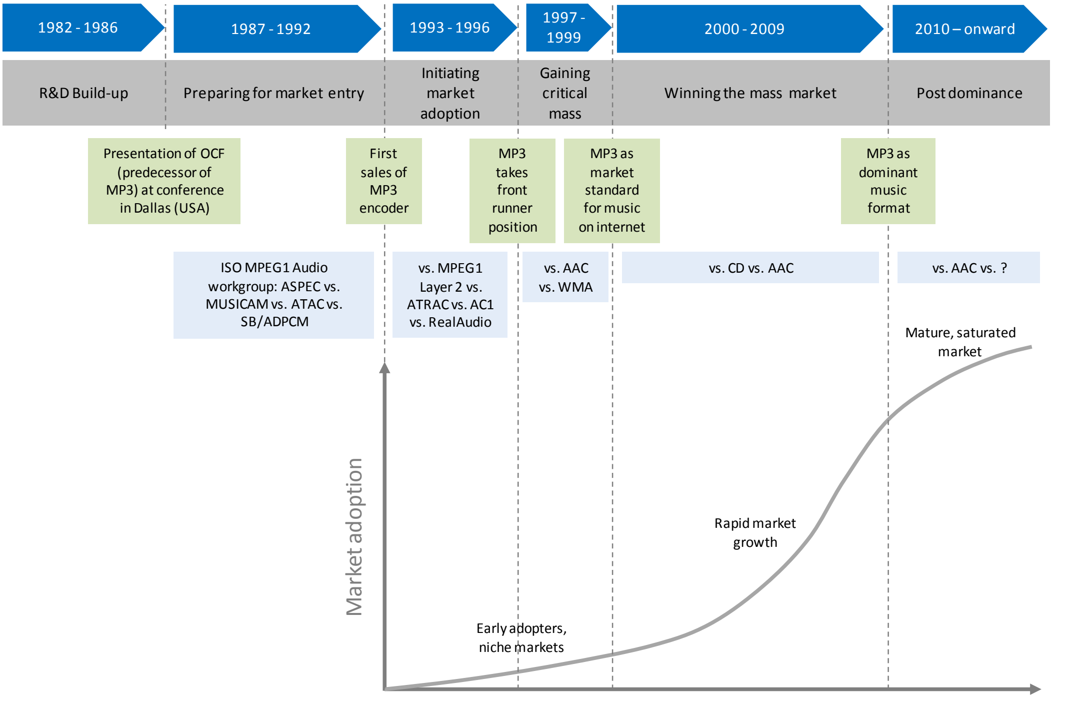


*Figure 48: Phases, respective timeframes and milestones in the rise of MP3 as the market standard*

Over the lifetime of MP3, there were several audio compression formats that competed for market dominance. The first major competitor for MP3 was MPEG-1 Layer 2. Initially, this technology had more market adoption. However, contrary to expectations, DAB failed to become a market success. With the rise of the Internet, the adoption of MP3 quickly surpassed that of MPEG-1 Layer 2. The parties behind

Layer 2 did not foresee the market of music distribution over the Internet, and the Internet had initially specific technological characteristics that gave MP3 a distinct advantage over Layer 2. However, while the Internet started to boom, the competing format AAC became available and various parties expected the market to switch to the new format. However, the market adoption of MP3 accelerated while the adoption of AAC progressed slowly. On the one hand, this was due to certain developments that benefitted the adoption of MP3 (the license to Microsoft and the hacked decoder), but on the other hand, it was also caused by certain errors by the AAC supporters (e.g. assigning the patent licensing and format promotion to a party that had a conflict of interest). When Microsoft launched its WMA on the market in 1999, MP3 had already become the dominant music distribution format on the Internet, and the first popular portable players had been launched on the market. However, during 2000 and 2001, WMA quickly gained market share. The rise of WMA was countered by rapid market adoption of portable compressed audio players supporting MP3, especially the iPod. WMA's market entry was too late and it missed the boost in market adoption caused by portable compressed audio players. The combined growth of portable players supporting MP3 and their positive reinforcement on the popularity of MP3 files sharing websites enabled the market to tip towards MP3, and as a result it became the dominant audio format. CD was well entrenched as the market standard, and much time (approximately 16 years after it entered the market) and momentum was required for MP3 to take over its position. Sony's MiniDisc technology could have been a significant threat to MP3. If it had replaced the CD between 1992 and 2000, the outcome of the competition against MP3 would have been unclear.

We identified 26 elements that influenced the platform competition. Following the detailed description in the previous sections, we determined nine key elements that enabled MP3 to become the dominant format (see Figure 49 for an overview). As can be seen from Figure 49, the focal point of the key elements is the phase of 'Initiating market adoption'. The combination of elements reflects the efforts to harness available chances and accelerate the initial momentum. In the period when mass market applications for compressed music formats emerged, the level of competition was reduced by the MPEG-1 audio standardization process (stimulating parties to collaborate and develop a single standard). The rise of MP3 was enabled by four technologies: the rise of the Internet, the CD which digitized music without content protection, personal computers with sufficient processing power and sound cards, and low cost integrated circuits able to perform real time encoding/decoding (leading to the introduction of portable MP3 players). The timing of MP3's market entry was another key factor. When the rise of the Internet took place, MP3 was one of the few fully developed audio compression formats, and it offered the highest compression ratio while maintaining near CD audio quality. The high compression ratio made it technologically superior to other formats. MP3 had very dedicated sponsors, Fraunhofer and Thomson, that actively promoted its use and had the endurance to explore various market niches. Before the Internet gained rapid market adoption, Fraunhofer managed to identify music distribution over the Internet as a 'killer application' that matched well with the benefits of MP3 and they facilitated the use of MP3 on the Internet. The weak regime of appropriability, caused by MP3's lack of content protection and the difficulty to enforce rights on the Internet, allowed MP3 files to be shared easily, made it difficult for the RIAA to take action against this, and made Fraunhofer and Thomson release their control over the use of MP3 decoders after the software was published as freeware by an Australian student. The popularity of MP3 was not only due to its technological benefits, but also caused by the availability of complementary assets: the large number of websites offering MP3 files and MP3 (software and hardware) players. Lastly, direct and indirect network effects created self-reinforcing mechanisms that tipped the market towards MP3.

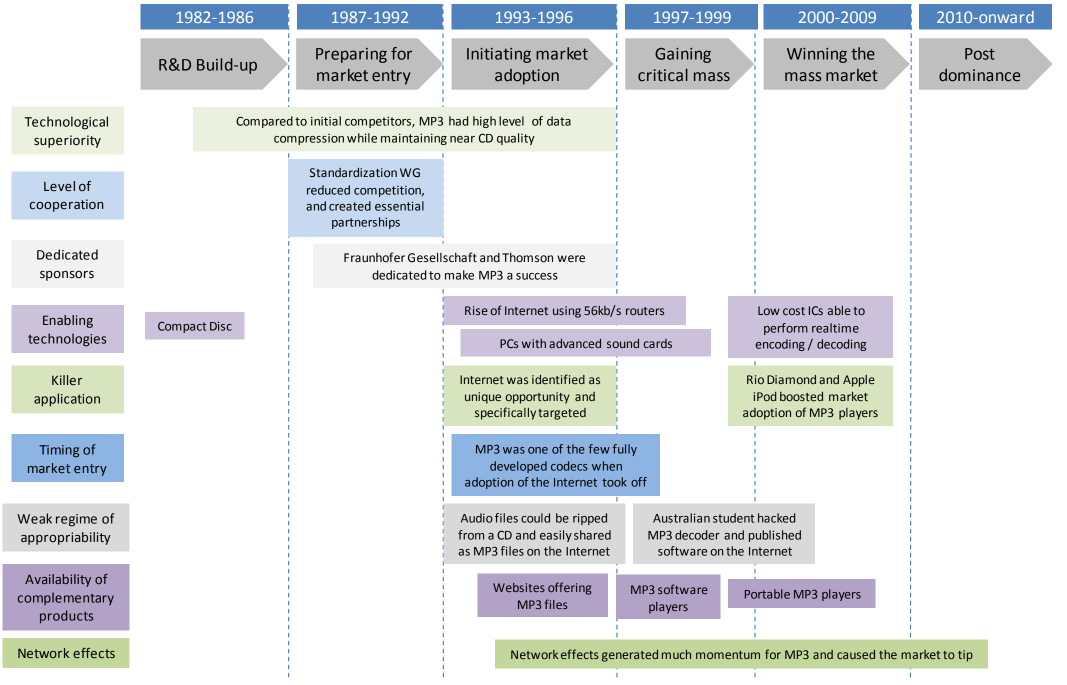


*Figure 49: Nine key elements that influenced the platform competition through the six phases of platform competition*

As noted in the theoretical overview, MP3 is a platform technology that enables 'platform-mediated networks'. In general, platforms face the difficulty that they first require support from the supply network (e.g. content providers such as record labels or film studios) before they can attract users from the demand network. A key differentiator of MP3 was that the demand network and supply network were one and the same. Consumers could copy music from a CD and transform this into an MP3 file for sharing on the Internet, whereas its predecessors and competitors were dependent on the support of record labels. Although platform mediated networks have strong (often indirect) network externalities, we have seen that when the demand and supply network become the same, the direct and indirect network externalities overlap and reinforce each other. This results in unparalled network effects which transforms an industry by undermining the position of the incumbent supply network. The turnover of the global music industry plummeted from roughly $36.9 billion in 2000 to $15.9 billion in 2010[313], and whereas the music industry was dominated by six major record labels in 1998, mergers reduced this to four major labels by 2005.

The success of MP3 was also influenced by the evolution of its organizational design. Of the four modalities suggested by Eisenmann[314], MP3 was initially organized as a shared platform. As shared platforms require governance arrangements, platform sponsors must decide whether to organize under the auspices of an informal alliance, a new industry association, or an established Standard Development Organization (SDO). During the phase of 'preparing for market entry', several parties decided to collaborate in an SDO's standardization process. This provided a level playing field for the various participants, reduced the amount of competition and created alliances that sponsored the resulting standard. Subsequently the main platform sponsors, Fraunhofer and Thomson, had to find the initial market niches where market adoption would take root and grow. The organizational design evolved by including elements from a licensing mode. Fraunhofer and Thomson entered into a joint licensing agreement and actively licensed their patents. This enabled many platform providers to enter the market and target various applications. The result was a significant amount of momentum which could not be counteracted by powerful sponsors with a proprietary platform approach, or industry associations enforcing legislation.

## 4.7 Conclusion

The paradigm shift towards compressed audio in the music industry is a textbook example of Christensen's Innovators Dilemma. The incumbent parties were among the first that were able to benefit but passed the opportunity on to others since they failed to recognize that the technology would be successful in the market. Whereas Christensen's lessons are derived from the hard disc drive industry, the MP3 case shows that similar events occur with platform technologies. Not only did the market leaders in consumer audio equipment fail to embrace the opportunity, but so did the content providers. This latter point is where the MP3 case adds to Christensen's lessons.

Our study adds to the field of platform competitions, by showing that platform mediated networks can have a demand and supply network which are one and the same. When the demand and supply network are one and the same, the direct and indirect network externalities overlap and reinforce each other. This enables fast market adoption and undermines the position of the incumbent supply network.

We add to the work of Eisenmann[315] by illustrating how a platform's organizational mode may evolve over time, and how these changes affect the platform competition. We subscribe to Eisenmann's claim regarding the importance of selecting the right organizational mode, but the case shows that the success of a particular organizational mode heavily depends on various other elements, such as the timing of market entry and the availability of complementary goods. A platform's organizational mode has an influence on these elements, but with multiple platforms competing in the market the influence is vice-versa.

The case of the MP3 audio compression format shows that the road to becoming the market standard is complex, involves many elements that influence the process, and takes many years. The case confirms known success elements, but also adds nuances;

- Technological superiority is a multifaceted concept whereby customer requirements are leading. Before audio compression formats, the history of music formats shows that a format had to have superior audio quality to become the market standard. While MP3 did not provide superior audio quality, it managed to outcompete the CD because the technology provided superior performance on other customer requirements;
- First mover advantage is only relevant when targeting the key applications. Several studies (e.g. Cusumano et al.[316]; Suarez[317]) have shown that being first to enter a market provides an advantage in building up an installed base. As the case shows, technologies often have several applications and competing in the right market is more important than being first;
- The killer application follows from product proliferation. It is difficult to identify up-front which application will drive a technology's market adoption to the extent that it becomes the market

standard. When implementing the technology in various products and addressing different applications, the chance to find the killer application increases.

We conclude that adding a sixth phase to Suarez's model was an important modification which enhanced our understanding of how technologies become the dominant platform. If we had taken Suarez's approach, the 'decisive battle' would have resulted in MP3 becoming the dominant format for music on the Internet, and the 'post-dominance' phase would have constituted the period when MP3 competed with the CD. As we see in this case, MP3 first became dominant in the niche of music distribution over the Internet, and subsequently competed with CD for the overall dominant music format. This distinction is essential for our understanding of how MP3 became the dominant format and underpins our assumption that a platform technology first becomes dominant in a niche market before competing for dominance in the product category.

## 4.8 Epilogue

As in the case of Blu-ray vs. HD-DVD, an epilogue was added to complement the published paper with additional information, and create consistency between the cases. This epilogue adds an overview of the interviewees, and the frameworks of Section 2.5 are applied to the case.

### *4.8.1 Overview of interviewees*

In Section 4.3 it is mentioned that eleven focused interviews were held, but it does not specify who was interviewed. Table 16 provides an overview of the eleven people that were interviewed.

Table 16: Overview of interviewees in the case of the emergence of MP3 as de-facto standard in music formats

| Company | Name | Relevance to case |
|---|---|---|
| University of Hannover | Hans Georg Musmann | Head of Institut für Theoretische Nachrichtentechnik und Informationsverarbeitung. Main research field is video and audio coding for communication systems. From 1988- 1992 Chair of the ISO MPEG/Audio group which developed the ISO Audio Coding Standards. |
| University of Erlangen | Dieter Seitzer | Started with the idea of compression and transmission of music over telephone lines in the 1970s. Founding director of Fraunhofer Institute for Integrated Circuits (IIS), and head of the institute from 1985-1998. |
| Fraunhofer Institute | Karlheinz Brandenburg | PhD on digital audio coding and perceptual measurement techniques. His research results were the basis of MPEG-1 Layer 3 and MPEG-2 Advanced Audio Coding. From 1989 to 1990 worked with AT&T Bell Laboratories on ASPEC and MPEG-1 Layer 3. In 1993, became head of the Audio/Multimedia department at the Fraunhofer Institute. Since 2000, full professor at Technical University of Ilmenau and director of the Fraunhofer Institute for Digital Media Technology. |
| | Harald Popp | Since 1987 responsible for development of real-time systems for audio coding at Fraunhofer IIS. From 1989 onwards contributed substantially to worldwide marketing and licensing of audio formats MP3 and AAC. Currently the head of the Multimedia Realtime Systems department at Fraunhofer IIS. |
| | Bernard Grill | 1988-1995 engaged in development and implementation of audio coding algorithms at Fraunhofer IIS. Since 2000 head of Audio department at Fraunhofer IIS. |

| | | |
|---|---|---|
| Philips | Leon van de Kerkhof | Philips representative during the development of the MPEG1 audio standard. One of the leading developers of MPEG Audio Layer 2. Former program manager of Philips audio processing activities. |
| | Gerard Lokhoff | Joined Philips in 1985. Attended early standardization meetings of the DAB specification (with a focus on Audio Coding), and the first MPEG Audio workgroup meeting. |
| Swedish Telecom | Thomas Ryden | Worked at Swedish Telecom from 1984 till 2000 and was often involved in ITU committees. Was Swedish Radio's representative for MPEG. |
| CCETT | Yves Francois Dehery | Head of CCETT's R&D department for audio and video signal processing from 1986-1995. |
| IBM | James D. Johnston | From 1976-2002 worked as member of the research staff of the Acoustics Research Department at AT&T Bell Labs, afterwards he held positions at Microsoft, Neural Audio, and DTC Inc. Primary researcher within AT&T working on music encoding during the period of the development of the MPEG-1 audio standard. |
| Deutsche Thomson-Brandt (Telefunken) | Jens Spille | Worked on subband coding and became the Thomson representative in the MPEG-1 audio standardization in 1989. |

### *4.8.2 Applying the frameworks*

Case analysis tool

Table 17 shows the result of using the case analysis tool on the case of MP3. While gathering data, this tool was used to (abstractly) note if a particular element influenced the technology competition in a particular phase. In addition, it helped to identify gaps in the analysis and provided guidance to the focused interviews. Each phase of the detailed case description, as presented in Section 6.5, is based in essence on the elements that were identified in a particular phase, and therefore these sections can be seen as the result of Table 17.

When applying the case analysis tool to the technology competition of MP3, I found that the five phases as provided by Suarez (2004) were not completely adequate for studying the case. After MP3 arose victorious from the 'decisive battle' against other compressed audio formats, it still had to displace the Compact Disc as de-facto standard. However, according to Suarez's process, the technology competition was now in the 'post-dominance' phase. Looking back at the case of Blu-ray versus HD-DVD, I saw the same; after Blu-ray had won from HD-DVD, it still had to displace DVD as the de-facto standard but according to the process that should take place in the 'post-dominance' phase. Therefore, I decided to add the phase of 'Winning the mass market' before the phase of 'Post-dominance'. This new insight placed the terms of the phases 'Creating the market' and 'Decisive battle' in a different light, and I renamed these into the more fitting 'Initiating market adoption' and 'Gaining critical mass'.

Table 17: Case analysis tool for the case of the emergence of MP3 as de-facto standard in music formats

| | | R&D Build-up | Preparing for market entry | Initiating market adoption | Gaining critical mass | Winning the mass market | Post-dominance |
|---|---|---|---|---|---|---|---|
| | | 1982-1986 | 1987-1992 | 1993-1996 | 1997-1999 | 2000-2009 | 2010-Onward |
| **Firm** | Reputation and credibility | | | | | | |
| | Installed base | | | | | | |
| | Pricing | | | X | X | X | X |
| | Entry timing | | | X | | | |
| | Marketing and pre-announcements | | | X | X | | |
| | Availability of products | | | X | | | |
| | Availability of complementary goods | | | X | | | |
| | Killer application | | | X | | | |
| | Size | | | | | | |
| | Complementary assets | | | | | | |
| | Technological knowledge and skill base | X | X | X | | | |
| | Absorptive capacity | X | X | | | | |
| | Pre-empting scarce assets | | | | | | |
| | Level of collaborative development | | X | | | | |
| | Organizational community of supporters | | | X | X | X | X |
| | Strategic partnerships | X | X | X | | | |
| | Product proliferation | | | X | | | |
| | Appropriability | | X | X | X | X | X |
| | Chance | | | X | | | |
| | | | | | | | |
| **Technology** | Technological superiority | X | X | X | X | X | X |
| | Installed base | | | X | X | X | X |
| | Network effects | | | X | X | X | X |
| | Switching and homing cost | | | | | | |
| | Backward compatibility | | | | | | |
| | Increasing returns to adoption | | | | | | |
| | Technological breakthroughs in subsystems | | X | X | X | | |
| | Type of technological innovation | | | | | | |
| | Adapters and gateways | | | | | | |
| | Technological performance trajectories | | | | | | |
| | Chance | X | | | | | |
| | | | | | | | |
| **Market / industry** | Market and industry characteristics | | X | X | X | X | X |
| | Level of competition | | X | X | X | X | X |
| | Rate and type of technological change | | | | | | |
| | Network effects | | | | X | X | X |
| | Availability of products | | | | | | |
| | Availability of complementary goods | | | X | X | X | X |
| | Killer application | | | | X | X | |
| | Availability of imitators | | | | | | |
| | Hetero- or homogeneity of customer needs | | | | | | |
| | Unclear assessment criteria | | | | | | |
| | Powerful rival technology sponsors | | X | | X | X | X |
| | Government intervention and industry regulation | | X | | X | X | |
| | Product proliferation | | | | | | |
| | Appropriability | | | X | X | X | X |
| | Chance | | | | | | |

Following the second application of the case analysis tool, the following insights became apparent:

- By using the tool, this time I identified 26 elements that influenced the technology competition.
- The level of collaborative development through the MPEG initiative was an initiative that came from the industry. Therefore, this element should not only be seen as a firm-related element, but also as an industry-related element

Applying the integrative framework

Based on the data gathered in Table 17, for each phase of the technology competition a snapshot was made by applying the integrative framework (Figure 50 - Figure 55). Each Figure shows only those elements that were at play during the respective phase. The relationships between the elements were reconstructed based on the written documents, public announcements and interviews. When the relationships were the same as presented in the integrative framework, these were marked in black. When the relationships were not presented in the integrative framework, these were marked in blue.

In this case, the scoring method (as proposed in Subsection 2.5.3) could not be applied. For each phase the main rival was a different technology (MP3 had multiple rivals over time), and this rendered the proposed scoring mechanism useless.

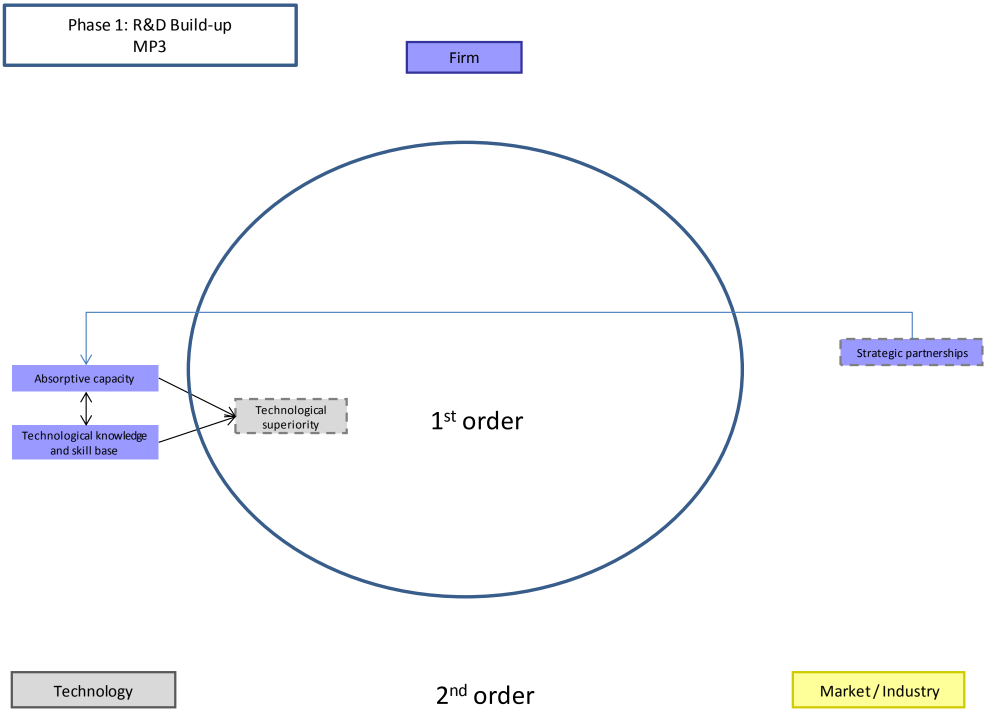


*Figure 50: Integrative framework applied to Phase 1 of the case of the emergence of MP3 as de-facto standard in music formats*

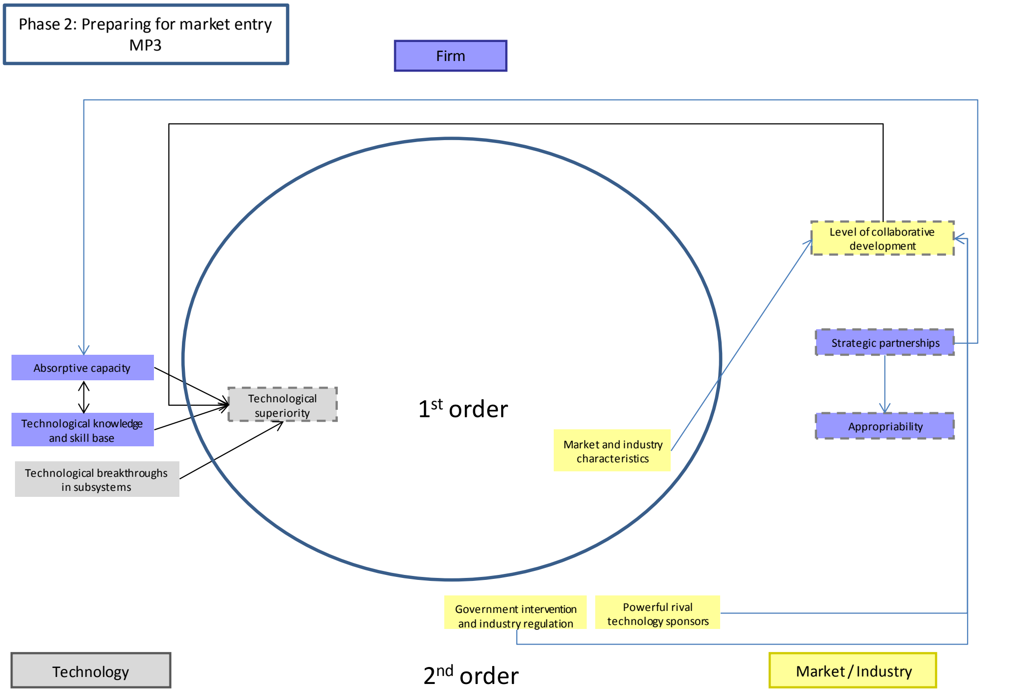


*Figure 51: Integrative framework applied to Phase 2 of the case of the emergence of MP3 as de-facto standard in music formats*

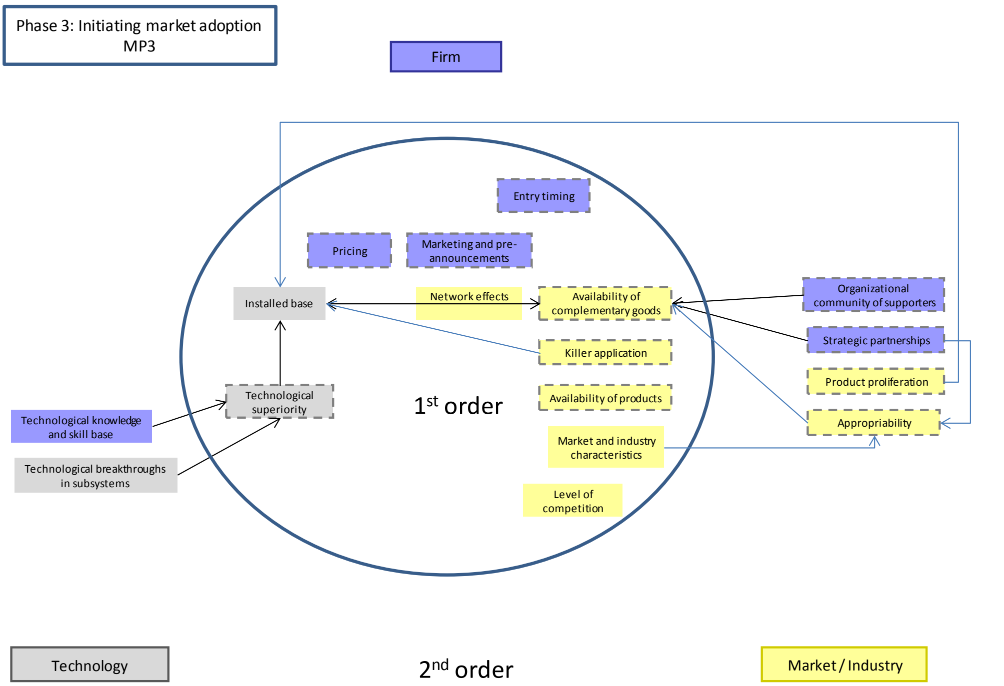


*Figure 52: Integrative framework applied to Phase 3 of the case of the emergence of MP3 as de-facto standard in music formats*

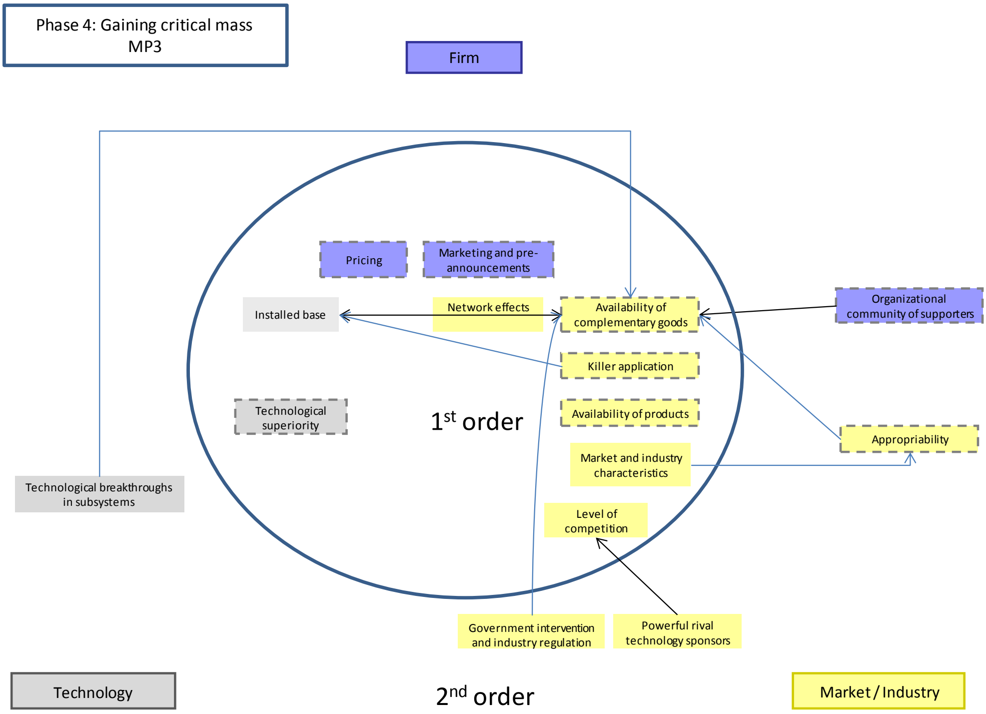


*Figure 53: Integrative framework applied to Phase 4 of the case of the emergence of MP3 as de-facto standard in music formats*

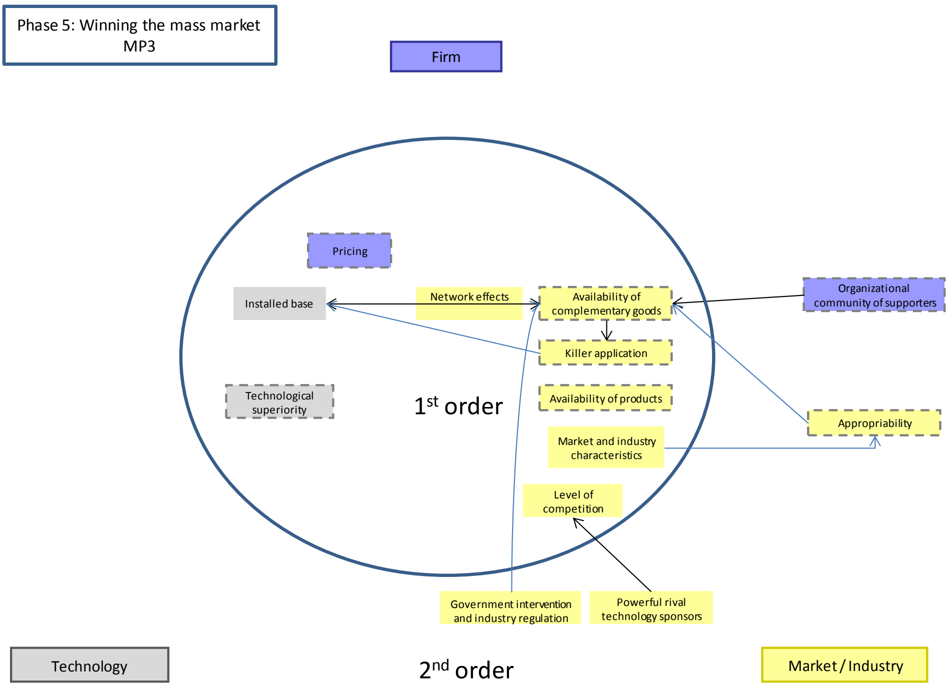


*Figure 54: Integrative framework applied to Phase 5 of the case of the emergence of MP3 as de-facto standard in music formats*

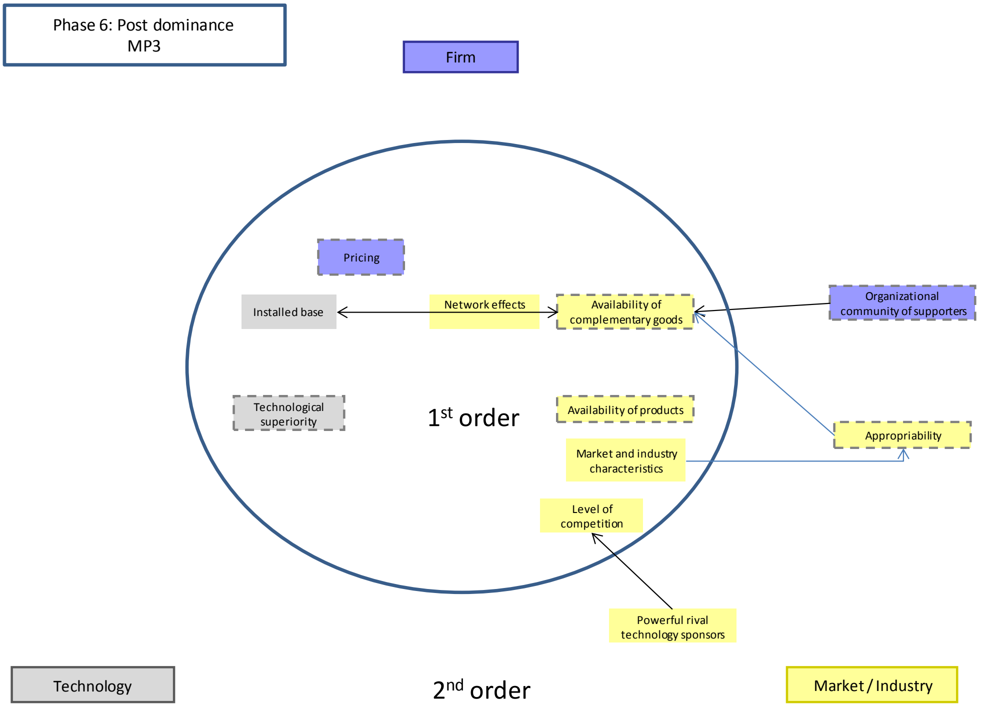


*Figure 55: Integrative framework applied to Phase 6 of the case of the emergence of MP3 as de-facto standard in music formats*

The emergence of MP3 as the de-facto standard is very different from Blu-ray's emergence. This is mainly due to the different type of technology sponsors (multinational companies versus an applied research institute) with very different resources and access to complementary assets, and a very different type of technology (Blu-ray constituted of physical products and complementary goods which requires access to shelf space and distribution channels, whereas MP3 constituted of digital products and complementary goods which could be distributed over the WorldWideWeb).

In the first phase of the technology competition, the R&D build-up, the technology sponsor focused on the technology development. As Figure 50 shows, in this case the broad technological knowledge and skill base, and the ability to easily implement ideas of others contributed to the technological superiority (amount of compression while maintaining a certain measure of sound quality).

Moving to the second phase, I note an increase in the number of elements, which in relative terms is similar to the case of high definition optical discs. The elements of the first phase were still in play, and seven new elements came into play. As shown by Figure 51, the new elements were mainly market / industry related. This is due to the MPEG standardization activity, which was mainly an industry initiative, whereby multiple powerful rival technology sponsors recognized the importance to develop a shared technology through a standardization body. The European Union had an influence by funding the EUREKA project for Digital Audio Broadcasting (DAB); the decision of this project to adopt the result of the MPEG standardization activity as the audio encoding format for DAB, motivated the rival technology sponsors to collaborate in the MPEG activity.

During the phase of 'initiating market adoption', the number of elements increased from 11 to 20, and the focus shifted to firm-related elements. As can be seen from Figure 52, the technology sponsor employed several elements to jump-start the market adoption of MP3. It used product proliferation to find an initial niche in order to create an installed base. While looking for potentially interesting markets the technology sponsor identified an application, music distribution via the WorldWideWeb, that turned out to be a killer application; the use of the WorldWideWeb grew quickly, users were very interested to share music and the technical features of MP3 made it well suited to address this application. The technology sponsor also proactively built an organizational community of supporters. This resulted in a range of complementary goods, which fuelled the network effects.

The phase of 'gaining critical mass', shows a small decrease in the number of elements. As Figure 53 shows, several firm-related elements have gone out of play, and are replaced by few market/industry related elements. In this phase the government agency RIAA attempted to shut down websites for sharing MP3 files (complementary goods). But due to the weak appropriability regime of the WorldWideWeb, many supporters of MP3 were able to enter the market with websites for MP3 file sharing and it was difficult for the RIAA to counteract this. Technological breakthroughs in subsystems enabled the commercial implementation of portable MP3 players. This increased the amount of complementary goods and enabled the MP3 technology to thread beyond its niche and compete for the mass market. During the phase of 'gaining critical mass', the powerful network effects were the main driver for MP3 to become the de-facto standard in the niche of music distribution over the WorldWideWeb. However, the strength of the network effects is not adequately reflected by Figure 53.

During the phase of 'winning the mass market', MP3 had to compete with the Compact Disc. Compared to the previous phase, this phase had the same elements, except for two that left the play. As such, this phase had very similar dynamics as the previous one. The major exception was that many portable MP3 players entered the market and from these, Apple's iPod emerged as killer application. This fuelled the network effects further and, combined with all the other elements such as the availability of the other complementary goods, the large installed base, and the weak appropriability regime, enabled MP3 to emerge as the de-facto standard in music formats. Lastly, we come to the phase of 'post dominance'. This phase has many of the same elements as the previous phase, as only two elements left the play.

What is interesting about the development of the MP3 case, is that during the first phases of the technology competition (from R&D build-up to Gaining critical mass) the fate of MP3 was dependent on a single technology sponsor (i.e. the Fraunhofer Institute), but after the technology was picked up by the market, very strong network effects came into play, causing the market adoption to have its own momentum and tip the market in its favor. A rare aspect of this case is that the technology sponsor was an applied research institute. As a result, none of the phases show the elements of 'size', 'complementary assets', 'reputation'. Fraunhofer was an institute that was not well known in the consumer market, and with little means to commercialize a technology and none of the conventionally important assets such as distribution channels and marketing capabilities. The success of MP3 hinged on Fraunhofer's identification of the WorldWideWeb as an upcoming technology, which turned out to be a killer application for MP3. A key benefit of this application, was that the WorldWideWeb functioned as a distribution channel, which allowed Fraunhofer to distribute its technology without the complementary assets that are usually attributed to companies.

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# Chapter 5 – Technology leapfrogging in high-definition audio platforms: The competition between SA-CD and DVD-Audio

## 5.1 Introduction

There are many examples of technology competitions whereby two technologies compete for market adoption (e.g. VHS versus Betamax in the home video recording systems, and Blu-ray versus HD-DVD in high definition optical discs). After one technology has prevailed over its rival, one would expect that this technology has acquired sufficient momentum to take over the mass market and become the new de-facto standard. An example of this is shown by the case of MP3. However, as this chapter will show, winning the technology competition is no guarantee for the victor to take over the mass market. This chapter describes the competition between Super Audio CD (SA-CD) and DVD-Audio (DVD-A), which occurred around the year 2000. These two technologies both aimed to take over the position of the Compact Disc as the de-facto standard for music storage and distribution. Although they were supported by major industry players, the technologies did not manage to gain substantial traction in the market. In the subsequent sections, first the methodology will be addressed, then a historic reconstruction of the technology competition between SA-CD and DVD-A is provided, and lastly the case is analysed using the integrative framework.

## 5.2 Research methodology

Data for the case study stem from several sources. First, a preliminary data analysis was conducted through market research reports, academic papers, public announcements, online interviews, discussion forums of user groups, and blogs. The aforementioned sources came from an extended online research on the search engine Google using the keywords Super Audio CD, DVD-Audio, as well as their abbreviations. Subsequently, in accordance with the case analysis tool, the start and end of each of the phases of the technology competition were determined. A content analysis of the preliminary data was performed, and the elements that were identified per phase were noted in the case analysis tool. To complement and triangulate the preliminary data analysis and gain an in-depth understanding of the technology competition, focused interviews were conducted with key persons from companies involved in the technology competition (i.e. professionals that were involved in the development and commercialization of SA-CD or DVD-A, record companies, hardware manufacturers and distributors of authoring and mastering systems). Several respondents were identified from the preliminary data analysis. In addition, the social network LinkedIn was used for identifying and contacting these professionals. Initially, a long list was constructed using the keywords Super Audio CD, DVD-Audio, as well as their abbreviations. Subsequently their LinkedIn profiles were more closely studied to understand their position during the technology competition. Based on this review, the long list was reduced to a short list and these people were contacted. The initial respondents were also asked to identify other experts. In total, twelve respondents were interviewed. The interviews were conducted during the period June-August 2012 and the length of the interviews varied from 0.5-3 hours. The interviews were conducted in person and by telephone. To ensure consistency and reliability, interview guidelines were used for all interviews. The interviews were recorded, and meeting minutes were sent back to the respondents for verification. The findings from archival sources were compared to the findings from the interviews. Whenever the comparison led to additional questions, these were asked by e-mail. After each interview, a content analysis was performed on the minutes, and the identified elements were noted in the case analysis tool. This resulted in a completed case analysis tool (Table 21) and a clear view of the technology competition. In total 30 elements were found to influence this technology competition. The data and the case analysis tool were used to construct a case description, and the integrative framework was applied to perform a case analysis. The results were sent to the interviewees for feedback.

## 5.3 Relevant background

During the technology competition between SA-CD and DVD-A, the de-facto standard for music storage and distribution was the CD. This technology, developed by Sony and Philips, was introduced in 1982 and became the de-facto standard in 1991 (as shown by Figure 42).

As mentioned in Chapter 3, following the success of the CD format, in December 1994 Sony and Philips announced that they were developing an optical disc format for digital video storage, the MultiMedia Compact Disc (MMCD). One month later a consortium of several companies including Panasonic (wanting to uphold its strong market position in video storage, which it had gained as main proponent of the VHS video storage technology), Toshiba and Warner Music announced that they were developing an alternative format: the SuperDensity (SD) disc. In September 1995, pressured by the computer industry, the two factions agreed to combine their technologies into a new format: the Digital Versatile Disc (DVD). The DVD format was much closer to the SD disc format than the MMCD format. Little of MMCD's fundamental technology was transferred into the DVD format. The groups united to form the DVD Consortium (which was renamed 'DVD-Forum' in 1997), to help the DVD format to rapidly gain adoption. The market introduction of DVD was very successful, and the transition from video cassettes to optical discs took only six years (from 1997 to 2003).

At the beginning of the competition between SA-CD and DVD-A, the music industry was comprised of six major record labels, and many small independent labels. Figure 56 shows the market shares of the record labels in 1996.[318] The largest record label, Polygram, was owned by Philips, and the second largest was owned by Sony. The sixth label, MCA, was sold by Matsushita Electrical Industrial Company (parent company of Panasonic, JVC and Technics) to Seagram Company in April 1995.[319] The market for CD and DVD players was also dominated by several major manufacturers and many small players. To illustrate this, Figure 57 shows the worldwide market share of DVD player manufacturers in the year 2000.[320] This Figure shows that Sony had the largest market share, followed by Toshiba. Roughly a third of the market was addressed by smaller manufacturers, whereby low cost DVD players from Samsung and LG were doing well in the Japanese market.[321]

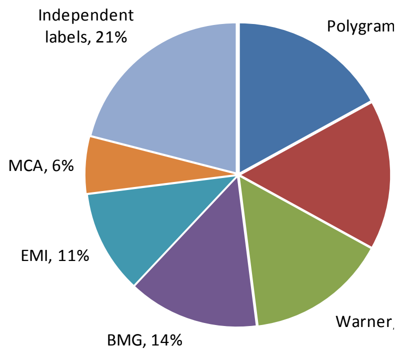



*Figure 56: Market share of record labels in 1996*

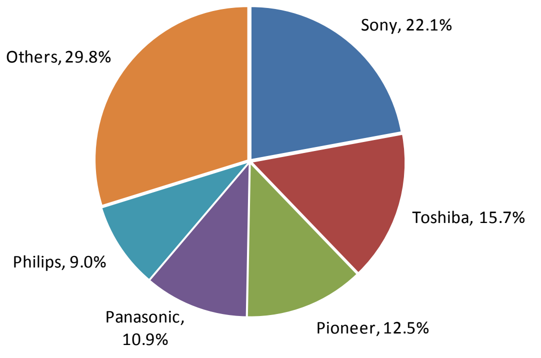



*Figure 57: Market share DVD player manufacturers in 2000*

## 5.4 Initial development of DVD-A and SA-CD, the R&D build-up (1996-1997)

The development of DVD-A began in January 1996, when the DVD-Forum started a working group to create a next-generation digital audio format. The main reason for initiating this activity was to leverage the technology of the DVD-Video format to adjacent areas. While DVD had the same form factor as CD, it was able to store roughly seven times as much data on a disc (4.7GB for a single layer DVD disc versus 650MB for CD). This made it possible to store audio with higher quality on the discs. In addition, Toshiba, Panasonic, and other consumer electronics manufacturers offering CD players had to pay license fees to Philips and Sony, and they were keen to have a new format in place that would allow them to collect license fees instead of paying them. The creation of the activity was pushed by Toshiba's Hisashi Yamada, the chairman of the Technology Coordination Group, which coordinated all the working groups within DVD-Forum. At that moment, the activities of the DVD-Forum consisted of three working groups (WG-1 for DVD-Video applications, WG-2 for the physical specifications for DVD-ROM, and WG-3 for the file system specifications for discs). Therefore the new working group became WG-4, and was chaired by the Victor Company of Japan (JVC). WG-4 consisted of 40 member companies, including Toshiba, Panasonic, Pioneer, Warner Music, Thomson, JVC, Hitachi, Mitsubishi, Sony and Philips. The most active members were Toshiba, Panasonic, Pioneer, and Warner Music, which had also closely collaborated in the development of DVD's predecessor (Super Density Disc).

In order to create buy-in from the music industry, and secure content for its format, WG-4 developed a close relationship with the 'International Steering Committee' (comprised of representatives from the Recording Industry Association of America, the International Federation of the Phonographic Industry, and the Recording Industry Association of Japan). WG-4 and the ISC met almost once a month. The purpose of these meetings was to review the ISC's Recommended Technical Requirements for a new format. The Recommended Technical Requirements were designed with two principal considerations in mind: copyright protection and maintaining strong consumer confidence in compact disc investments as the industry considered a new format. The top four items of the ISC's Recommended Technical Requirements were as follows:[322]

1) Active Copyright Management Systems (ACMS); a new copyright management system which would enable comprehensive protection of rights holders in the sound recording;
2) Copyright Identification; the discs and players had to contain a copyright identifier;

3) Anti-Piracy Measures; (a) all discs should carry SID mold codes, (b) space must be allocated on the disc to allow for anti-piracy identifiers, (c) recordable and prerecorded discs should carry identifying and distinguishing marks;
4) Compatibility; (a) CD discs must play on the new players, (b) the new discs must play on CD machines.

As WG-4 wanted to leverage the DVD technology, it re-used several aspects: the physical format of the disc, and the Linear Pulse-Code Modulation (PCM) format to store audio on the disc. As noted before, the disc offered more storage space than a CD, which was used to:

- Increase the sampling rate and quantization[323] levels. Whereas CD used a sampling rate of 44.000 samples per second and 16 bits per sample, DVD-A typically used 96.000 samples per second and 24 bits per sample;
- Record in surround sound. Whereas CD could only use two channels (stereo sound), DVD-A was able to use six channels, which enabled surround sound.

In terms of content protection, WG-4 decided to adopt CSS2. CSS2 was a newer version of DVD-Video's content scrambling system (CSS), and was developed in a collaborative effort by Matsushita, Toshiba, Intel and IBM.[324] Table 18 provides a comparison between the discs of CD, DVD-Video and DVD-A.

Table 18: Comparison between features of Compact Discs, DVD-Video discs, and DVD-A discs[325]

| | CD | DVD-Video | DVD-A |
|---|---|---|---|
| Disk Capacity | 650Mb | 4.7Gb - Single layer | 4.7Gb - Single layer |
| Stereo (2 channel) audio options | Uncompressed PCM at 16-bit resolution, sample rate of 44.1kHz | Data-compressed: Dolby Digital Uncompressed: PCM at 16, 20 or 24-bit resolution, sample rate of 48 or 96 kHz | Uncompressed PCM at 16, 20, or 24-bit resolution. Sample rates from 44.1 (CD standard) to 192kHz |
| Multichannel surround audio options | Does not support multichannel | 5.1 discrete surround using Dolby Digital or DTS data compression | 6-channel surround, uncompressed, at resolution up to 24 bits and sample rate of 96 kHz |
| Frequency Response | 5 - 20kHz | 0 - 20kHz | 0 - 96kHz (max) |
| Dynamic Range | 96db | 108db | 144db |
| Maximum Data Rate | 1.4Mbps | 6.144 Mbps | 9.6 Mbps. |
| Security | None | CSS | CCS2 |
| Region coding | No | Yes, six regions | No |

In addition, the hardware of the DVD-A players was largely similar that of DVD-Video players. The main difference was that the DVD-A players had to physically support the 6-channel surround capability. By reusing so many aspects of the DVD-Video technology, the participants of WG-4 ensured that the DVD-A format would be able to benefit from economies of scale in components, manufacturing equipment, and production facilities.

While DVD-A discs could have been developed to be backwards compatible with the installed base of CD players and DVD-Video players, the companies involved in WG-4 opted to only make the discs compatible with DVD-Video players. The decision to omit a CD-type data layer was based on the additional cost and lack of copy protection. Compatibility with DVD-Video was realized by adding a DVD-Video type data layer on the disc. However, a DVD-Video player could not provide the high resolution benefits of the DVD-A format. Most DVD-A discs provided three different audio playback options:[326]

1) A high-resolution stereo track
2) A high-resolution surround sound track
3) A default DVD-Video compatible surround sound track based on DTS or Dolby Digital.

Due to the overlap between the hardware in DVD-A and DVD-Video players, the companies in WG-4 expected at some point all DVD-Video players would also have the DVD-A capability. With the rapid adoption of DVD-Video, this would result in a large installed base of DVD-A players.

Although Sony and Philips were part of WG-4, they just observed the meetings. During 1996, it became clear that DVD-Audio could become a serious threat to the CD, and Sony and Philips decided to develop their own next-generation digital audio format outside the DVD-Forum; Super Audio CD (SA-CD). Since the DVD-Forum was a large organization with conflicting interests and slow decision making, Sony and Philips believed they could develop SA-CD faster than the DVD-Forum. In addition, their collaboration allowed them to combine their latest technologies, which were covered by new intellectual property rights that could replenish the pool of CDs expiring patents[327].

In developing SA-CD, Sony and Philips decided to take a radically different approach for the signal processing. Instead of using PCM, Sony contributed an encoding technology called Direct Stream Digital (DSD)[328]. Sony originally developed DSD for archiving, but the technology could also be used for high quality sound. Whereas conventional CD used 16 bit PCM with a sample-rate of 44,1 kHz, the DSD technology used a 1-bit signal, sampled at 64 times 44,1 kHz (2,8224 MHz). As a result, it provides a dynamic range over 120 dB and a bandwidth of 80-100 kHz, whereas CD has a dynamic range of 96 dB and a bandwidth of 20 kHz.[329] In addition, due to the high sample rate of DSD, less steps were required (see Figure 58) and signal distortions were virtually absent. Due to the DSD technology, some considered the audio quality of SA-CD as superior to DVD-Audio,[330] whereas others questioned whether people were able hear the difference. DSD was covered by recent intellectual property that could be used to extend the lifetime of Sony and Philips' lucrative CD license program. A drawback of DSD was that making recordings was more expensive than with PCM.

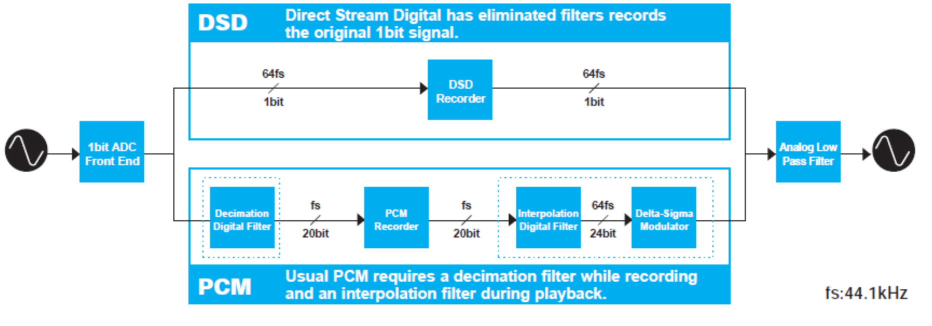



*Figure 58: Comparison of DSD versus PCM (source: Sony and Philips)*[331]

Philips contributed the multichannel capability and her Analog to Digital Conversion (ADC) technology. Due to the DSD encoding, a storage capacity of 4-5GB was required. Therefore, Sony and Philips decided to also use the physical format of the DVD discs. The downside of these discs was that they were not backward compatible with the CD format. Philips valued backwards compatibility to reduce consumer switching cost, and pushed for dual-layer discs ('hybrid' discs with a CD and SA-CD audio layer) to offer a transition path to the new technology. However, due to the two audio layers these discs were more expensive to manufacture, and the record labels were not in favor of hybrid discs because they did not mitigate the issue of copying music from the CD layer (which lacked content protection). The architecture of SA-CD players was based on DVD players, but required additional hardware. A special chip was required to decode the DSD signal, and another one to deal with the copy protection. Therefore, SA-CD discs could not be played on the installed base of DVD players, and the extra hardware resulted in an increased price for SA-CD players. Both Philips and Sony had the capabilities to manufacture these chips.[332]

In order to meet the content protection requirements of the music industry, Sony and Philips incorporated several lines of defense.[333] The first was the 'Super Audio CD mark', which scrambled the lead-in data area of a SA-CD and prevented a disc drive to initialize reading the disc. Only disc drives that were licensed for SA-CD could read the Super Audio CD mark. However, PC disc drives did not receive a license and this made it impossible for hackers to copy the information to their hard disc drives. The second was the 'Pit Signal Processing Physical Disc Mark' (PSP-PDM). This mark was embedded into the relief structure of the disc during the manufacturing process, and a SA-CD would first detect the PSP-PDM before playing a disc. This made it impossible for a consumer to make copies of a disc. Lastly, the DSD data on the disc was scrambled with a complex 80-bits encryption, which would take months on a high end computer to descramble. Considering that every album had a unique 80 bits encryption, this exhaustive 'key search' would have to be repeated for each SA-CD album.

At the 103rd Audio Engineering Society in New York, on September 26-29, 1997, Marantz, Sharp and AccuPhase announced their support for SA-CD.[334] In October, Sony and Philips unveiled details of the Super Audio CD technology, and claimed that they were confident it would satisfactorily address all criteria set by the ISC.[335] On December 8, 1997, Sony announced that it planned to market the SA-CD technology in Japan by Spring of 1999.[336]

WG-4 released a first draft of its DVD-Audio specification in January 1998.[337]

Compressed audio codecs, like MP3, were not considered a threat by the sponsors of DVD-Audio and SA-CD because these formats were positioned as a high quality that supported multichannel sound (two features that compressed audio codecs lacked), and they used a form factor that was well understood by the consumer and could use the existing distribution channels. The sponsors regarded compressed audio codecs as a technology that was suitable for the niche of low-quality music sharing via the WorldWideWeb.

## 5.5 Preparing for market entry (1998-1999)

On February 17, 1998, Philips and Sony held the first demonstration of SA-CD at the Abbey Road Studios in London. They also announced plans to license SA-CD, whereby licensees of the audio CD format would have the option of expanding their agreements to include the SA-CD under the same royalty structure; new licenses for SA-CD would be issued under the same terms and conditions.[338] In

April, version 0.95 of the SA-CD specifications was released.[339] At the same time, it was announced that SA-CD was supported by four additional companies; Sharp, Marantz (a subsidiary of Philips), Nakamichi Corp. and Accuphase Laboratory Inc. These companies were Japan-based hi-fi audio manufacturers.

On May 22 1998, Philips sold Polygram to Seagram, parent company of Universal (previously named MCA).[340] The two record label divisions were merged into the Universal Media Group, and the combined market shares strengthened its position as the largest record label worldwide. This left Sony as the last major consumer electronics manufacturer which owned a major record label.

At the Hi-Fi '98 tradeshow in June, audiophile labels DMP, Mobile Fidelity Sound Lab and Telarc announced their support for the SA-CD technology.[341]

In June 1998, WG-4 released version 0.9 of the DVD-Audio specification.[342] The music industry reviewed this specification and provided several requests to WG-4, of which the most important was to add the option of a lossless transmission system for multichannel signal processing. The record labels, and Universal in specific, believed that multichannel was a differentiating factor that would appeal to the mass market. To accommodate to this request of the music industry, WG-4 issued a request for lossless-compression technology proposals, which delayed issuing the 1.0 version of the standard by three months.[343] Two proposals were received, and in August 1998,[344] a technology called Meridian Lossless Packing (MLP) was selected. Although the company Meridian developed the technology, it was Dolby Labs that licensed the technology out to interested companies.

During 1998-1999, Sony and Philips approached record labels in order to convince them to support SA-CD. They held several demonstrations to the "golden ears" of the music industry in order to get feedback regarding the quality of the format. They started with independent labels, and provided them with recording equipment which would run in parallel to their existing equipment. They also sponsored labels with editing and mastering equipment.
In the same period, Panasonic also approached various record labels to convince them to support DVD-A, including Sony Music US and independent labels. Panasonic also sponsored record labels, in a similar fashion as Sony and Philips.

The Consumer Electronics Show (CES) in January 1999 was the first time that retailers could hear demonstrations of both DVD-A and SA-CD.[345] At the event, DVD-A demonstrations were held by Pioneer, Toshiba, JVC, Technics, Kenwood, and Meridian. Of these, the first four also demonstrated their first prototype DVD-A players. These were combined DVD-A and Video players. During a press conference, Universal Music announced its support for DVD-A and stated that it would release its first DVD-A discs later that year.[346] During the interviews, the Panasonic representative stated that Universal had a close relationship with Matsushita. Universal was the second major record label (next to Warner Musci that was an active member of WG-4) to support DVD-A, giving DVD-A an advantage over SA-CD which only had Sony Music as record label. On the side of SA-CD, Sony and Marantz demonstrated prototypes of SA-CD players. Philips provided a demonstration of the SA-CD technology, but did not demonstrate a product prototype.

The final DVD-A 1.0 specification was approved in February 1999 and released in March. Upon the release of version 1.0, the ISC stated: 'The DVD-Forum's approval of Version 1.0 will facilitate development and adoption of the copyright protection technology that is vital in the modern digital era; the rollout of DVD-A products is near, and it will be a milestone for consumers to enjoy a totally new music listening experience.'[347] At the same time, March 1999, the specification for SA-CD was finalized, and version 1.0 of the 'Scarlet Book'[348] was released.[349]

On March 3, 1999, it was announced that the five major record labels, including Sony Music Entertainment, approved the content protection framework for DVD-A, which was developed by IBM, Intel, Panasonic and IBM.[350]

On March 22, 1999, TWICE (This Week In Consumer Electronics) reported that EMI Music and BMG Entertainment confirmed plans to ship DVD-A discs in the fourth quarter, considering that this would coincide with the market launch of DVD-A players in the U.S.[351] This meant that four out of the big five music companies (the other two being Warner and Universal) would provide content for the DVD-A format. The last remaining big music company, Sony Music, also stated it would release DVD-A discs. A Sony Music spokesperson said 'Sony Music is eager to support formats with copy-right protection, including DVD-A".[352] Although Sony Music US was indeed interested in exploring opportunities regarding DVD-A (they had created some prototypes of DVD-A titles), due to pressure from Sony's hardware department they never introduced a DVD-A title. Among the major labels, no company other than Sony announced plans to support SA-CD. A spokesperson from EMI stated 'We have not been informed of SA-CD's copy-protection scheme yet, so we can't commit yet'. BMG also indicated that they were not fully informed about Super Audio CD's copyright protection framework. A music industry executive was quoted saying 'the music companies gave feedback to Sony and Philips about needed copyright-protection requirements months ago, but literally months have gone by and we still don't know where they are with copy protection. There hasn't been continuous proactive outreach'.

During the Hi-Fi '99 trade and consumer show, 11-16 May in Chicago, Sony announced that it would introduce its first SA-CD player in the US in October 1999, and the model would be accompanied by 56 titles from Sony Music and six independent labels.[353] Separately, Panasonic announced during its dealer event in Hawaii that its first two DVD-A/Video players would likely be introduced in the fall at prices of roughly $1,000. At the same event, Universal Music Group announced they would support Panasonic's DVD-A launch with 15-20 titles.

## 5.6 Initiating market adoption (1999-2001)

On May 21 1999, Sony launched its first SA-CD players in Japan. These players, the SCD-1 and SCD-777ES, were accompanied by 13 software titles that were offered by Sony Music.[354] Sony would subsequently launch the SA-CD players in the US in October 1999 and in Europe in autumn 1999. The SCD-1 was priced at $4,595 (500,000 yen) and the SCD-777ES was priced at $3,500.[355] They were high-performance component systems, targeted to appeal mainly to the so called 'audiophiles' or 'music lovers' that would appreciate the high quality of the format. The US launch was accompanied by 40 SA-CD titles, of which half were provided by Sony Music. The discs were priced at $24.98. In order to reduce the price mark-up of SA-CDs versus CDs and stimulate the adoption of SA-CD discs, Sony and Philips initially subsidized the recording process of the record labels. The titles which were released by Sony Music were only in single (SA-CD) layer, and therefore not compatible with the installed base of CD players. A director at Sony Music Japan believed that releasing hybrid discs upon launch would be the wrong strategy; the initial titles were re-releases of existing titles, and he believed consumers wouldn't buy a title they already had. Sony Music International followed Sony Music Japan in this approach.

On August 1st, Panasonic announced that it would ship its first two DVD-A/Video players, the Panasonic DVD-A7 and the Technics DVD-A10, in October to retailers in the United States.[356] The DVD-A7 would be priced at 'roughly 1,000 dollars' and the DVD-A10 at around 1,200 dollars. On October 4th, Pioneer announced it would introduce two DVD-A/DVD-video players to the Japanese domestic market by late December 1999.[357]

During the IFA tradeshow in Berlin, late August, Philips surprisingly announced plans to enter the DVD-A market.[358] A representative announced that Philips was planning to first introduce a DVD-Video / SA-CD player by end of the second quarter of 2000, and subsequently an all-in-one SA-CD / DVD-A / Video player in the third quarter of 2000. This announcement was a blow to the SA-CD camp.

By October 1999, SA-CD had the first mover advantage, but DVD-A held a major advantage in terms of the number of major record labels and consumer electronics manufacturers supporting the format.

Beginning of December, Matsushita and Toshiba announced they would delay the launch of their DVD-A products until mid 2000.[359] The cause of these announcements was the release of a software program called DeCSS on November 5 by a small group of Norwegian hackers.[360] This program could break the CSS encryption on almost any DVD disc, including the CSS2 system developed for DVD-A. As a result of this hack, Matsushita, Toshiba, Intel and IBM had to develop a new system of copy protection with a much stronger key and completely new encoding system,[361] and propose this to DVD-Forum's WG-4 for inclusion in the DVD-A standard. Announcing its decision, Matsushita expressed that withholding products at this stage, just weeks before their planned launch, would not be beneficial to the DVD-A industry.

Pioneer decided otherwise and moved forward to launch two combined DVD-A/DVD-Video players in December 1999 for the Japanese market only.[362] As the expectation was that it would take six months or more to have a new copy protection system in place, Pioneer did not want to lose time and offered customers a free upgrade when the new system was finalized. The two products were the DV-S10A, priced at 200,000 yen (US$1,950) and capable of playing DVD-A, DVD-Video and Audio-CD discs, and the DV-AX10, priced at 500,000 yen ($5,500) was able to also play SA-CD discs.[363]

The hack not only affected the hardware manufacturers, the record labels supporting DVD-A also decided to postpone the introduction of DVD-A software titles until a more effective copy protection system was developed.[364]

In December 1999, Sharp introduced its first SA-CD player in Japan, the DX-SX1, priced at 250,000 Yen.[365]

At the Consumer Electronics Show 2000, January 19, Matsushita and Toshiba announced a new DVD-A encryption system[366], called CPPM.[367] Although the music industry was still evaluating the proposed encryption technology, Matsushita and Toshiba were optimistic that the music industry would move quickly to endorse the proposal - which they said would allow for summer or fall commercial launches of hardware and software. A Toshiba representative stated its first DVD-A/ Video player, the SD9200 ($1,999 retail price), could ship as soon as August 2000. A Philips representative reaffirmed previously announced plans for third-quarter U.S. availability of a Philips multichannel SA-CD / DVD Video player, but the model would exclude previously planned DVD-A playback due to the delay caused by the format's encryption-standard reevaluation.

Marantz launched its first SA-CD-player, the SA-1, in Japan in February 2000. It was priced at 550,000 Yen.[368] It went on sale in Europe around September.[369] On October 2, it was launched in the US with a suggested retail price of $7,500.[370] In addition, Marantz offered its PM-17SA Stereo Integrated Amplifier and SM-17SA Stereo Power Amplifier, two high-end components designed to complement the SA-1.

In June, Sony launched the SCD-XB9 SA-CD player, priced at 80,000 yen ($735), significantly lower than its first SA-CD player to appeal to a mass market.[371]

In July, the first DVD-A players with the new and approved CPPM copy protection system were introduced in the US. These products were the Panasonic DVD-A7 and the Technics DVD-A10, priced at $999.95 and $1,199.95 respectively.[372] Technics also introduced a line of DVD-A ready components which were necessary to gain the full fidelity of the DVD-A format. This line was comprised of the SA-DA8 ($599.95) and SA-DA10 ($799.95) DVD-A ready receivers and speakers, SB-T300 ($599.95) and SB-AFC300 multi-purpose speaker for front, center or surround sound ($149.95).

On August 1st, Toshiba, entered the fray by launching their first DVD-A player in Japan. This device, the SD-9200, was priced at 220,000 Yen ($1,999.95).[373] It was launched in the US and Europe early 2001.

At the 109th Audio Engineering Society conference in September, the Sony / Philips SA-CD booth displayed logos of 22 companies supporting the format, including 12 manufacturers of SA-CD players: Accuphase, Kenwood, Krell, Marantz, Nakamichi, Onkyo, Philips, Pioneer, Sharp, Sony, Teac, and Yamaha.[374]

On October 8, Warner Music released the first DVD-A discs;[375] they initially released seven titles. An independent record label, Silverline Records, soon followed suit by announcing to release several titles as well.[376]

From November 2000 till end of January 2001, Panasonic started a rebate action to promote the adoption of its DVD-A products. They offered a $75 rebate with the purchase of a Panasonic DVD-A7 or $100 with purchase of a Technics DVD-A10 DVD-A/Video player, and customers could choose two or three DVD-A recordings (depending on product purchased).[377]

At the end of 2000, SA-CD had over 200 titles available.[378] The average SA-CD disc retail price was about $25. Half of the SA-CD's were issued by labels owned by Sony (Sony Music, Legacy, Columbia), and the other half by specialty record companies.

At CES in January 2001, Sony unveiled the SCD-CE775, a $400 SA-CD player, and the SCD-C555ES, priced at $1,700.[379] From the side of DVD-A, three record labels offered DVD-A titles: Warner Music (about 15 titles) and independent labels 5.1 Entertainment (36 titles) and Surrounded By Entertainment (3 titles).[380] BMG announced it would release its first titles during 2001. An executive from Universal Music declined to say when the studio would deliver titles.

Philips entered the market with its first SA-CD player (SA-CD-1000) in January 2001. This player, priced at $1999, was the first SA-CD player to play multichannel as well as stereo recordings. In addition, it could play DVD-Video, CD, CD-R and CD-RW. Philips considered the feature of multichannel audio and multichannel SA-CD disc titles as a key requirement for the market adoption of SA-CD. Market research had shown that approximately 60% of the people couldn't hear the difference in audio quality between CD and SA-CD (the DVD-Audio supporters had learned the same for CD and DVD-Audio). However, people could clearly hear the difference between stereo and surround sound, and they valued this feature. The launch of the SA-CD-1000 coincided with the release of the first multichannel SA-CD by a major record label; the album 'Tubular Bells' of Virgin Records (at the time owned by EMI).[381]

During IFA 2001, a major consumer electronics show in Berlin, several major record labels announced their support for SA-CD. On August 25 2001, Universal Music announced they would release SA-CDs, thereby supporting both formats.[382] Then on August 31, EMI, the third largest record label and parent company behind Virgin Records and Capitol Records, announced that they would release SA-CD titles, thereby also supporting both formats.[383]

## 5.7 Gaining critical mass (2002 - mid 2004)

In order to regain momentum for DVD-A, on March 25 2002, Panasonic Automotive Electronics introduced and demonstrated its first DVD-A system for in-car music delivery. Panasonic considered cars an ideal environment for surround sound. They worked closely with car manufacturers to convince them to include DVD-A. On March 9 2003, Honda announced that its 2004 Acura model would be the first U.S. car with a DVD-A system as standard feature.[384] Although the sales of the car itself were good, and Honda actively promoted the DVD-A feature, the effect on the market adoption of DVD-A was minor.

In April 28, 2002, BMG's RCA record label issued several SA-CDs in the Hong Kong market, which marked the first time that BMG and RCA Records issued albums in the SA-CD format.[385] During the 112th AES Conference, on May 13, 2002, Sony and Philips announced that the BMG Group of Record Labels (e.g. RCA Victor, J Records, Arista) would release their first SA-CD discs outside the Hong Kong market.[386] This meant that BMG would support both SA-CD and DVD-A. With BMG's support to SA-CD, both formats had an even amount of support from the major record labels.

On August 9, 2002, DVD-A proponents, ranging from record labels to CE manufacturers, staged a press event at Dolby Labs in Los Angeles in the hopes of rekindling interest in their format. Warner Bros Records called the effort a "re-launch".[387] During the event, it was announced that there were 230 DVD-A titles available, which were being sold through 160 retailers with 2000 retail locations. A representative from Warner stated that in 2001 and 2002 they had so far sold 170,000 discs to consumers. Regarding the hardware, they announced 40 DVD-A players were available from 12 manufacturers.

Besides the number of albums, another important aspect was securing popular albums for the high definition audio formats. On May 30, 2002, during Home Entertainment 2002, the major independent record label ABKCO (of which albums were distributed by Universal Music), announced a collaboration with Sony to reissue their entire catalog (22 records) of early recordings by the Rolling Stones.[388] This ‘remastered’ series was released on August 27 2002 and was very successful.[389] During the Surround 2002 Expo on 13 December, engineer Alan Parsons confirmed that the release of the 30th Anniversary edition of Pink Floyd’s famous hit album ‘Dark Side of the Moon’ album would be released on DVD-Audio.[390] This album held the record of staying 741 weeks on Billboard’s Album Chart and had (at that moment) sold over 30 million albums. Therefore, the 30th Anniversary edition was expected to provide a significant amount of sales. However, on January 10 2003, EMI Recorded Music announced that ‘The Dark Side of the Moon’ would be released worldwide on hybrid SA-CDs (capable of playing on both CD and SA-CD players) on March 3, 2003.[391] Tony Wadsworth, Chairman and CEO of EMI Recorded Music UK, explained: “The hybrid SA-CD technology allows us to give the Pink Floyd fan a highly value-added product, both as a fully surround sound capable disc on SA-CD players and as a newly remastered CD for CD players.” On June 5 2003, during the Home Entertainment Show in San Francisco, Sony announced that ‘The Dark Side of the Moon’ reached #1 on the Billboard catalog chart and was rapidly approaching 100,000 unit sales in the U.S. since its release.[392] On May 20, 2004, Sony announced that the Rolling Stones' "Remastered" Series (with more than 2.2 million units sold), Pink Floyd's "Dark Side of the Moon" (800,000) and ABKCO's Sam Cooke reissue series (300,000) were leading the sales of SA-CD recordings.[393]

While there were several positive events for SA-CD, it faced some problems as well. These were mostly related to customer confusion. The SA-CD standard was developed in such a manner that companies had flexibility regarding both the players and the discs; some players supported two-channel audio, whereas other players supported multichannel, and some discs were hybrids (and therefore backwards compatible with CD players), whereas others only had the SA-CD layer, and lastly not all discs were released as multichannel recordings. Therefore, a consumer that purchased a SA-CD player and SA-CD discs had to look carefully at the product specifications.

On June 5 2003, it was announced that SA-CD gained support from additional hardware manufacturers, including manufacturers of high-end audio players such as Bel Canto, Krell, MSB Technology, and Musical Fidelity.[394]

On June 23, during the Home Entertainment Expo, the DVD-A Marketing Council was announced.[395] This organization was founded by eight DVD-A supporters; Warner Music, Silverline Records, BMG, EMI Recorded Music, 5.1 Entertainment Group, Meridian Audio, Dolby Laboratories and Panasonic. The DVD-A Marketing Council served as a resource for all technical, press and marketing information related to the DVD-A format in the United States and Europe. It also educated hardware and software retailers to the benefits and features of DVD-A while simultaneously promoting consumer awareness of the format.

During the IFA 2003 consumer electronics show in Berlin, Philips announced a partnership with Harman International to develop car SA-CD players.[396] In addition, Philips announced that over 1,300 SA-CD titles were available worldwide from more than 100 record companies, including four of the five major record labels (i.e. Universal Music, Sony Music Entertainment, EMI/Virgin and BMG).

In October 2003, Sony announced that it was preparing a $20 million promotional campaign in the US to boost the awareness of SA-CD.[397] In the same announcement, Sony noted that prices of SA-CD discs were dropping to $19-20 per disc which was helping the market adoption.

On November 7, 2003, Sony Music (the 2nd largest music label), and BMG (the 5th largest music label) announced that they would merge their activities, forming Sony BMG.[398] At that time, the music industry was facing a decline in music sales due to a weaker retail market and a rapidly growing use of file-sharing services on the Internet.

At CES 2004 in January, Toshiba and Samsung announced their first DVD players which supported both DVD-A and SA-CD.[399] Toshiba showed two models; the SD-4960 was introduced in June 2004 and retailed at $179.99, the SD-6915 (a carrousel model) was introduced in May 2004 at a price of $199.99. Samsung also showed two models, the DVD-HD841 and the DVD-HD941.[400] Both became available in the third quarter of 2004, and retailed at $249.99 and $349.99 respectively.

By May 5 2004, the 2000th SA-CD title was released.[401] The announcement also noted that well over 20 million SA-CD discs had been sold. A representative from Sony noted an increase in dedicated space for SA-CD with European retailers. On May 20, it was announced that the SA-CD camp comprised of 26 manufacturers offering more than 118 SA-CD-compatible products.[402]

By mid 2004, both formats had an equal amount of support from the major record labels, and of the major consumer electronics manufacturers, five supported SA-CD, versus three for DVD-A. As Figure 59 shows, by mid 2004 SA-CD had roughly three times as many titles available. As Figure 60 shows, in 2003 and 2004 DVD-Audio sales were negligible. In 2004, SA-CD discs outsold DVD-A discs 3:1. An announcement in September 2004 noted that the installed base of SA-CD players had reached 10 million units,[403] versus 1 million DVD-Audio players in March 2003.[404] Based on these insights, one could say that by mid-2004, SA-CD was dominating the market for high definition audio.

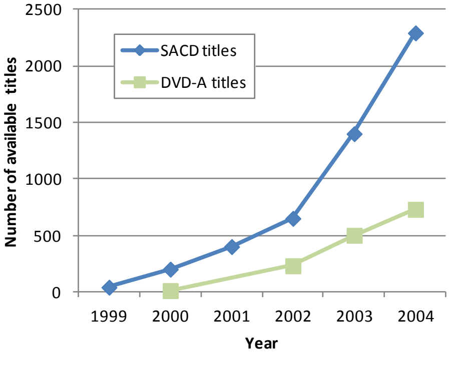



Figure 59: Number of available SA-CD and DVD-A titles from 1999-2004

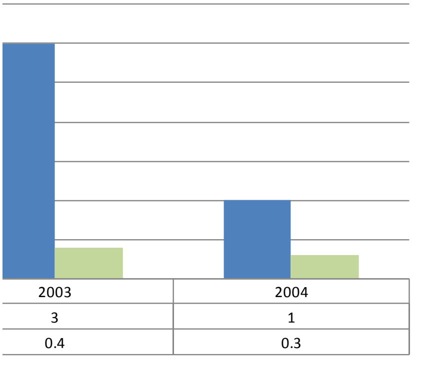



Figure 60: Sales of SA-CD and DVD-A discs in the US from 2003-2004[405]

## 5.8 Winning the mass market (mid 2004 - onwards)

From mid 2004 the focus shifted towards a competition with the incumbent de-facto standard, CD, and the other (substitute) technologies that aimed to replace CD as de-facto standard as well. There were two substitute technologies at this time that could be seen at the main rivals; MiniDisc (an optical disc based technology sponsored by Sony) and MP3 (see Chapter 4). As can be seen from Figure 61, from the year 2002 the sales of CDs and MiniDiscs were declining.

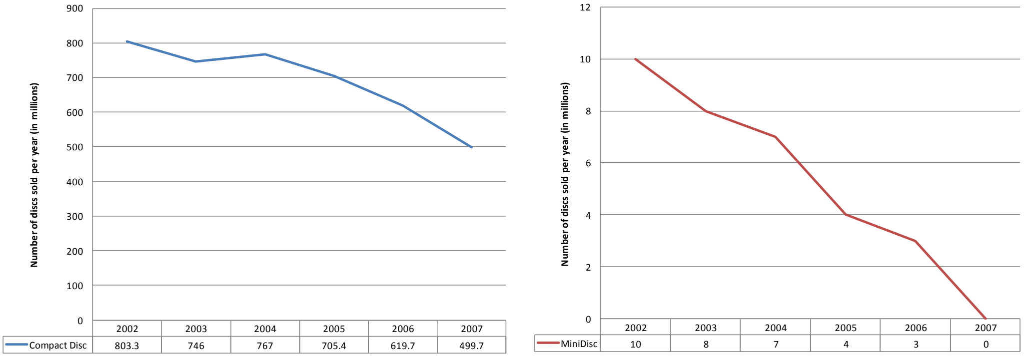



*Figure 61: Number of CDs and MiniDiscs sold in the US from 2002-2007*[406]

If one compares these numbers with the sales of SA-CDs as shown in Table 19, two things become apparent:

- the sales of SA-CDs were only a fraction of CDs
- instead of growth of sales, which one would expect during the phase of 'gaining critical mass' and 'winning the mass market', the sales of SA-CDs were also declining, similar to the sales of CDs and MiniDiscs

Table 19: Sales of SA-CD discs from 2003-2005 (in millions)[407]

| | 2003 | 2004 | 2005 |
|---|---|---|---|
| USA | 3 | 1 | 0.6 |
| Canada | 0.18 | 0.19 | 0.06 |
| UK | 0.6 | 0.5 | 0.4 |
| Germany | 0.48 | 0.25 | 0.2 |
| France | 0.28 | 0.3 | 0.25 |
| Italy | 0.04 | 0.05 | 0.04 |
| Spain | 0.14 | 0.15 | 0.01 |
| Netherlands | 0.16 | 0.2 | 0.15 |
| Australia | 0.1 | 0.07 | 0 |
| Japan | 1 | 1 | 0.7 |
| **Total** | 5.98 | 3.71 | 2.41 |

These declining sales were caused by the rapid market adoption of compressed audio files, in particular MP3, as was shown in Chapter 4. With the rise in popularity of compressed audio formats, manufacturers of disc players started to phase out both SA-CD and DVD-A support, and started to add docks for compressed audio players (e.g. Apple's iPod) instead.

By September 2004 the declining sales of SA-CD was not yet publicly known. SA-CDs' growing number of titles and hardware sales were recognized, but it was noted that SA-CD struggled to find space at retail.[408] At that point 2.300 SA-CD album titles were available, from more than 250 record labels. A representative of Universal Music said 'We are ready to go mass market. There's sufficient production capacity, but it is hard to get it permanently and visibly at retail. It is difficult to convince the retailers to put SA-CD prominently, because they will not sell big quantities.' It was further noted that retailers such as Tower Locations, Best Buy, Circuit City, Borders Books and Music in the U.S., HMV and Virgin in the United Kingdom, FNAC in France, and Media Markt in Germany were proactive in stimulating SA-CD sales. According to a Sony representative, the sales of SA-CDs took off with the introduction of hybrid SA-CDs in 2001. In addition, it was noted that sales of SA-CD players were close to 10 million.

By May 2006, the installed base of SA-CD players had reached 13 million units worldwide.[409]

SA-CD supporters expected that market adoption would get a great boost when Sony decided to include a SA-CD decoder in its PlayStation3 (PS3). Sony wanted its game console to also function as a high quality audio and video player, for that reason they made it capable of playing SA-CD and Blu-ray discs. On 11 November 2006, the PS3 was launched in Japan, and the week thereafter in the US. The PS3 was well received and sold roughly 12 million units worldwide in its first year (as shown by Figure 31). However, price competition in the game console market was extreme and Sony decided to remove the hardware required for SA-CD support (a chip for decoding the copy protection) from its third generation PS3. This third generation PS3 was launched in the last quarter of 2007, so one could argue that the PS3 added roughly 12 million units to the installed base of SA-CD players. It is unknown if this led to an increase in SA-CD disc sales.

On November 15, 2007, the Steering Committee of the DVD-Forum decided to merge WG-4 with WG-1 (DVD-Video), effectively disbanding WG-4 and transferring its activities to WG-1.[410]

In 2011, Warner Music Group released their first SA-CD titles for the Japanese market.[411] The titles were reissued from their dormant DVD-Audio line. Warner was the last of the major record labels to release SA-CDs.

To date, the SA-CD format still exists, however it is well recognized that it resides in its niche for 'audiophiles'. As Figure 62 shows, over time there has been a steady increase in the number of available SA-CD titles. According to Philips, roughly 60% of the SA-CD discs that have been sold were multichannel recordings, and 40% were stereo recordings.

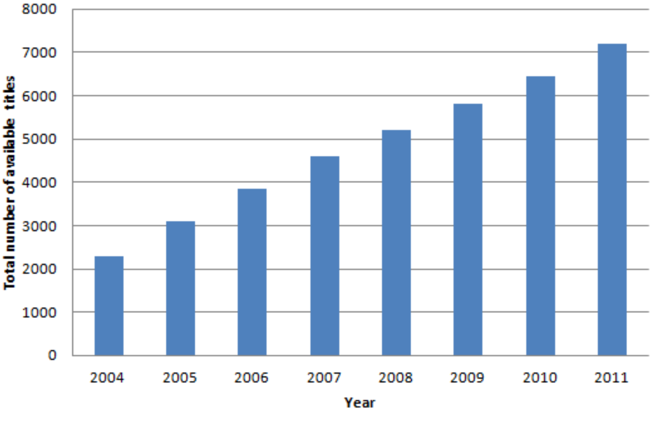



*Figure 62: Number of available SA-CD titles from 2004-2011*[412]

## 5.9 Epilogue

In order to maintain consistency with the other cases, an epilogue was added. In this epilogue, an overview of the interviewees is added and the frameworks of Section 2.5 are applied to the case.

### *5.9.1 Overview of interviewees*

In Section 5.2 it is mentioned that eleven focused interviews were held, but it does not specify who was interviewed. Table 20 provides an overview of the twelve people that were interviewed.

Table 20: Overview of interviewees in the case of the high definition audio discs

| Company | Name | Relevance to case |
|---|---|---|
| JVC | Nick Kuroda | Chairman of the DVD-Forum's WG-4 from 2004 |
| Panasonic | Gene Kelsey | Involved in the marketing and market introduction of DVD-A in US under the Technics brand |
| MediArte | Markus Hintz | From 1999-2003 involved with DVD-A as Managing Director of DVD Produktions, a 100% subsidiary of MediArteH, offering DVD-A production services and equipment to Deutsche Grammophon, Philips, DECCA, TELDEC, Warner Music, EMI, Sonopress / Bertelsmann and others. After 2003 he moved to MediArte, as Director International Business in charge of European distribution of digital audio, video, DVD and SA-CD workstations |
| Universal Music Group | Larry Kenswil | Headed the eLabs department from 1999 until 2008. Prior to that, he held the position of Executive Vice President, Business and Legal affairs. Held Board of Directors seat on the RIAA and IFPA |
| Sony | David Walstra | Involved with the development of DSD on a laboratory level. Started preparing the recording industry for SA-CD in 1997 |
| Philips | Wally Heijnemans | Responsible for overall development and commercialization of SA-CD |
| | Gerard Lokhoff | Worked as Technical Project Leader on the SA-CD system on behalf of the Standards and Licensing. From that position he led the Philips team involved in the standardization discussions with Sony |
| | Menno Treffers | Technology Manager for the development of SA-CD's copy protection technology, including contract negotiations with the record companies and licensing agreement negotiations of the format |
| | Jos Bruins | Worked on the commercialization of SA-CD technology as the Commercial Project Leader |
| | Yoeri Geutskens | Editor of www.sa-cd.net , a website dedicated to SA-CD. Worked from 1996-1998 in Consumer Electronics Market Intelligence, conducting research including focus groups, with regard (amongst others) to SA-CD. From 1999-2000 Product Manager of SA-CD players for Philips Consumer Electronics |
| | Charles Knibbeler | In charge of development of several SA-CD prototypes |
| Pentatone | Giel Bessels | Senior VP for Philips Classics until 1999 when the department was closed. In 2001, he founded PentaTone Music B.V. together with two other former executives of Philips Classics and Polyhymnia International |

### 5.9.2. Applying the case analysis tool

Table 21 shows the result of using the case analysis tool on the case of SA-CD vs. DVD-A. In accordance with the outcome of the MP3 case, the phase of 'Winning the mass market' was included in the case analysis tool. While gathering data, the tool was used to (abstractly) note if a particular element influenced the technology competition in a particular phase. In addition, it helped to identify gaps in the analysis and provided guidance to the focused interviews. Each phase of the detailed case description, as presented in Section 5.4-5.8, is based in essence on the elements that were identified in a particular phase, and therefore these sections can be seen as the result of Table 21.

While applying the case analysis tool to this particular case, I noticed that as the phases progressed it became increasingly difficult to identify the milestones that marked the transition from one phase to the next. This was especially the case for the last three phases. In this technology competition a substitute leapfrogged both SA-CD and DVD-A, and as a result the market adoption of both technologies already started to decline during the phase of 'gaining critical mass'. Although the approach of the phases and milestones appears to be applicable to cases where a de-facto standard emerges, this case shows that it has some limitations in technology competitions where no de-facto standard emerges.

Table 21: Case analysis tool for the case of the high definition audio discs

| | | R&D Build-up | Preparing for market entry | Initiating market adoption | Gaining critical mass | Winning the mass market | Post-dominance |
|---|---|---|---|---|---|---|---|
| | | 1996-1997 | 1998-1999 | 1999-2001 | 2002-2004 | 2004-onwards | |
| Firm | Reputation and credibility | X | X | X | | | |
| | Installed base | | | | | | |
| | Pricing | X | X | X | X | X | |
| | Entry timing | | | X | | | |
| | Marketing and pre-announcements | | X | X | X | | |
| | Availability of products | | | X | X | X | |
| | Availability of complementary goods | | | X | X | X | |
| | Killer application | | | | | | |
| | Size | | X | X | | | |
| | Complementary assets | | X | X | X | | |
| | Technological knowledge and skill base | X | | | | | |
| | Absorptive capacity | | | | | | |
| | Pre-empting scarce assets | X | X | | | | |
| | Level of collaborative development | X | X | | | | |
| | Organizational community of supporters | X | X | X | X | X | |
| | Strategic partnerships | | | | | | |
| | Product proliferation | | | | X | X | |
| | Appropriability | X | | | | | |
| | Chance | | | | | | |
| | | | | | | | |
| Technology | Technological superiority | X | X | X | X | X | |
| | Installed base | | | X | X | X | |
| | Network effects | | | | | | |
| | Switching and homing cost | X | X | X | X | X | |
| | Backward compatibility | X | X | X | X | X | |
| | Increasing returns to adoption | | | | | | |
| | Technological breakthroughs in | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | subsystems | | | | | | |
| | Type of technological innovation | X | | | | | |
| | Adapters and gateways | | X | X | X | X | |
| | Technological performance trajectories | | | | | | |
| | Chance | | | | | | |
| | | | | | | | |
| **Market / industry** | Market and industry characteristics | | | X | X | | |
| | Level of competition | X | X | X | X | | |
| | Rate and type of technological change | | | | X | X | |
| | Network effects | | | X | X | | |
| | Availability of products | | | X | X | X | |
| | Availability of complementary goods | | | X | X | X | |
| | Killer application | | | | | | |
| | Availability of imitators | | | | | | |
| | Hetero- or homogeneity of customer needs | | | | | | |
| | Unclear assessment criteria | | | X | X | | |
| | Powerful rival technology sponsors | X | X | X | X | | |
| | Government intervention and industry regulation | | | | | | |
| | Product proliferation | | | | | | |
| | Appropriability | X | X | X | | | |
| | Chance | | | X | | | |

### 5.9.3. Applying the integrative framework and case analysis

Based on the data gathered in Table 21, for each phase of the technology competition a snapshot was made by applying the integrative framework (Figure 63 - Figure 67). Each Figure shows only those elements that were at play during the respective phase. The relationships between the elements were reconstructed based on the written documents, public announcements and interviews. When the relationships were the same as presented in the integrative framework, these were marked in black. When the relationships were not presented in the integrative framework, these were marked in blue.

Considering that DVD-A and SA-CD were in direct competition during multiple phases, I also attempted to apply the scoring method in accordance with Subsection 2.5.3 (an overview of the scoring options can be found in Table 10). I based the scores on the insights from the written documents, public announcements and interviews. Although this approach seems rather subjective, the scores were often based on solid data (sales data, product pricing, size of the organizational community of supporters, etc). I did not attribute scores to the elements in the last phase of the technology competition, because in this phase of 'winning the mass market', SA-CD had prevailed over DVD-A and faced different competitors.

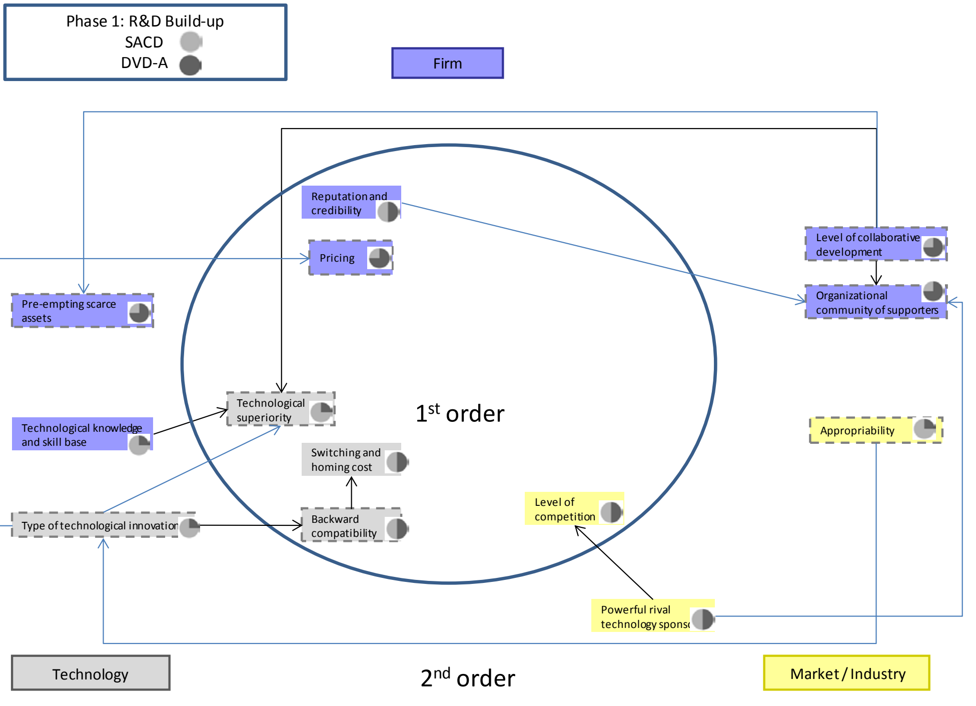



*Figure 63: Integrative framework applied to Phase 1 of the case of high density audio discs*

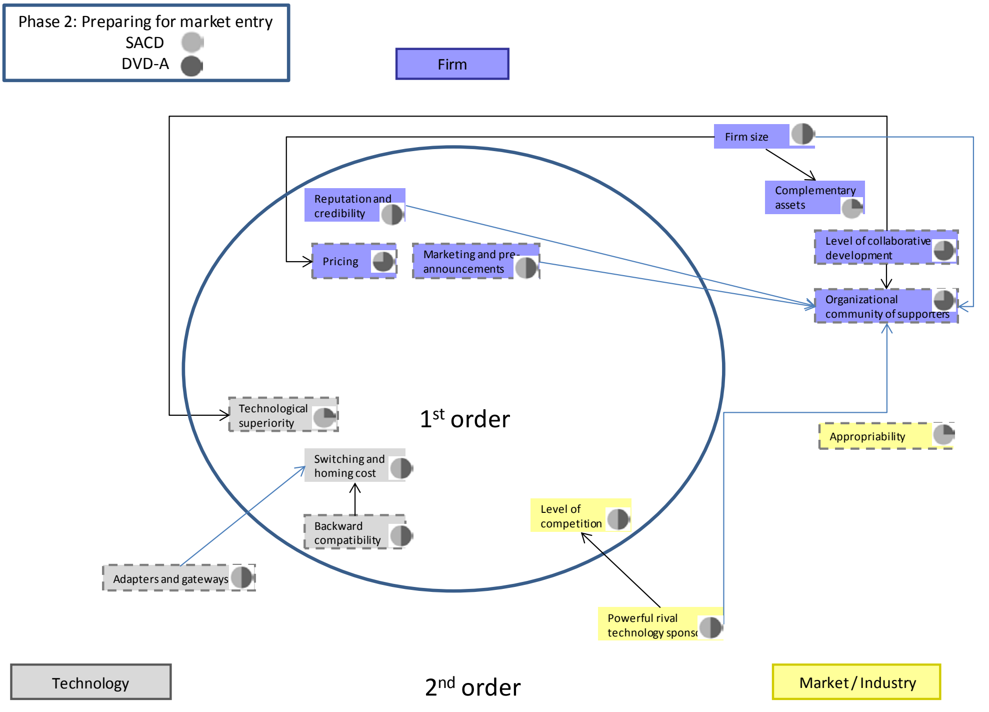



Figure 64: *Integrative framework applied to Phase 2 of the case of high density audio discs*

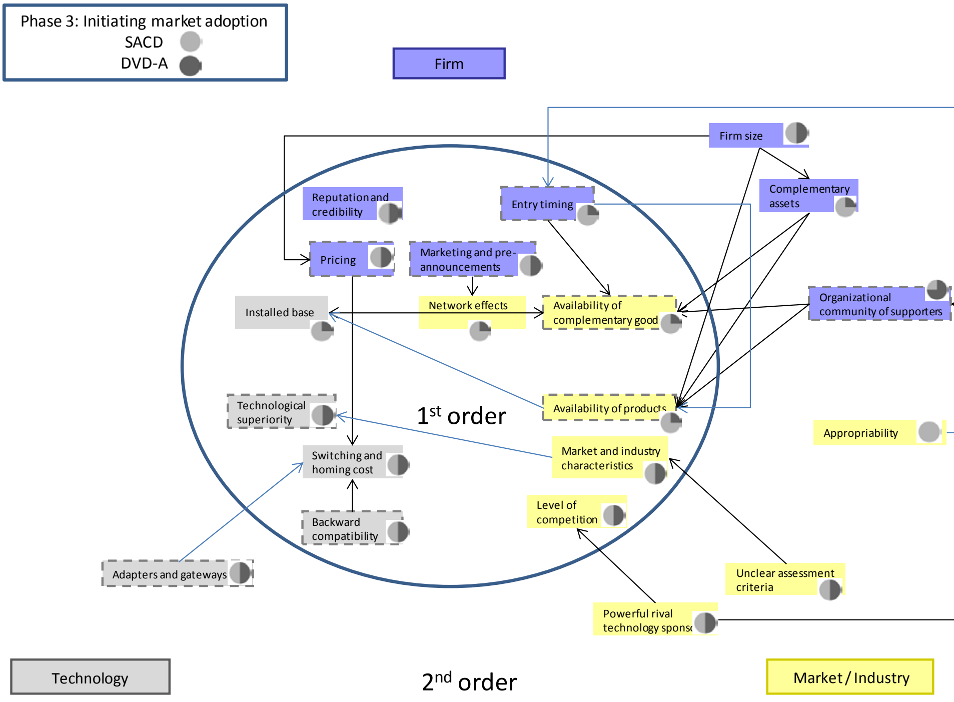



Figure 65: *Integrative framework applied to Phase 3 of the case of high density audio discs*

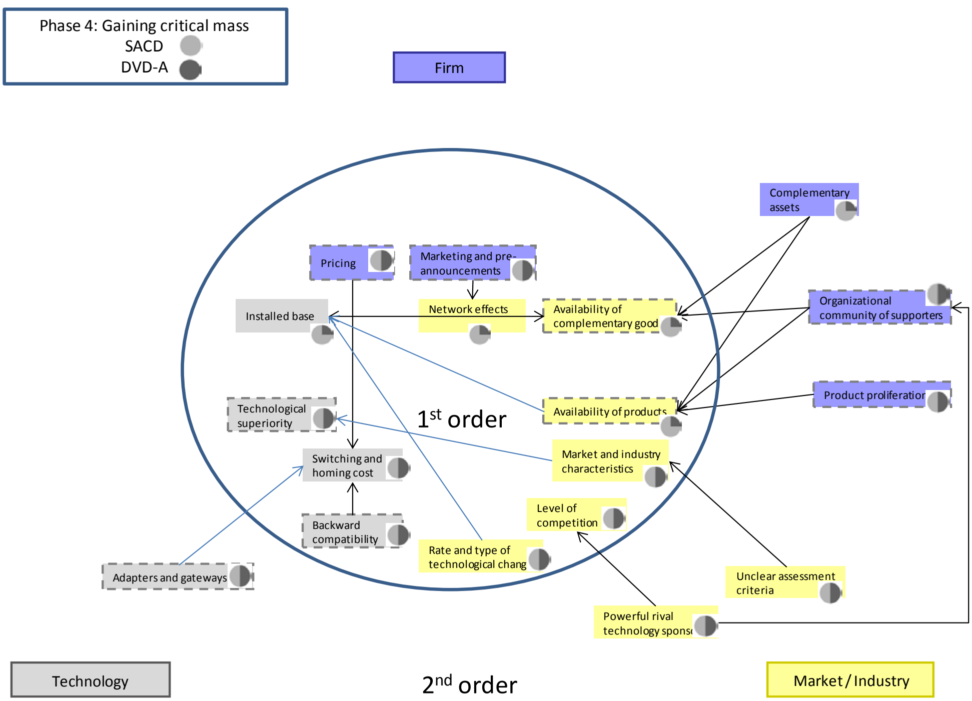



Figure 66: *Integrative framework applied to Phase 4 of the case of high density audio discs*

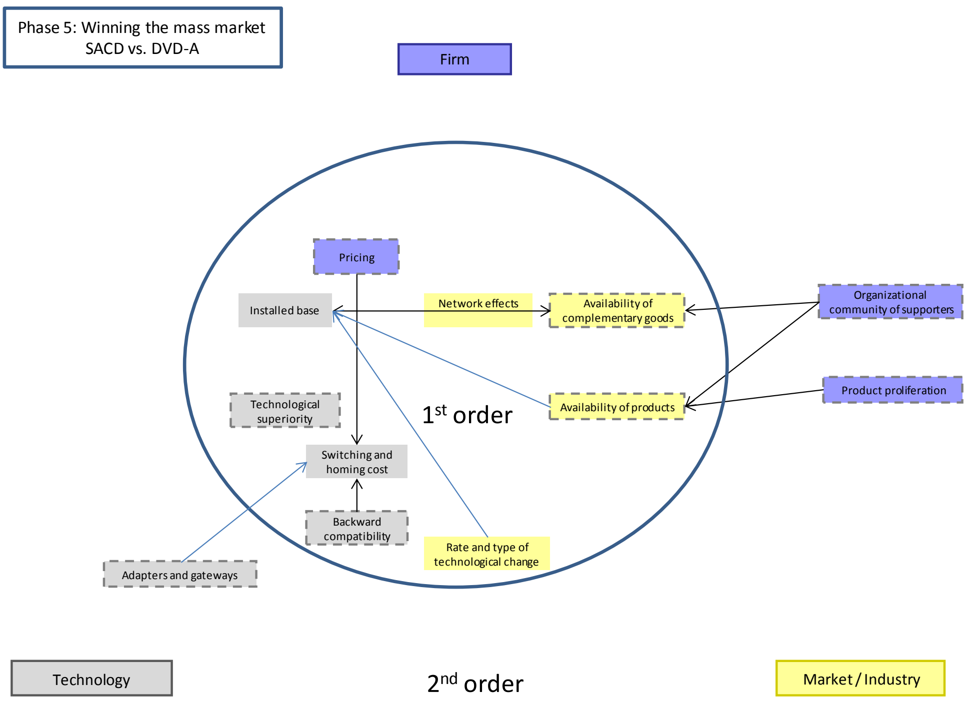



*Figure 67: Integrative framework applied to Phase 5 of the case of high density audio discs*

As Figure 63 shows, there were already 14 elements in play during the phase of R&D build-up. These elements were mostly firm- and technology related, but also included some market/industry related elements. Similar to the cases of MP3 and Blu-ray, the technology sponsors focused on the technology development. The sponsors of both technologies made different decisions regarding the type of technological innovation, influencing its backward compatibility and technological superiority. Different from the other two cases, the technology sponsors started early with developing their technologies in collaboration with others, and to establish an organizational community of supporters. The collaborative development of SA-CD influenced its measure of technological superiority versus DVD-A, whereas the collaborative development of DVD-A helped to build an organizational community of supporters and pre-empt scarce assets (i.e. support from the major record labels and the major consumer electronics manufacturers). As there were two rival camps, both with powerful rival technology sponsors with formidable reputations in establishing de-facto standards, both sides made an effort to actively build an organizational community of supporters for its technology.

During the phase of 'preparing for market entry', there was a minor increase in the number of elements and the focus shifted slightly from the technology development towards building an organizational community. As Figure 64 shows, the organizational community of supporters was influenced by the level of collaborative development, the reputation and credibility of the technology sponsors, marketing and pre-announcements, and the powerful rival technology sponsors in the industry.

In the phase of 'initiating market adoption', there was a rapid increase in the number of elements; nearly all elements from the previous phase stayed in play, and ten new elements came into play. The new elements were mainly firm- and market/industry related. As Figure 65 shows, an appropriability-related event in the industry impacted the entry timing, which in turn impacted the availability of complementary goods and the availability of products.

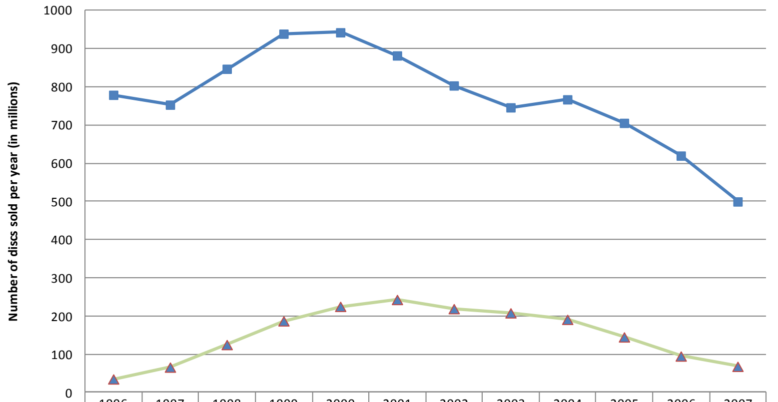
In the phase of the decisive battle, there is a small decrease in the number of elements; five elements go out of play and are replaced by two new ones. As can be seen from Figure 66, the elements in this phase are well balanced between firm-, market/industry- and technology related elements.

In the phase of 'winning the mass market', there is a rapid decrease in the number of elements. This is mainly due to market/industry-related elements leaving the play (e.g. caused by the victory over the direct competitor in the previous phase). In this phase there are no new elements, and the remaining elements are mainly firm- and technology-related.

Figure 63 to Figure 66 show the sponsors of SA-CD and DVD-A used very similar strategies. From an early stage, both focused heavily on collaborative development and building an organizational community of supporters. The DVD-A sponsors had an advantage in the sense that they were the first to start the development of a high definition audio disc, and they started from a position whereby much of the required technological basis was already in place. In order to differentiate from DVD-A, the SA-CD supporters decided to take a different technological approach, which required more technological development. In order to catch up with the DVD-A development, and ensure they would be able to enter the market around the same time, the SA-CD supporters adopted a closed collaboration model; Sony and Philips managed to win time by combining their respective technologies which were required for the SA-CD format, and they limited the number of technology sponsors to only themselves. This enabled them to efficiently address any issues and quickly move forward, however this was not beneficial to gaining support from other companies. On the other side, the open collaboration model that the DVD-A sponsors adopted was beneficial to building an organizational community of supporters, but as 40 companies were involved in WG-4, agreement on technological solutions was more difficult and progress was slower. The approach by the SA-CD supporters paid off, in the sense that it was the first on the market, thereby offering a product to consumers with similar performance as the announced DVD-A technology. However, the DVD-A camp was set to introduce products and complementary goods shortly after SA-CD was launched, and outperform SA-CD in terms of the number of available products and complementary goods. In addition, these would be offered at a substantially lower price. Although SA-CD was a worthy competitor and would have hampered the market adoption of DVD-A, the signs indicated that DVD-A would win the competition. However, fate struck when, a few weeks before the market introduction of DVD-A, the content protection of DVD was hacked and various DVD-A supporters decided to cancel the launch of their products and complementary goods. This delayed the market introduction of DVD-A by eight months (from December 1999 to July 2000), and gave SA-CD a time to market advantage of little over a year. This timing advantage allowed Sony to introduce a new SA-CD player which was cheaper than the announced DVD-A players, a few months before the DVD-A players were launched in July 2000. In addition, the timing advantage combined with the element that Sony was the only remaining consumer electronics manufacturer that owned one of the major record labels, allowed SA-CD to have a distinct advantage in the availability of complementary goods by the time DVD-A entered the market. As can be seen from Figure 64 and Figure 65, the element of appropriability impacted the element of entry timing, which in turn shifted the advantage in the technology competition from DVD-A to SA-CD. When comparing Figure 65 and Figure 66, it becomes apparent that the SA-CD sponsors were successful in winning organizational support for their technology (both from consumer electronics manufacturers as well as record labels). Thereby, the last advantage of DVD-A was neutralized, and this element (combined with the network effects) enabled SA-CD to win from DVD-A. As shown by Figure 66, both parties engaged in market efforts to enhance network effect, and utilized product proliferation to enhance the availability of products, however this had little effect on the adoption of the technologies. This can be explained by the impact of the rate and type of technological change on the installed base; the rapid adoption of a substitute technology hampered the adoption of both SA-CD and DVD-A, and it was too late for their product proliferation and marketing efforts to counter this.

Does this second application of the scoring method provide insight if a technology sponsor could evaluate the situation and identify the relevant elements to shape the odds in its favor? In retrospect, from a strategic choice perspective there was little that the DVD-A sponsors could have done to shape the odds of the competition in their favor; the two major events in the competition (i.e. the timing of the hack of DVD's content protection, and the rise of a substitute that became the de-facto standard) were unforeseen and outside the scope of control of the DVD-A sponsors. Additionally, during the first two phases the DVD-A sponsors were focusing on the right aspects (i.e. building an organizational community of supporters) and managed to obtain a clear advantage versus its main competitor. In hindsight, the DVD-A camp could have improved its situation if it would have applied product proliferation (e.g. DVD-A systems for cars) during the phase of 'initiating market adoption'. This could (in theory) have brought forth a 'killer application' that could have boosted the market adoption.

While the integrative framework can be used to clarify the dynamics of the technology competition, this case shows that the model insufficiently accounts for the power of substitutes. If we take a broader scope and investigate the state of the CD and MiniDisc sales from the start of the technology competition between SA-CD and DVD-A (Figure 68), this shows that the sales of CD did not grow between 1999-2000, and after 2000 the sales of CDs rapidly decreased. The same applies to MiniDisc after 2001. Considering this information, one could argue that in retrospect the timing of SA-CD and DVD-A in 1999 and 2000 respectively was fine (perhaps one year earlier would have been even better). However, the technology competition between SA-CD and DVD-A caused consumer confusion, and hampered their market adoption. By the time the technology competition was resolved in favor of SA-CD in 2004, not only the sales of SA-CD, but also the sales of CD and MiniDisc were rapidly declining as compressed audio formats, led by MP3, were rapidly adopted by the market. One could argue that (in hindsight) if the consumer electronics manufacturers and record labels had agreed on a single technology (as had been done with DVD), this would have greatly benefitted the market adoption of high definition audio discs. It would, however, be too liberal to state that this new technology would have slowed down the momentum of MP3.




| | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Compact Disc sales in US | 778.9 | 753.1 | 847 | 938.9 | 942.5 | 881.9 | 803.3 | 746 | 767 | 705.4 | 619.7 | 499.7 |
| MiniDisc sales worldwide | 35 | 66 | 125 | 187 | 225 | 243 | 219 | 208 | 191 | 145 | 95 | 68 |

*Figure 68: Number of CDs and MiniDiscs sold in the US from 1996-2007*[413]

As this case shows, strategic decision making during a technology competition could benefit from a good assessment of the sales of the incumbent de-facto standard and the substitute technologies aiming to become the de-facto standard. The utility of the integrative framework would improve if it would take these aspects into account.

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326 http://www.modernhometheater.com/howto/dvdaudio/main.shtml (retrieved December 21, 2013)

327 Compact Disc was introduced in the market in 1982, therefore most patents on the format would be expired by 2002

328 The technology behind DSD is Delta Sigma Modulation (DSM) which was introduced in 1952 by F. de Jager at Philips Research. DSM was used in the 80's for telecommunication and military purposes. Sony's Mr. Nichio developed the algorithms and chose the parameters in order for the DSM technology to be used into high resolution audio encoding. One of the envisioned applications of DSD was archiving, and therefore record labels with big music libraries were approached. However, very soon it became clear that the technology could also be used for high quality sound and the target shifted to recording new productions.

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## Prologue Chapter 6

As explained in Section 1.5, in the upcoming chapter the limitations and comprehensiveness of the integrative framework are further investigated by 'zooming in' on the relationship between two elements. When selecting the particular relationship, I took into account the relevant themes in academia regarding de-facto standards in 2010. This resulted in aligning the selected relationship with a special issue of the prominent academic journal 'Organization Studies'. The topic for the special issue was 'the dynamics of standardization', and a closer investigation of the relationship between the elements 'collaborative technology development' and 'organizational community of supporters' appeared to be fitting. Figure 69 highlights the selected relationship between the two elements in the integrative framework. In collaboration with three colleagues, several competitions between compatibility standards were selected (i.e. Blu-ray vs. HD-DVD, USB vs. Firewire, and WiFi vs. HomeRF), and in-depth case studies were performed to investigate the effect of the measure of collaborative technology development on the size and diversity of the organizational community of technology supporters.

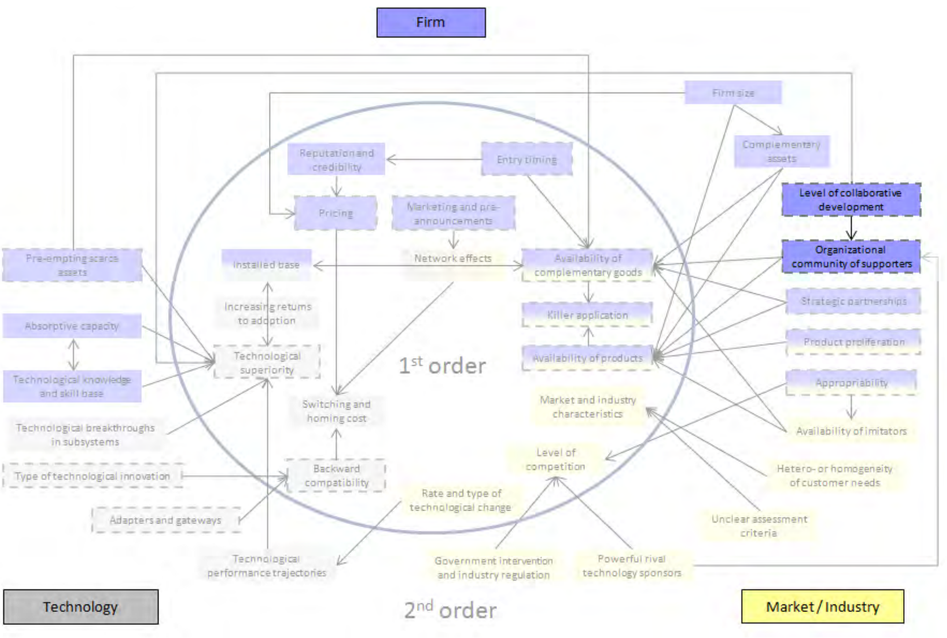


*Figure 69: Position of the two selected elements and their relationship in the integrative framework*

# Chapter 6 - The Paradox of Standard Flexibility: The Effects of Co-evolution between Standard and Interorganizational Network

**Published in Organization Studies May-June 33, 2012: pp.705-736**

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## 6.1 Introduction

Several authors have studied the effects of networks of standard supporting organizations on the success of standards (Keil[414], Markus et al.[415]). They showed the influence of network characteristics, such as the size of the network in standardization committees (Egyedi[416], Fomin[417], Schmidt and Werle[418]) or industry consortia (Weiss and Cargill)[419] and the diversity of actors (Gomes-Casseras)[420] on the chances that a standard achieves dominance. Some authors go a step further and study the antecedents of the formation of standard setting alliances (Axelrod et al.[421], Vanhaverbeke and Noorderhaven[422]). However, authors have, thus far, treated the standard itself as exogenous to network formation. In other words, the literature has studied how the network of standard supporters affected standard success, but considers the standard itself as an effect of the network members' actions and not as an endogenous element in the formation of the network.

In this paper, we study the reciprocal relation between standard flexibility and interorganizational network formation. We focus on compatibility standards, defined as 'codified specifications defining the interrelations between entities in order to enable them to function together' (based on De Vries[423]; Garud and Kumaraswamy[424]). Standard flexibility refers to the number and degree of changes to a standard over time. The concept of standard flexibility is paradoxical since standards aim at creating sustained compatibility between different technologies, and therefore stability in markets, while flexibility creates instability. However, we show that flexibility of standards can promote support by a network of supporters and thereby stability on the longer term. More in particular, we propose that on the one hand standard flexibility can enhance both network diversity and size, and on the other hand the diversity of standard-supporting networks will have further effects on standard flexibility. Through an exploratory study of three cases of compatibility standards, we examine the specifics of the co-evolutionary process resulting from this reciprocal relationship over time and show its effects on standard success. In addition, by investigating the emergence of path dependencies in the process, we explore the forces that restrict the process over time.

By studying the reciprocal relationship between network characteristics and network outcomes, we not only contribute to the standardization literature, but also to the social network literature in general. In this literature, there is widespread recognition that social networks are important for the performance of individuals, firms or even regions (e.g., Borgatti and Foster[425]; Burt[426]; Granovetter[427]). There has also been some attention to the antecedents of networks (Brass et al.[428]; Nebus[429]). However, in part due to the limited availability of longitudinal network studies (Elfring and Hulsink[430]; Streier and Greenwood[431];

Zaheer and Soda[432]), the effects of network outcomes on the dynamics of the network itself have hardly been addressed (Perry-Smith and Shalley[433]). Exceptions are Autry and Golicic's [434] study on buyer-supplier relations and Lee's[435] study on patent networks. Our study contributes to this research by investigating a so far unaddressed issue: the effects of the interaction between changes in network outcomes (standard flexibility) and network characteristics (size and diversity) on (standard) success.

The paper proceeds as follows. First we explain our theory on the relation between networks of organizations supporting standards and standard flexibility. We also address the issue of path dependency in standardization processes. We then present our methodology and the three case studies of standards battles, each followed by a short analysis. This is followed by a cross-case analysis. In the discussion and conclusion section we summarize our findings and relate these to existing literature. We also address the practical implications of our study. Finally, we set out paths for future research.

## 6.2 Networks and standard performance

Standardization literature has pointed to several characteristics of interorganizational networks affecting the success chances of standards. The seminal paper of Cusumano et al.[436] on standard competition in the video recorder industry shows that the size of the interorganizational network was an important determinant in the success of VHS over competitors such as Betamax and V2000. The VHS network included more stakeholders from the core industries, consumer electronics and film studios, and this stakeholder network was built earlier. Other authors studied the effect of a firm's position in a network on the firm's influence in standard setting (Leiponen[437]) and the role of networks of individuals for the firm's influence in standards setting (Dokko and Rosenkopf[438]).

In accordance with general literature on social and interorganizational networks (Burt[439]; Coleman[440]; Provan et al.[441]), standardization literature on interorganizational networks emphasizes the benefits of networks for collective action and coordination of tasks. Amongst others, it shows that coordinated action is required in the interorganizational network behind a standard, in order to develop a joint marketing strategy, such as a market penetration strategy (Ehrhardt[442]), and to spend sufficient resources on marketing the standard (Schilling[443]). Collective action can also refer to strategic marketing communications (pre-announcements) which discourage users from adopting rivals' standards (Besen and Farrell[444]; Shapiro and Varian[445]), or to a collective licensing strategy with respect to the standard (Bekkers et al.[446]; Clarke[447]; Marasco and Dodson[448]; Merges et al.[449]).

The general network literature shows the importance of networks for information exchange, particularly diverse information (Burt[450]; Campbell et al.[451]; Coleman[452]; Granovetter[453]). The notion that diverse information, if combined, can lead to new knowledge is deeply rooted in the literature on innovation (Allen[454]). Information and coordinated action are mutually reinforcing and cumulative over time (Burt[455]). Also in the standardization literature, information exchange between actors with diverse backgrounds is considered important, particularly in the early phase of the development of a standard (De Vries[456]; Markus et al.[457]; Susanto[458]). Diversity of participants in standards development shapes the contents of the standards, and improves performance (Beckman and Haunschild[459]; Egyedi[460]; Schmidt and Werle[461]). Involvement of stakeholders will likely result in a standard with a content that reflects their specific needs (Markus et al.[462]). Evans et al.[463] and Lundval[464] show this in the case of user involvement in standardization. On the other hand, diversity can put challenges for decision making. Cargill[465] suggests that the key to successful standardization is managing the diversity of the participants; in turn, their input leads to a standard's content that meets the needs of the sectors represented by the stakeholder. Deliberation processes resulting in consensus can be extremely important (Scherer and Palazzo[466]), but the more participants, the more difficult it is to achieve consensus (Rada[467]; Vercoulen and Van Wegberg[468]) leading to delay.

A third benefit of networks refers to their role in creating status and legitimacy (Podolny[469]). The reputations of firms in standard supporting networks with respect to successful standard setting in the past are important in creating future prospects for customers and other parties (Axelrod et al. [470]). A group of standard supporters with a good reputation will also find it easier to attract new members to join the group (Foray[471]). The standardization literature has also shown that the involvement of a broad variety of stakeholders may contribute to the legitimacy of the standard development process and the resulting standards (Lundval[472]; Scharf[473]), thus yielding a higher likelihood of market acceptance.

In this paper we focus on the role of interorganizational networks for information exchange and coordinated action. Information can provide actors with opportunities, and coordinated action can provide the cooperative behaviour needed to explore those opportunities (Podolny and Baron[474]). Of course, when collective action leads to an extension of the network of standard supporters, the legitimacy of the network is often also strengthened. While the standardization literature emphasizes the importance of information exchange between actors in the early phase of the life of a standard, in this paper we extend the role of information exchange to later phases. We expect that diverse network members can use their repositories of knowledge and the experience acquired in the standard diffusion process to define the future direction of the standard. Subsequently, collective action serves to adapt the standard to current and expected future requirements, particularly to the requirements from different industries and consumer groups. The modification of the standard will attract network members from those new industries, further increasing the diversity and size of the network. Information exchange in the network can subsequently lead to new adaptations of the standard to suit both current and prospective network members.

The topic of standard flexibility has been addressed by Egyedi and Blind,[475] who speak of 'standards dynamics', referring to 'the changes to and interactions between standards, that is, what happens to standards once they have been set' (p. 4). While they use the term standard dynamics to include local changes in the standards by specific implementers, and the succession between standards, we use the term standard flexibility for changes in a standard's contents over time. While Egyedi and Blind[476] emphasize the replacement of standards, and thus a selection perspective, we apply an adaptation perspective, emphasizing the abilities of standard supporting networks to change the standard as well as the network over time (Hodgson[477]; Lewin and Volberda[478]).

Since we study the joint dynamics of standards and their supporting networks, we include in our analysis the processes that create path dependencies in the evolution of a standard. The evolutionary economics literature has pervasively shown how so-called network effects may lead to path dependencies in the development of products and markets. These network effects occur as a consequence of the installed base (direct network effects) of a standard and the availability of complementary products (indirect network effects) (Adler[479]; Farrell and Saloner[480]; Van den Ende and Wijnberg[481]). Network effects lead to self-reinforcing processes, resulting in path dependencies and sometimes in a winner-takes-all situation. Actors become locked in to a single standard, unless switching costs are very low (Shy[482]). A classic and well known example of lock-in is the QWERTY keyboard. Existing skills of typists reinforce the dominance of a keyboard layout geared to the needs of mechanical typewriters (David[483]). Not always do networks effects lead to a single outcome. For instance, in the case of video game consoles (Schilling[484]) and flash memory cards (De Vries et al.[485]) multiple standards remained to co-exist.

In this paper, we investigate how the reciprocal process between a standard's support network and standard flexibility contributes to network effects and path dependencies. For instance, the network of standard supporters may contribute to the installed base and availability of complementary products, and thus enhance both direct and indirect network effects. On the other hand, standard supporting networks themselves represent a certain degree of vested interests and stability, and thus may create path dependencies in the dynamics of standards. Thus, networks of standard supporters can be a source of network effects as well as of path dependencies and lock-in. We will study phases in the dynamics of standard supporting networks and standards. Schreyögg and Sydow[486] and Sydow et al.[487] distinguish three phases in the process of creating path dependencies:

(1) The pre-formation phase: the range of options in the choice of a solution is broad;
(2) The formation phase: self-reinforcing processes narrow the range of options, and the process becomes partly irreversible – a path is evolving;
(3) The lock-in phase: the dominant decision pattern only leaves room for very limited change, since this pattern becomes deeply embedded in organizational practice and is replicated.

According to the authors, specific events trigger the transition from Phase 1 to Phase 2. Sydow et al.[488] give the example of the standard for video recorders, where the initial cooperation between the dominant actor, Matsushita, and movie studios for complementary product development (pre-recorded movies) initiated indirect network effects and path dependencies that led to the dominance of VHS.

In this paper we specifically investigate to which extent different phases can be distinguished in the evolution of standards, how network formation and standard flexibility evolve in the different phases, and how they contribute to path dependencies. We also address the events that trigger the transition between phases from a network perspective. This analysis of the role of networks in path dependency may reveal the conditions under which the co-evolutionary, and sometimes spiral, process between network formation and standard flexibility terminates.

In summary, we explore the antecedents and effects of changes in standards, particularly with respect to diversity and size of the standard's network. We presume that information exchange within and the collective action of the network of standard supporters leads to a dynamic relation between standard flexibility and network formation. Specifically, we examine the effects that changes in a standard's content have on the size and diversity of the network of standard supporters, and in turn, the subsequent effects of the network's increased size and diversity on further adaptations of the standard. Additionally, we explore the role of the network-flexibility dynamics in path dependencies which in turn limit the reciprocal process between the standard and the standard supporting network.

## 6.3 Methodology

Since we are the first to conduct a focused study on the relationship between standard flexibility and interorganizational networks, we perform explorative research based on a case study approach, involving an in-depth study of standards battles. We selected three cases of battles between compatibility standards: the battle between Blu-ray and HD-DVD for a high definition optical disc standard, the battle between

Firewire and USB (Universal Serial Bus) for interconnectivity of peripherals to the PC and the battle between WiFi and HomeRF for wireless connectivity in the home.

For each standards battle, we examined news archives including Factiva and Lexis-Nexis and press releases from the websites of the organizations that develop and promote the standards. We also analyzed written documents to gain a general insight on the development paths of the standards. These documents included the minutes of meetings (organized by standards committees and consortia), presentations, press releases and actual standards drafts and specifications. To complement the data and assess the substantiality of each change in the standards, we conducted focused interviews with key persons involved in the development of each standard. Often one interviewee introduced us to a key informant at another company involved in the battle. These contact persons gave us access to relevant documents as well. In total, fifteen face to face interviews were conducted in Europe, Japan and the US, complemented with thirteen telephone interviews in Europe, Japan and the US. In the case of Blu-ray versus HD-DVD, we interviewed ten respondents, including members of the Board of Directors of the Blu-ray Disc Association, the President of the Blu-ray Disc Association, and one of the key members of the HD-DVD promotion group. For the USB versus Firewire battle, we interviewed eight respondents, including Intel's project leader for the implementation of USB and a technology manager closely involved in the development of Firewire. For the WiFi versus HomeRF case, we interviewed ten respondents, including the chairman of the IEEE 802.11 committee (from 1990 to 2000), the co-founder of the WiFi alliance, the former internal WiFi project leader at NCR (the company that initiated the WiFi standard), and a project manager involved in the HomeRF standard. The interviews were conducted from 2007 to 2010 and the length of the interviews varied from one to 2.5 hours. To ensure consistency and reliability, we used interview guidelines for all interviews. We communicated the results to the interviewees for verification. We translated quotations from non-English-speaking interviewees into English.

We define the *success* of a standard in terms of market share; a standard is highly successful (dominant) when it has achieved more than 50% market share among new buyers in a certain product or service category for a significant amount of time (Lee et al.[489]; Suarez[490]). A standard achieves medium success if it survives for a long period of time, but does not become dominant. Low success means that the standard disappears from the market. We define the *network of a standard* as all the connections between two or more actors with the goal of developing and promoting the standard (Mulder 1992, as cited by Egyedi[491]). Examples of networks include standardization alliances (Hill[492]), consortia, and committees of formal standards organizations (De Vries[493]). We define *network diversity* as the number of relevant industries that are represented in the network. According to Jiang et al.[494], alliances can be differentiated in terms of degree of variance in partners (industry diversity, national diversity, and organizational diversity), functional purposes, and governance structure. In our research, the industry diversity is the main point of interest. Our definition of standard diversity is based on the notion from network literature that diverse network members use their knowledge and experience to adapt a standard to the requirements from different industry groups, and that the modified standard will attract network members from those new industries. If actors operate in multiple industries, we looked at the divisions within the firm that participated in the network and counted the number of industries in which these divisions were active. *Network size* is defined as the number of companies that supported the standard by, for example, adopting the standard in their products.

*Standard flexibility* is defined as the number and degree of changes since the start of the standard's development. To the extent possible, we distinguish substantial changes from minor changes. Substantial changes are modifications of the specification that are important for the functionality of the standard. Examples are, in the case of Blu-ray, the addition of region coding and copy protection or the removal of a disc cartridge. The first and the second of these changes modified the standard's functionality to the benefit of content providers, and the third lowered cost and improved ease of use. Minor changes are modifications that do not or hardly impact the standard's functionality.

Each interview began by presenting the interviewee with a chronological list of changes for each of the standards, which we deduced from the initial desk research. We asked the interviewee to modify the list where needed. For every change, the interviewee was asked how substantial the change was, which parties proposed the change, which parties were active in drafting the new version of the specification and which parties were involved in approving it. Then, we asked about the reasons for changing the standard. Subsequently, we inquired whether certain changes were incorporated with the goal of attracting other parties to the standard and whether these parties originated from new industries. We also asked whether these new parties contributed to the success of the standard and whether they would have joined had the standard not been changed. Lastly, we asked whether these new parties contributed to the further development of the standard.

The data was analyzed following Miles and Huberman's[495] recommended three steps: data reduction, data display, conclusion drawing and verification. First, we analyze the primary and secondary data marking the events that took place during each standards battle. We focused on changes in the standards and in the networks supporting the standards. This resulted in a historical reconstruction of the standard development, respective changes and support network build-up. To assess how standard flexibility, network diversity, network size and standard success related to each other in each case, we triangulated the evidence obtained from the news archives, written documents and interviews. Based on this triangulated evidence, we derived, for each standard, the values for each variable. We created several displays to evaluate the changes in our constructs of interest over time. We examined the displays and narratives to fully understand each case. We also assessed to what extent different phases can be distinguished in the dynamics of the evolution of each standard. Then, we determined whether patterns could be established for our constructs across different standards battles to arrive at evidence regarding the nature of the relationship between our constructs. This was a highly iterative process in which we frequently reviewed our data to verify and reformulate our claims. It resulted in additional data collection including several follow-up interviews.

## 6.4 Case study 1: Blu-ray versus HD-DVD

### Background

In 1998, the market introduction of commercial high definition televisions in both the US and Japan created the need for a commonly accepted, inexpensive way to record and play high definition content. Two standards competed for dominance; Blu-ray and HD-DVD. In 2008, Blu-ray became dominant (see Table 22 for a chronology).

### Blu-ray

At the end of 1997, Sony and Philips decided to combine their high definition optical disc technologies and develop Blu-ray. Primarily, the consumer electronics divisions of Sony and Philips were involved in the development, but also the disc replication and optical disc drive manufacturing divisions of Sony participated. Sony and Philips developed the new technology to be backwards compatible with DVDs, but substantially better in terms of disc capacity. An interviewee at Philips expressed that: "*It was a strategic choice to work on a technology with five times more storage capacity than DVD because we believed that in the future motion picture studios would have the need for more disc capacity"*. The development started with standards for re-writable discs and disc recorders.

After developing the standard up to version 0.5, Sony and Philips invited other major consumer electronics companies with the goal of preventing a standards battle. Simultaneously, in April 2001, Panasonic (then known as Matsushita) presented a competing format (Peek et al. 2009). A respondent from Sony noted: *"Through history, when Panasonic supported a technology, that technology won the standards battle. Therefore Panasonic was an obvious key player that we wanted to attract in the Blu-ray development"*. Panasonic was approached for a collaboration, which they accepted, and they contributed their dual layer technology, doubling the storage capacity. The three companies started attracting other large consumer electronics manufacturers and planned to form a group of ten companies. One of them, Toshiba, decided not to accept the invitation and continued to work on its own format, HD-DVD. In February 2002, nine major consumer electronics companies established the Blu-ray Disc Founders consortium. They completed version 1.0 in June 2002.

The new network members made clear that pre-recorded discs and content were required to make the technology successful. This led to a substantial change by parallel development of variations in the standard in different working groups – for re-writable, recordable and read-only discs. In April 2003, Sony introduced the first commercially available high definition disc recorder for recording HD images, but in Japan only. Consumer adoption was disappointing due to the price and technological problems; production was soon stopped.

With the shift in focus towards pre-recorded discs, the companies supporting Blu-ray realized that gaining commitment from movie studios and the IT industry was imperative. Sony's movie studio and computer manufacturing business joined in 2003. In January 2004, they gained the support from the two largest computer manufacturers, HP and Dell. This was done by adhering to their requests to make substantial modifications to the format replacing Sony's logical format with the non-proprietary Universal Disc Format and working towards a disc without a cartridge. In March 2004, TDK (a leading manufacturer of optical discs) joined the consortium. Their hard-coat technology eliminated the need for the disc cartridge. In order to obtain support from the major Hollywood studios, the Blu-ray Disc Foundation agreed to a new and substantial set of changes in the standard, by including two additional layers of content protection, region coding and a new video application format. According to an executive at Panasonic, "*20th Century Fox and Walt Disney have fewer, but very strong titles in comparison to other major film studios, and due to their size it is more difficult to launch movies world-wide on the same date. Therefore, both content protection and region coding are especially important to these two studios*". As a result, between October and December 2004, 20th Century Fox, the Walt Disney Company and Buena Vista Home Entertainment decided to join the Blu-ray consortium. A year later, this also led to non-exclusive support from two other major film studios, Paramount and Warner Bros. (which initially exclusively supported HD-DVD).

In May 2004, before the movie studios announced their support, the 13 members of the Blu-ray Disc Founders created an open platform which any company could join; the Blu-ray Disc Association. This boosted the amount and diversity of company support: three months later, more than 70 companies from the consumer electronics, information technology, media and software industry had joined. The Board of Directors of the Blu-ray Disc Association initially consisted of the 13 founders and over time grew to 19 members. In 2005, the association evaluated its video format, from Sun Microsystems, against Microsoft's video format. It decided to stick with its application for technological reasons and because the movie studios preferred the format. This choice led Microsoft and Intel to choose exclusively for HD-DVD. Soon HP followed.

In 2005, at the request of the Japanese government, Toshiba, Panasonic and Sony negotiated to arrive at a common standard. However, the negotiations stalled, leaving it up to the market to decide which technology would win. The first Blu-ray players entered the market in June 2006. In November 2006, Sony launched its PlayStation3 video game console with integrated Blu-ray player. In January 2008, Warner Bros. decided to exclusively support Blu-ray. Warner saw that the market was leaning towards Blu-ray since it had the most support from the consumer electronics and movie studio industry and because of the success of the Playstation3. With four of the six major movie studios exclusively supporting Blu-ray, influential retailers such as Walmart followed. Blu-ray became the dominant standard for high definition optical discs in 2008. After this victory, the standard was upgraded to keep it up to date e.g. by increasing the disc capacity and integrating 3-D technology. The network's diversity and size stayed stable, since the exit of some parties was compensated by new entrants.

**HD-DVD**
After deciding not to join the development of Blu-ray, in August 2002, Toshiba and NEC announced the competing format, HD-DVD. HD-DVD was built upon the intellectual property of the DVD standard and a combination of new technology from both companies. By building on the DVD format, there was less freedom to modify the HD-DVD standard. Toshiba and NEC had activities in the consumer electronics, computer and optical disc drive industry. They immediately tried to expand the number and diversity of supporting companies by getting it accepted by the DVD-Forum, the existing organization for support of the DVD standard. The companies supporting Blu-ray, which were also members of the DVD-Forum, managed to prevent this twice. But in November 2003 the DVD-Forum decided to officially support HD-DVD. The HD-DVD format became the focus of development in Working Group 11 of the DVD-Forum. Adoption by the DVD-Forum greatly enhanced the amount and diversity of companies that supported the standard; by March 2004, 79 companies were involved in Working Group 11. The DVD-Forum's Steering Committee approved Version 1.0 in June 2004. Subsequently, there were numerous follow-up changes. These were often 'optional specifications' that constituted small amendments to version 1.0.

Toshiba and NEC made an effort to gain commitment from movie studios with which they had a good relationship. In November 2004, three of the six major Hollywood studios announced that they would issue movies for HD-DVD. In December 2004, Toshiba, NEC, Sanyo and Memory Tech established the HD-DVD Promotional Group to provide additional momentum behind the standard and to enhance the development of content and hardware made in compliance with the standard. This increased support for the standard: by September 2005, 84 companies were participating in Working Group 11, and 110 companies in the Promotional Group.

In 2005, Microsoft and Intel, dissatisfied with Blu-ray, issued exclusive support for HD-DVD. Microsoft's software and hardware knowledge helped Toshiba with some minor changes to create a fully-formed playback system and special menu features. Microsoft decided to provide an HD-DVD drive as a separate add-on to its Xbox360 game console – a further diversification of HD-DVD's support network. The Xbox360 itself had been launched in November 2005, but only contained a traditional DVD drive.

In March 2006, Toshiba released their first HD-DVD player in Japan and, one month later, in the United States. In 2007, the HD-DVD camp increased efforts to obtain exclusive support from Hollywood studios, but Warner Bros. decided to exclusively support Blu-ray. As a result, in February 2008, Toshiba announced discontinuing production of HD-DVD products and the HD-DVD promotion group was dissolved in March 2008.

**Case analysis**

This case suggests three phases in the development of each of the two standards. In the first period, a limited number of companies from the same industry started developing the standard. In the second period, the initiators started adapting the standard and inviting companies from other industries. In this phase the standards battle took place. In the third phase, which started when Blu-ray became dominant, the network became stable although the standard continued to be adapted to new requirements.

The size and diversity of the two networks were initially similar, but the dynamics of the processes and the market shares of the network members in their respective industries were different. Some of Blu-ray's new members requested several substantial changes in the content of the standard. These changes also served to attract new members, particularly IT and movie companies, with a significant market share in their respective industries. Specifically the substantial changes that Blu-ray made to accommodate the requirements of the movie studios created higher commitment and support in that sector.

HD-DVD showed less dynamics (see Figure 70). Microsoft's involvement led to minor changes. By incorporating the DVD-Forum in the network, Toshiba and NEC created a large and diverse network, but this network was less committed since the standard had not been adapted to the requirements of the network members from the beginning. The reason for Toshiba and NEC's strategy of requesting adoption by the DVD Form was that they were later in the process of inviting other companies, and support by the DVD-Forum was the fastest way to build up industry support.

Other reasons for the difference in dynamics are firstly that HD-DVD had more technical limitations to modification than Blu-ray due to the initial choice to use DVD technology, and secondly because the development of HD-DVD started later than Blu-ray. Therefore Toshiba focused on completing the format and did not want to delay market introduction by modifying the format. HD-DVD eventually had the advantage of being slightly earlier to the market, and at a lower price, whereas Blu-ray's technical superiority was not a strong driver for consumer adoption. Thus, this case also shows that price, early timing of market entrance and technical superiority are of influence, but are not decisive. By being more flexible and adhering to some of the wishes of non-participating stakeholders, the Blu-ray supporters managed to bring these stakeholders on board with a high level of commitment; once on board they more often than with HD-DVD provided exclusive support to the format.

Table 22: Chronology of events for Blu-ray and HD-DVD

| **Blu-ray** | | **HD-DVD** | |
|---|---|---|---|
| Events relating to standard | Events relating to network | Events relating to standard | Events relating to network |
| | 1997: Sony and Philips (consumer electronics, disc replication and optical disc drive manufacturing) start development. | | |
| 2000: Preliminary record-only format finalized. | | | |
| 2001: Disc storage capacity doubles to 50GB. | 2001: Panasonic (consumer electronics) joins. | | |
| 2002: First version record-only format finalized, focus changed to read-only, additional copy-protection and region coding. | 2002: Six major consumer electronics companies join. | | 2002: Toshiba and NEC (consumer electronics, disc replication and optical disc drive manufacturing) start development. |
| 2003: Removal of disc cartridge, change in logical format, new video based application format. | 2003: Sony's computer manufacturing and movie studio join. | | |
| 2004: First version of read-only physical specifications finalized incorporating bare disc system. | 2004: Computer manufacturers (Hewlett Packard, Dell), optical disc manufacturer (TDK), Sony's game console department, movie studios (Walt Disney, 20th Century Fox) join. | 2004: First version of read-only and rewritable physical specification finalized. | 2004: Movie studios (Paramount, Universal and Warner Bros.) join. |
| 2005: Improved version writable and rewritable physical specification finalized, using bare disc system. | 2005: Hewlett-Packard (computer manufacturer) drops exclusive support. | | 2005: Software and game consoles (Microsoft), semiconductors (Intel), and computer manufacturer (Hewlett Packard) join. Warner Bros. and Paramount drop exclusive support. |
| 2006: Improved version read-only format, new video-based application format, additional copy protection and region coding. | | 2006: First version of read-only file system specification finalized. | |
| | | 2007: Storage capacity increased to 51GB. | 2007: Paramount provides exclusive support. |
| | 2008: Warner Bros (movie studio) exclusively supports Blu-ray. | | 2008: Warner Bros. (movie studio), Walmart, Bestbuy and Netflix (retailers) leave. HD-DVD promotion group is dissolved. |
| 2009: 3D functionality added. | | | |
| 2010: Writable format storage capacity increased to 100GB. | | | |

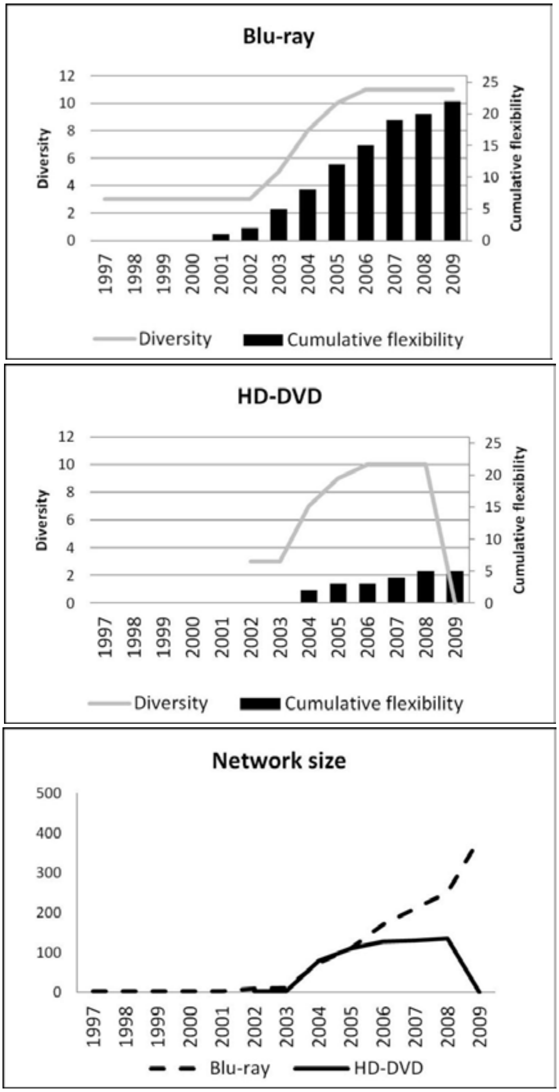


*Figure 70: Network size, diversity, and standard flexibility for Blu-ray and HD-DVD (Standard flexibility relates to the number of major changes only).*

## 6.5 Case study 2: Firewire versus USB

### Background

Peripheral computer devices such as speakers and webcams and products like digital cameras, requiring connection to the PC, arrived to the market in the 1990s. Two standards emerged specifying this connection, Firewire and USB. USB achieved dominance but Firewire continued to be used in specific niche markets (see Table 23 for a chronology).

**Firewire**

Apple started to develop its Firewire standard in 1986. The first version was ready in 1987. Apple submitted it to the Institute of Electrical and Electronics Engineers (IEEE) in order to obtain support for the standard. It was difficult for other companies to influence the further development of the standard because Apple sent many experts to the committee. One respondent noted: *"Apple was sitting on their core standard as a chicken protecting her egg; nobody was allowed to touch it."* In 1995, the standard was ratified as IEEE 1394. The consumer electronics industry perceived the need for greater bandwidth capacity and from 1995 companies such as Sony became involved. One respondent noted: *"People do not accept it when the television suddenly malfunctions whereas PC people accept it because they can press the reset button… Therefore, at the time, we chose the Firewire standard because we knew that this standard would always function properly"*. As a result, network diversity increased from one (Apple, computer manufacturers) to two (consumer electronics). Actors from other relevant industries such as semiconductors, pre-packaged software, and computer networking were not involved. In 1994, Apple established the 1394 Trade Association, open to all companies that wanted to implement the standard in their products.

In 2000, IEEE 1394a was ratified enabling higher efficiency and additional functionality (such as streaming). In 2002, IEEE 1394b was ratified, enabling a higher bandwidth capacity and reliable data communication over a longer distance. The intention was to make the standard appropriate for new areas such as home networking and automotive electronics. Some companies from those industries adopted the standard, which increased the size of the standard supporting network. Also, more computer manufacturers adopted the standard; their interest was driven by the standard's increased speed which could be used for the internal bus within the PC.

From 2002 to 2008, additional changes were incorporated in the standard which further strengthened the standard's position in its high bandwidth niche market. For example, in 2006, an interface specification was added which enabled interconnection with Ethernet-based Local Area Networks. The size and diversity of the support network remained stable.

**USB**

Intel started the development of the USB (Universal Serial Bus) in 1992. When, in November 1994, the standard was developed up to version 0.7, they decided to formally sign-up other companies. According to Intel's USB project leader: "*A personal computer is based on open interfaces, but the industry does not trust an 'open standard' developed by just one company*". Intel wanted the group's size small enough for rapid progress, but large and diverse enough to sufficiently represent the industry. Intel scheduled a meeting in which it invited several companies, including Apple, to present the specification they prepared. However, Intel did not want to further collaborate with Apple because of Firewire.

In March 1995, Intel established a two tier alliance; the USB Promotor Group (for developing and promoting the USB standard) and the USB Implementers Forum (open to a larger group of firms in order to create products and market momentum). The standard supporting network became diverse: semiconductors (Intel), computer manufacturers (Compaq, IBM), pre-packaged software (Microsoft), computer networking (Northern Telecom), and companies operating in several of these industries (DEC, NEC).

Between versions 0.7 and 1.0 there were no substantial changes to the standard; only details were refined. Version 1.0, launched in 1996, enabled a data rate sufficient for data communication between personal computers and peripheral devices. This capacity improvement satisfied the direct needs of the companies involved in the USB Promoter Group. In order to build industry momentum, the USB Promoter Group organized compliance workshops for peripheral suppliers and a conference for developers. This resulted in the rapid increase of members in the USB Implementers Forum. New companies, including suppliers of personal computers and consumer electronics, were invited to participate and suggest changes in the standard. This led to several extensions to the standard. One respondent noted: *"If we can think of a couple of applications for the standard and establish working groups for these applications, then automatically the standard will be implemented in more products"*.

USB version 1.1 was introduced in 1998 to increase USB applications and make the standard fit for audio, voice and video by increasing data rate. As a result, Philips (consumer electronics) and Lucent (telecommunications) joined the USB Promoter Group in 1999. Their membership increased network diversity and the legitimacy of the standard in the eyes of potential adopters. New participants became involved in the further development of the standard. The USB representative at Philips noted: "*In USB 1.1, it was certainly not possible to get a good quality audio signal over USB. In that respect Philips certainly contributed to the standard. We also contributed to making the USB hub more robust.*" As a result, more consumer electronics companies chose to adopt the standard.

In 2000, USB version 2.0 was introduced, enabling an even higher data rate. As a result, many companies from different industries including consumer electronics, digital photography, and data storage chose to adopt USB for products such as video peripherals and hard disks. After 2000, additional functionality was added to the standard through many changes (e.g., battery charging functionality through USB, and the possibility for USB peripherals to communicate directly with each other). As a result the standard attracted many producers of complementary products (including MP3 players, external hard drives, and mobile phones). The number of companies supporting the standard grew from 600 in 2000 to 900 in 2002. After 2002, the number of supporting companies remained constant. Since 1999, the diversity in the Promoter Group has also remained more or less constant; some parties left the group while others joined.

**Case analysis**

Also in the case of Firewire and USB, the three phases can be distinguished. Single companies, Apple and Intel, started the development of the two standards, Firewire (1986) and USB (1992) respectively. In the second phase, after one or two years, each standard initiator decided to seek broader support. Apple did this by participating in IEEE. Consumer electronics companies in need of high capacity joined and the group upgraded the standard (higher data rate). The 1394 Trade Association was established to bind implementing companies together, and membership grew steadily. However, the dominant role of Apple and its reluctance to allow major changes in the standard hampered other companies in coming up with suggestions to improve the standard. As a consequence, the group did not take full advantage of the opportunities of attracting other actors to the network. Figure 71 shows that the number of changes remained relatively low, while network diversity and size were lower for Firewire than for USB. Nevertheless, the standard acquired sufficient support to maintain a foothold in the high bandwidth niche market.

Intel aimed for a cheap standard with a broad application. It was more active in its attempts to extend the network. Figure 71 shows that they allowed many more modifications and were more successful in terms of size and diversity of the network. The standard supporters also created a separate "Implementers Forum" and actively invited parties to propose modifications of the standard. This strategy resulted in the network's growth in both size and diversity as well as growth in the standard's market use. The case thus confirms our expectation that changes in the standard can facilitate the growth of network size and diversity, and thereby increase the standard's chances of success. But the case also shows that the attitude and behaviour of the dominant actor or actors with respect to flexibility can have substantial influence.

The process came to a halt around 2002 when the growth in size and diversity of the networks of both standards ended, entering the rather stable third phase. To date, USB outperforms Firewire considerably in market share, but Firewire keeps its niche. Users can choose between the two standards although in most cases they opt for USB. Only in some cases of high bandwidth capacity Firewire is preferred. After 2002, both standards continued to change and we cannot exclude the possibility that future upgrades of USB may affect Firewire's position and vice versa.

Table 23: Chronology of events for Firewire and USB

| **Firewire** | | **USB** | |
|---|---|---|---|
| Events relating to standard | Events relating to network | Events relating to standard | Events relating to network |
| 1987: First version finalized. | 1986: Apple (computer manufacturer) starts development of Firewire. | | 1992: Intel (semiconductors) starts development of USB. |
| 1995: Data rate increases to 400 mbps. | 1995: Consumer electronics industry (e.g. Sony) joins. | 1994: First version USB finalized.<br>1996: Data rate increases to 1.5 mbps.<br>1998: Data rate increases to 12 mbps. | 1995: Computer manufacturer, pre-packaged software, and computer networking industry join. |
| 2000: Changes incorporated enabling higher efficiency and additional functionality such as streaming.<br>2002: Date rate increases to 3200 mbps. Changes incorporated to enable more reliable data communication over longer distance.<br>2006: Changes incorporated enabling interconnection with Ethernet-based Local Area Networks. | | 2000: Data rate increases to 480 mbps.<br>2006: Functionality added to enable USB peripherals to communicate directly with each other.<br>2007: Battery charging functionality added.<br>2008: Data rate increases to 5000 mbps. | 1999: Consumer electronics (Philips) and telecommunications (Lucent) industry join. |

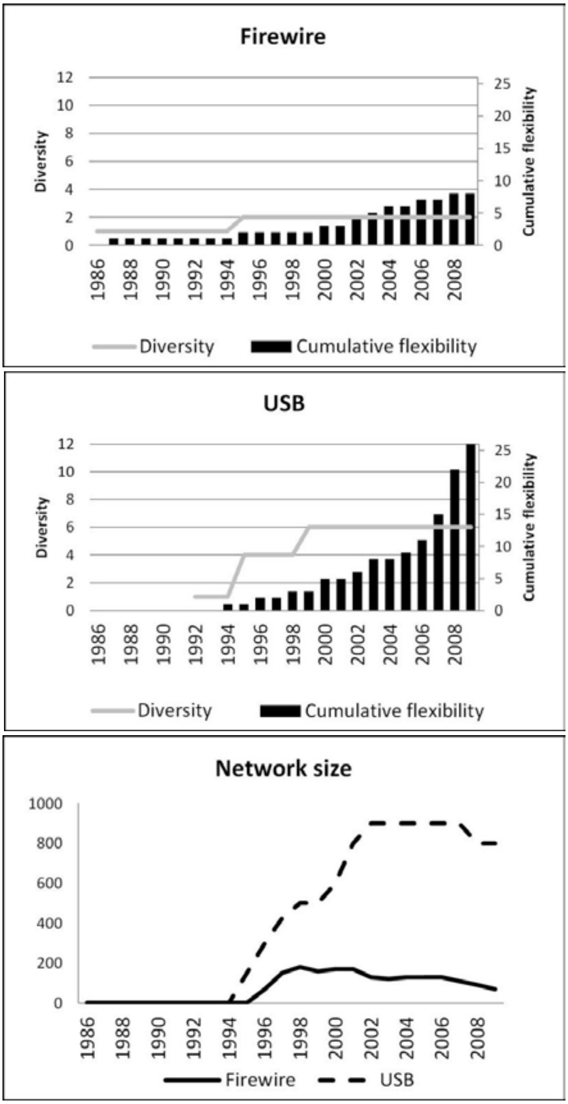


*Figure 71: Network size, diversity, and standard flexibility for Firewire and USB (Standard flexibility relates to the number of major changes only)*

## 6.6 Case study 3: WiFi versus HomeRF

### Background

The third case describes the battle between two standards for commercial wireless data communication: WiFi and HomeRF. The battle resulted in a clear winner: WiFi has become the dominant standard for wireless networks in homes and offices (see Table 24 for a chronology).

**WiFi**

In 1985, the Federal Communications Committee (FCC) passed a ruling which made commercial wireless data communication possible in the US. This triggered National Cash Register (NCR) to begin a study into the feasibility of a wireless radio for cash registers sold in the US. The goal was to achieve the highest possible bandwidth capacity so that wireless communication would feel like wired communication. The data from the banking terminals and cash registers had to be downloaded in the morning. The project leader explains: *"When you come in with a wireless solution and you say that you could move the cash registers around anywhere you want that's fine, but you can't say 'And by the way when you turn it on in the morning you will have to wait for half an hour'."* A small team of engineers worked on succeeding prototypes.

In 1988, NCR engaged with the IEEE to identify an appropriate wireless protocol for the standard. In 1990, the IEEE 802.11 working group was established. From 1990-1997 mostly computer manufacturers (such as IBM) and computer networking manufacturers (such as NCR) were active on the committee. The standard was finally approved as IEEE 802.11 in September 1997. In 1998, Breezecom joined, later followed by other telecommunications companies (such as Nokia and Motorola). This increased network diversity. Earlier, work had started on two specifications for a higher bandwidth capacity. Wireless data communication was possible in two frequency bands, low and high. In some countries, the low band was reserved for other purposes and the only option was to use the high band. In France, for example, the organizers of the Tour de France had exclusive access to the low band. At the November 1996 meeting, two projects were established: project 802.11b for a low bandwidth capacity over longer distances in a low band and project 802.11a for a high data rate over shorter distances in a high band. These revisions, enabling speeds of 11 megabit per second (mbps) and 54 mbps, were approved in December 1999 and January 2000, respectively. The IEEE 802.11 committee chairman explained the importance of increased bandwidth capacity: *"At that time Ethernet* [a wired alternative for WiFi] *already guaranteed a data rate of 10 mbps so consumers perceived the data rate of 2 mbps to be too slow. To respond to their wishes we began work on an extension for a higher data rate."* The former CTO of NCR added to that: *"We were always trying to keep up with the wired equivalent of the LAN. […] You always had this sort of data rate hungry appetite."* The increased bandwidth capacity attracted many companies to the standard. In 2000, the diversity in the network increased further as consumer electronics companies (such as Philips and later Samsung) joined. In 1999, the Wireless Ethernet Compatibility Alliance (WECA) was established in order to promote the standard and certify products. This further increased network size.

From 2000 onwards, many companies became active in the IEEE 802.11 committee and established different task groups which each worked on several enhancements to the IEEE standard. The committee also specifically invited firms to form task groups to ensure that certain required changes would be incorporated in the standard. As the chair of IEEE 802.11 commented: *"We began with a standard that worked, then you can adapt that standard and by doing so create a larger market for it. […] Through these changes the number of applications that can make use of the standard increases and so more companies joined*". Many revisions were developed which resulted in an increase in complementary products that could make use of the standard and subsequently in an increase in the number of companies that adopted the standard. Also, network diversity continued to increase. In 2002, the pre-packaged software industry (Microsoft) joined and in 2003, the aircraft industry (Boeing). Boeing wanted to use WiFi in its manufacturing process. However, for them the connection had to be more reliable as planes are built in an environment with a lot of reflections creating background noise. After 2003, the diversity in the network remained constant over time while the size of the network gradually increased.

**HomeRF**

In 1997, Intel established the Home Radio Frequency Working Group to develop a standard for wireless communication of both data and traditional telephone signals. At that time, WiFi was not fit for providing home telephone applications of sufficient quality. Working group participants covered semiconductors (Intel), pre-packaged software (Microsoft), computer manufacturing (e.g. Compaq), telecommunications (e.g. Ericsson) and consumer electronics (Philips). From 1997 to 1998, several meetings were held resulting in a first standard (version 1.0). As one respondent notes: *"The initial meetings were very open, everybody was encouraged to work on the first HomeRF specification with the rules of the FCC that, at that moment, applied.[…] The development process was very efficient and quick; there was little friction between the members as they were highly committed."* The FCC rules implied that the bandwidth for 'Frequency Hopping' could reach a limited capacity. The HomeRF workgroup chose the 'Frequency Hopping' modulation technology instead of the 'Direct Sequence' modulation technology since devices that implement 'Frequency Hopping' are cheaper, use less power, and are more reliable. In that respect they were not as flexible as WiFi which chose to support both modulation technologies in its standard.

Later, HomeRF meetings were less efficient. As one respondent noted: "In later meetings some of the big firms in the developing process had some serious doubts about the standard. […] They disagreed about the standard". As a consequence, it took a long time before the members could agree on additional changes to the standard. In 1999, Philips left the group, followed in 2000 by Microsoft. The main reason for departure was that the choice to stick to the 'Frequency Hopping' modulation technology could not provide them with the higher bandwidth capacity they required.

In 2000, the FCC changed the rules for frequency hopping enabling higher bandwidth capacity. Following that decision, the Working Group started to develop a new generation of the standard. However, as one of the members noted: *"The FCC ruling came just too late for us"*. Indeed, by the time HomeRF 2.0 was introduced (2001), WiFi had also been upgraded sufficiently. Intel left the group causing many companies to follow. Eventually, the Working Group was disbanded.

**Case analysis**

The development of the WiFi standard started in the second half of the 1980s, when NCR saw a business opportunity in developing a solution for wireless interconnection. Around 1988 they recognized that they needed others, primarily for knowledge (protocols), and engaged with IEEE, which formed a working group. The diversity of the group was relatively low, but nevertheless it had difficulty making decisions. As Figure 72 shows, the group needed six years to develop the standard. Due to the lack of diversity, this standard did not meet all market needs.

In 1997, Intel initiated the development of a competing standard for high-quality wireless phones at home. They immediately involved other companies and together established a consortium. They invited more companies so they were fast in establishing a broad and diverse network. This triggered the IEEE committee working on WiFi to create additional organisational opportunities for participation: anyone could propose changes and form 'task groups' to address the proposed changes. As a result, participation increased in both numbers and diversity. However, while HomeRF had a jump-start with highly motivated participants, the group gradually faced more problems in achieving consensus; they became too slow in upgrading the standard. They stuck to their initial technological choices resulting in a standard that enabled a comparatively lower bandwidth capacity in only one frequency band. WiFi, on the other hand, was more flexible; it chose to support two modulation technologies in its standard instead of one and developed a standard for both of the available bands. Furthermore, they not only – like HomeRF – sought improvements in bandwidth capacity, but also in other functionality. As a result, many companies left HomeRF and chose to support WiFi. Size and diversity of the HomeRF network decreased considerably. The companies that left HomeRF chose to adopt the WiFi standard, contributing to its dominance. It made no sense for HomeRF to continue, the consortium was dismantled. This marks the start of the third phase, in which, as Figure 72 shows, work on improving WiFi continued and its network grew further in size, but not in diversity.

So, both standards initially obtained a similar network diversity. The explanation for the higher success of WiFi and the failure of HomeRF is mainly related to the flexibility of the standard. Due to lower flexibility, industries left HomeRF, and the use of the standard diminished.

Table 24: Chronology of events for WiFi and HomeRF

| **WiFi** | | **HomeRF** | |
|---|---|---|---|
| Events relating to standard | Events relating to network | Events relating to standard | Events relating to network |
| 1997: First version WiFi finalized. | 1985: NCR (Computer networking) starts development of the standard.<br><br>1990: Computer manufacturer industry (e.g. IBM) joins. | 1998: First version HomeRF finalized. | 1997: Intel (semiconductors) starts development of the HomeRF standard together with firms representing pre-packaged software, computer manufacturing, telecommunications, and consumer electronics industries. |
| 1999: Data rate increases to 11 mbps (over the low band). | 1998: Telecommunications industry (Breezecom) joins. | | 1999: Consumer electronics industry leaves. |
| 2000: Data rate increases to 54 mbps (over the high band). | 2000: Consumer electronics industry (Philips) joins. | 2001: Data rate increases to 10 mbps. | 2000: Pre-packaged software industry leaves. |
| 2003: Data rate increases to 54 mbps (over the low band). | 2002: Pre-packaged software industry joins.<br>2003: Boeing joins. | | 2003: Network disbanded . |
| 2004: Changes incorporated to resolve security issues and to support more frequencies.<br>2005: Functionality (streaming) added.<br>2008: Changes incorporated: higher efficiency (reduced power consumption) and additional functionality (fast roaming).<br>2009: Data rate increases to 600 mbps. | | | |

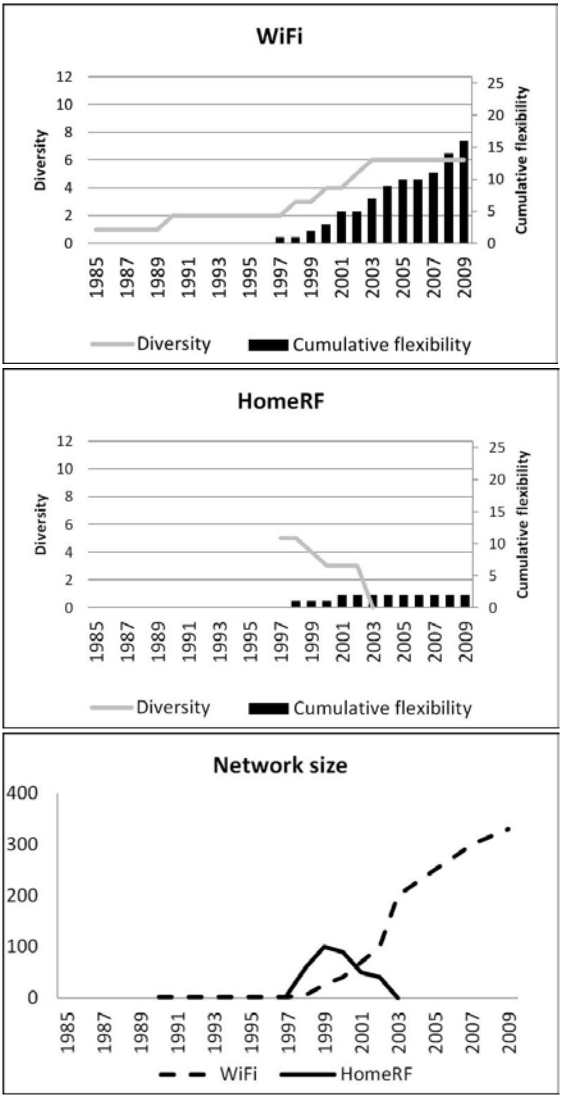


*Figure 72: Standard flexibility, network diversity, and network size for WiFi and HomeRF (Standard flexibility relates to the number of major changes only)*

## 6.7 Cross-case analysis

The cases show that the evolution of each standard was characterized by three phases. In the initial phase, one or a small group of firms, often from a single industry, took the initiative to develop the standard. In the second phase, they invited additional companies, often from a diverse set of industries, to support the standard. In this phase, the more successful standards (Blu-ray, USB, and WiFi) show a strong increase in the size and diversity of the standard supporting network. More than their competitors, the networks of standard supporters each made substantial changes to the standard. As a result, new actors joined. In the case of Blu-ray, firms in the consumer electronics, disc replication and optical disc drive manufacturing industry started the development, but adaptations of the standard helped to include companies from the computer manufacturing industry and movie studios. In the USB case, a company from the semiconductor industry started the development, later joined by other companies from other industries and the standard was modified to include consumer electronics and telecommunications firms. In the WiFi case, companies from the computer networking industry started the development, but they managed to involve consumer electronics and other companies by adapting the standard. The additional companies were invited at a point when they could have sufficient influence on the specifications; the standard still had substantial development flexibility. These companies subsequently collaborated to develop improved versions of the standard. In the third phase, both the support network of the standard and the market position of the standard were relatively stable (dominant, surviving or disappearing).

In the cases of the less successful or failed standards, the dynamics between flexibility of the standard and size and flexibility of the network took place to a lesser extent. Firewire lacked flexibility, network size and diversity, explaining its minimal success. The strategy of Apple as the dominant actor was the main reason. In both of the other cases, the degree of diversity of the networks supporting the failed standards (HD-DVD and Home RF) was relatively high but the flexibility of the standard remained low. In the case of HD-DVD, the main reason was the initial choice to make use of existing DVD technology (for reasons of Intellectual Property Rights (IPR)), which limited flexibility considerably. The higher flexibility of the Blu-ray standard led to higher commitment. In the HomeRF case, the actors valued aspects such as reliability of the data connection more than increasing the data rate whereas the latter turned out to be decisive for market acceptance. As a result, important actors left the HomeRF WG and joined WiFi instead. So, in this case the initial diversity did not lead to flexibility and thereby diversity did not continue to grow over time.

## 6.8 Discussion and conclusion

This paper focuses on the relationship between standard flexibility and network evolution. We investigated the reciprocal relation between changes in standards and changes in interorganizational network size and diversity. We made an exploratory study of three cases of standards battles. In each, we investigated the networks of the two most prominent standards in the battle.

Our cases provide clear support for the existence of a reciprocal relationship between standard flexibility and network formation. Successful standards showed more dynamic interactions between standard flexibility and network formation, in particular during the second phase of the process. The paradox of standard flexibility appeared to entail that flexibility involves a temporary instability of the standard, but contributes to the standard's acceptance which results in stability. Changes in the standard's contents led to the inclusion of new actors in the network; often from new industries, thus increasing both the size and diversity of the network. In some cases, these changes were made with the deliberate intention of attracting new companies, and then often the changes in the standard and in the network took place simultaneously. In other cases, the extension of the network occurred later (e.g., Boeing in the WiFi case). Network extensions sometimes led to further adaptation of the standard's contents in order to meet requirements of existing and potential new network members. This process created a spiral co-evolutionary process of standard flexibility and growing network diversity, leading to increased network size. In the case of Blu-ray, standard flexibility also appeared to increase actors' commitment, strengthening the ties in the network as compared to the competing HD-DVD case. For the less successful or failed standards the co-evolutionary process took place to a lesser extent, for different reasons. In the Firewire case, the central actor, Apple, allowed only for minimal changes to the standard, and as a consequence the network did not grow sufficiently to make the standard a real success. In the HD-DVD case, initial choice of technology was the main reason. In general, our cases show that creating the reciprocal evolution between standard flexibility and network formation is key to the success of the standard. We visualized the most important relations in this process in Figure 73. We did not include the effects of flexibility on commitment of actors, since the Blu-ray case is the only one in which we clearly observed this effect.

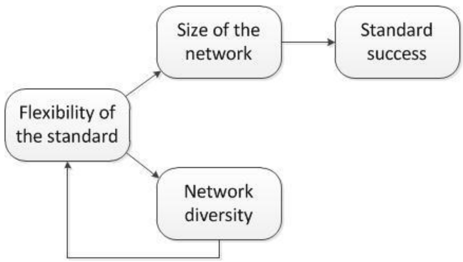


*Figure 73: Relations between flexibility, network characteristics and success.*

Our cases suggest that early timing of the co-evolutionary process between standard change and network build-up was important for the outcome of the battle, and even more important than an early start of the standardization process itself (Takahashi and Tojo[496]). In two cases, Blu-ray and USB, the standard network that was earlier in engendering the relationship between standard flexibility and the network achieved dominance. Firewire started much earlier than USB, but still USB was more successful. In the third case, WiFi started earlier but initially made hardly any progress. The start of HomeRF triggered the WiFi consortium to become more active and, better than HomeRF, create the dynamics between flexibility and network formation.

We also observed an increasing degree of path dependency in the evolution of the standards. In the first phase, the initiators had a broad range of options for the standard. In the second phase, the room for choices in the standard's specifications was still clearly available, but diminished for three reasons. First, existing network members and market applications of the standard, and the growing diversity of the members, limited the range of options. This is the reason of lock-in (Arthur[497]). For instance, we saw that the Blu-ray Disc Association did not adopt technology from Microsoft because the new technology conflicted with the interests of some of the already committed companies. Second, inherent inflexibility of standards themselves could restrict changes in this phase (Egyedi and Blind[498]; Thomke[499]). Inherent inflexibility refers to the lack of capacity to change functioning (De Haan et al.[500]) resulting from the technical specifications laid down in the standard, which limit the room for later adaptations. Inherent inflexibility is established at the start of the process and potentially causes a tradeoff: in the beginning it may create an advantage in the price of the products or a shorter time-to-market due to simpler product development. This may increase the standard's initial success. However, in the second phase of the process, inherent inflexibility limits the standard consortia in developing and changing the standard specifications to address the needs of new product and market combinations. For example, in the case of HD-DVD, a large and diverse group of firms were included in the network of the standard, but the choice to base the HD-DVD on DVD technology limited standard flexibility. The standard could not provide the level of interactivity and security preferred by movie studios, and consequently the network co-evolution process hardly took place. Third, our cases showed an example of restriction of the number of alliance members to keep decision-making manageable (Das and Teng).[501] In the USB case, Intel preferred the group to remain small. This also limited the co-evolutionary process between standard flexibility and network formation. However, the USB consortium solved the problem by creating a parallel group to implement the standard (the USB Implementers forum). In Phase 3, the room for changes in the standard was lowest. Particularly market implementations limited the room for change in this period. Nevertheless upgrades continued, sometimes in the form of variations next to the main standard.

We see that the networks of organizations supporting the standard were one of the reasons for the emergence of path dependency, particularly in the second phase of the process. Over time, the increasing installed base of network partners that have implemented the standard limited the freedom to adapt the standard, and thus flexibility. Standards, by definition, are intended and expected to 'freeze' a solution and thus to stabilize after a certain period (De Vries[502], Verman[503]). In this paper we show that the flexibility in the process before the freeze is most influential on success.

**Theoretical implications**

Our results have implications for the standardization and general network literature. The standardization literature recognizes that the size and diversity of the network are important for standard success. For instance, Cusumano et al.[504] showed that size of the network contributes to standard success because network members use the standard leading to a higher installed base. Others have shown that the size of the network also signals market support causing others to follow (Katz and Shapiro[505]). Rosenkopf and Padula[506] studied the evolution of standardization networks but did not include the effects on the success of standards. Our study confirms the effects of networks on outcome, but shows that the content of the standard itself contributes to network formation. Some authors have already investigated the relation between diversity and content of standards. They argued that a diverse network contributes to reflecting the needs of more different user groups in a standard's content, and that a more user-oriented standard will attract more supporters and products, and generate better sales (Cargill[507], Evans et al.[508], Lundval[509], Markus et al.[510]). However, these authors apply a static perspective in the sense that they suggest that diversity would be required at the start of the standard development process to exert its one-time positive effect on the standard contents. We add by showing that the relation between diversity and standard contents is dynamic and develops in a co-evolutionary manner over time. We even show that networks of organizations supporting a standard do often start from a single industry and that only in the second phase diversity increases while the standard is modified. In doing so, we follow Rosenkopf and Padula's[511] recommendation to connect network evolution to technological trajectories.

Remarkably, data from earlier case descriptions in the standardization literature (Funk[512], Schmidt and Werle[513]) implicitly illustrate the dynamics addressed in this paper. However, the authors do not reflect on the influence of the change on the acceptance of the standards. For instance, Cusumano et al.[514] mention that Sony adapted the Betamax standard (to facilitate two hours playing time) before seeking new partners. In this case the change in the standard prolonged the life of the product, but didn't rescue it in the longer term, which partly justifies the lack of attention for it by the authors. In a study of conflict resolution in standardization processes, Schmidt and Werle[515] mention that in the battle for the fax standard, one of the consortia, led by Matsushita and NEC, increased support for its solution by including a specific modulation system. The authors do not mention this change in the standard when they discuss the reasons for the dominance of the standard. Leiponen[516] shows that firms propose changes to standards in an attempt to influence the contents of the standard to their own advantage but not as a strategy to create dominance of that standard in competition with other standards. The same emphasis on competition between committee participants is given by Funk[517] who describes that in the development of the GSM standards for mobile telecommunications deliberately German and French technology was added to the initial standard specification to enlarge the network with firms and governments in those countries. Both were essential for common European support for the standard. These examples suggest that the dynamics addressed in this paper are more widespread in standardization processes, but are often interpreted only as competition within committees and not as part of the dominance battle between that standard and competing ones.

Another contribution of this paper to the standardization field relates to the topic of Funk's[518] study, the distinction commonly made between coordination via 'committees' and 'markets'. Committees involve explicit communication and negotiation before irrevocable choices are made. The market mechanism involves no explicit communication and depends on unilateral irrevocable choices: it succeeds if one agent chooses first and the other(s) follow(s) (Farrell and Saloner[519]). Our cases show that this distinction does not hold – agreement in a committee does not guarantee market acceptance, since also committee standards may have to compete for acceptance in the market. Leiponen[520] has already shown that committees and consortia complement each other in standards development, but she only shows how consortia served as preparation of committee decisions. In her cases, those decisions were final. Our study shows that committees and consortia may also compete in the market, that committees and consortia sometimes support the same standard in the battle, and that committees are not necessarily the winners. Both committees and consortia are networks as such and may be part of a larger network including non-members of the committee or consortium. The strength of this overall network is an important factor for success.

Our findings are relevant for the literature on path dependency (Arthur[521], Shapiro and Varian[522]). While that literature has concentrated on the economic mechanisms behind path dependency of standards, we focus on the role of the networks of organizations supporting a standard. Amongst others, we demonstrate that existing network members pose their requirements with respect to standards, in that way creating path dependency during the development process. We also showed how we can recognize three different phases in this process, similar to the three phases that Sydow et al.[523] distinguish. The similarity of our phases with the ones of Sydow appears mainly from the scope of action in each phase: broad in the first phase, a narrowing range of options in the second phase, and lock-in in the third phase. We contribute to their theory in several ways. First, we show that concrete mechanisms, particularly interorganizational networks and their characteristics and inherent inflexibility, are antecedents of the diminishing scope of action in the different phases, so of the path dependency process. Second, we show that networks are not a simple cause of the scope of action, but that choices made within this scope (changes in the standards) strengthen the network. And thirdly, while Sydow et al.[524] demarcate the first phase from the second by means of a rather unspecified 'critical juncture', we defined the transition between the phases based on changes in the diversity of the standard supporting network. In the first phase a limited group of actors use their freedom to define a first version of the standard, the second phase shows the dynamics between involving more diverse stakeholders and adapting the standard, and in the third phase there is less or no adaptation of the standard and the stakeholder network is stable.

Our study also contributes to the investigation of the network-outcome dynamics in the general network literature. Two types of network outcomes can be distinguished: the definition of the object to which the network refers (the standard, a research project, an NPD project, a commercialization project) and the degree of success of the network. Our project investigates the influence of changes of the first type of outcome, in our case the contents of the standard, on network characteristics, and thereby on the type of second outcome, the success of the network. The literature on networks of organizations is paying attention to the formation process of networks. For instance, Doz et al.[525] explored the relations between environmental elements, partner behaviors and performance in the formation process of networks, but did not address the network-outcome dynamics. This network-outcome dynamics may also be evident in other areas of network collaboration, such as NPD alliances, where adapting the product design may help to interest new partners in the alliance and increase commitment. Another contribution of our study to this field concerns the effects of diversity of networks. Both positive effects of network diversity on performance (Brass et al.[526]) and U-shaped relationships have been found in the literature (Jiang et al.[527]). Our study supports the first view by suggesting a positive effect of industry diversity on performance in the context of networks of organizations supporting a standard.

Finally, this paper contributes to the literature on co-evolution. Several authors have emphasized co-evolution between firm behavior and firm environment (Lewin et al.[528], Koza and Lewin[529]). Authors in this field hold that firms have reciprocal relationships with their environment, leading to specific outcomes. Our paper contributes to this literature by addressing not just co-evolution between developments between single firms and their environment, but the interaction between the development of networks of organizations and one of the main outcomes of those networks, the changing contents of standards. As indicated above, we also address the endogenous and exogenous forces that bring the co-evolutionary process to a stable state.

**Implications for practice**

The outcome of standards battles depends on the amount of industry support for the standards, including a willingness from manufacturers to use the standard for their products and customer decisions to buy these products. These groups differ in the needs they may have. Our study shows that it is important to involve a variety of manufacturers and in some cases also professional customers (see our example of Boeing) in the development of the standard; and, if necessary, to adapt the standard to meet their requirements. This can be done before they belong to the network, in order to persuade them to join, but also once they have joined opportunities to propose modifications (such as upgrades) to the standard should be provided. Our study shows that the adaptations of standards over time should not be considered an unwanted side-effect, but an integral part of the standardization process – a part that should be carefully managed.

Our study indicates the importance of timing. Being early to incorporate changes appears to be important for success, and potentially more important than just early timing of market entry (Schilling[530]). The phases we distinguished may be helpful in this respect. They suggest that it may be appropriate to make a jumpstart with just a few actors who possess essential know-how than with a bigger and diverse group. However, the latter is essential to prepare for broad market acceptance and to avoid that essential stakeholders join a competing alliance. Thus, the process of expanding the initial network and adapting the standard (Phase 2) should be started early. The network can then be gradually extended further – the required speed also depends on what the competing standards alliances, if any, do. Creating a layered network structure in which modifying activities on the standard are separated from standard promotion keeps the processes manageable. Flexibility of the standard may be hindered by inherent technical limitations and therefore it makes sense to be aware of possible later changes in the standard when making initial technical choices. It may be a disadvantage in the beginning (higher costs), but an advantage in later phases. During the third phase, adaptations may be needed to keep pace with technical progress and keep the standard attractive to the members of the alliance, but the implications of modifications for the network become less prominent in that phase.

**Limitations and future research**

Of course this study has its limitations. One limitation concerns our measures. In our description of our cases, we distinguished minor versus substantial changes in standards. Although we asked our respondents about the significance of every change, we had no hard criterion to make the distinction. Future research should develop more objective measures regarding the size of standard changes. For instance, this set of measures could be based on an analysis of the technical contents to come to an even better understanding of the influence of standard flexibility.

A second limitation of this study was its exploratory nature. As such, we performed in-depth case-studies. Future research should validate our findings with large scale empirical research. More longitudinal studies are needed which include other elements, such as additional, structural network characteristics, power relations in networks (Knoke[531]), technological developments and changing customer requirements over time.

As a third limitation, we focused on two characteristics of standard networks – diversity and size. We briefly touched upon a third characteristic, tie strength, when discussing the role of commitment in the Blu-ray vs. HD-DVD case. Future studies should also address the relation between other network characteristics and network outcomes. An interesting avenue for future research in this line is to further investigate the roles of committee networks versus consortia networks. As we indicated above, these are not separate worlds, but these two standardization processes co-exist and interact, and some parties may be a member of the two types of networks, creating ties between them. An interesting question concerns the effects of these two types of networks and their interaction on standard success. Also the role of the layered network structures mentioned above can be integrated in such studies.

Fourth, our study was confined to compatibility standards, which define interrelations between entities in order to enable them to function together. Typically, such standards describe a solution whereas other types of standards may provide performance criteria or a method for measuring. However, we expect that our findings also apply to such types of standards and we see no reason why there should not also be a reciprocal relationship in the evolution of these standards. For instance, the recently published international standard ISO 26000 on corporate social responsibility is intended to bring unity between different, but similar standards on social responsibility. Consumer representatives united in ISO's Consumer Policy Committee ISO/Copolco – a rather homogeneous group – initiated ISO 26001 in 2001. The drafting process started in 2005 and involved a diverse group of stakeholders, such as nations, firms, and research institutes, adapting the standard over time (Frost[532]). This standard has been modified to make it more acceptable for a variety of stakeholders. For instance, industry representatives were afraid that governments would refer to this standard in future legislation so that they would be forced to meet CSR requirements. In order to get them involved it was decided from the outset that this standard should be a guidance document only, that it should not be used as a basis for certification and that it should thus not be appropriate for reference in laws. This also had consequences for the contents, which was not allowed to resemble the existing management system standards. The relevance of our findings for such categories of standards is an interesting topic for further research.

Extensions of this study do not have to be confined to standards, but may also concern new product designs. The literature on new product development has emphasized the importance of flexible product designs during development as a means to adapt to changing customer requirements and new technological knowledge (Garud et al.[533], Kamoche and Cunha[534]; MacCormack et al.[535]). However, while this literature focuses on reactive adaptation to changes in the environment, particularly with respect to user requirements, we focus on modifications (in standards) to shape the environment and the network of actors supporting the standard. In this way, the network of supporting actors can create new markets for products in which the standard is implemented. This topic also deserves attention in research on new product development, since firms can include complementary product developers and specific user groups by adapting the product design.

## 6.9 Epilogue: Reflection on the limitations of the integrative framework

The findings from this Chapter indicate the integrative framework has two limitations.

Firstly, little is known about the nature of the relationships that are shown in the framework. From the body of literature, both Hill[536] and Garud et al.[537] found that collaborative technology development has a positive effect on the organizational community of technology supporters, but little is known beyond that. This Chapter has shown there is a reciprocal relationship between the measure of modifications to a compatibility standard, and the diversity of the organizational community supporting the technology, which subsequently leads to a greater size of the organizational community. As such, this part of the integrative framework appears to be very dynamic.

Secondly, when investigating relationships in more detail it can become useful to split-up an element in sub-elements. In this Chapter, the element of 'organizational community of supporters' was split into two determinants; 'size of the network' and 'network diversity'.

## References Chapter 6

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## Prologue Chapter 7

As explained in Section 1.5, with the upcoming Chapter the limitations and comprehensiveness of the integrative framework are further investigated by 'zooming in' on a single element and its position in the framework. I decided to study a new element; accessibility of intellectual property rights. There are three motives for this selection:

- Firstly, I took into account the relevant themes in academia regarding de-facto standards in 2012. This resulted in aligning the selected element with a special issue of the prominent management journal 'California Management Review' on 'intellectual property management'.
- Secondly, the topic of intellectual property has an interesting link to the findings of Chapter 6. One of the main findings from Chapter 6 is that a higher measure of collaborative technology development leads to a larger organizational community of supporters. However, the higher the measure of collaborative technology development, the more the intellectual property on the technology is fragmented over its contributors, and the more difficult it becomes for companies to obtain access to the intellectual property and join the organizational community of supporters. So one element that has a positive impact on the size of the organizational community may have a negative effect on another element that could impact the size of the organizational community. This matter requires further investigation.
- Lastly, the topic of intellectual property rights was traditionally underappreciated in the body of literature on de-facto standards. Efforts have focused on appropriability: a firm's ability to protect its innovation from imitation. Appendix 1, no.3, provides a synthesis of the literature on de-facto standards regarding appropriability.

The upcoming Chapter investigates the measures taken by technology sponsors to make their intellectual property rights accessible, in order to facilitate the growth of an organizational community of technology supporters. In addition, the impact of an increasing degree of collaborative technology development on the accessibility of intellectual property rights is studied.

In order to study the accessibility of intellectual property rights, a multiple case study was conducted. First, three de-facto standards where technology sponsors were successful in enhancing the accessibility of their intellectual property rights (i.e. three generations of optical disc technologies: Compact Disc, DVD, and Blu-ray) were studied. Subsequently, two de-facto standards were studied from a different industry where technology sponsors were unsuccessful in enhancing the accessibility of their intellectual property rights: UMTS and LTE, two generations of mobile telecommunications technologies. The material on the latter two cases was written as part of one of the drafts of the paper for California Management Review, but on recommendation of the editors omitted in order to give the paper a clearer focus. Therefore, this information had been allocated to the epilogue of this chapter (Subsection 7.5.1.).

# Chapter 7 - Managing Intellectual Property using Patent Pools: Lessons from three generations of pools in the optical disc industry

## Published in California Management Review, 55 (4), 2013, pp.31-50

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The development of consumer electronics, telecommunications, computer and related high-tech industries is defined by a myriad of technologies. Increasingly, these technologies involve numerous blocking patents owned by multiple patent owners. A recent example is the competition between three prominent smartphone operating systems: iOS, Android and Windows Mobile.[538] The companies that developed these operating systems use patents to make the other platforms more expensive and spread uncertainty among app developers. When a technological field develops through the contributions of many entities, negotiating the number of requisite patent licenses may become inefficient and too costly for users. To solve this issue, which is inevitable for any area where many parties invest in research and development, companies increasingly employ a patent pool licensing model. A patent pool aggregates intellectual property rights (IPR) for the purpose of joint licensing. It is an innovative business model to enhance technology adoption and IPR monetization by facilitating the interaction of multiple licensors with many licensees. This paper analyzes the conditions for successful patent pools by examining three generations of patent pools in the optical disc industry. We observe that patent pools are becoming more and more sophisticated. The current state of the art is the novel 'pool-of-pools'. We present a generic framework to guide strategy and innovation managers in establishing and managing a patent pool through the four phases of its lifecycle.

## 7.1 Using patent pools to facilitate market adoption and appropriate IPR

Companies have been pooling patents since the mid-1900s.[539] However, due to anti-trust scrutiny, the concept was nearly abandoned until in 1995 the U.S. Department of Justice (DoJ) issued new intellectual property guidelines that recognized the precompetitive aspects of patent pools.[540] These guidelines triggered the creation of 'modern' patent pools, in a wide variety of industries (shown by Figure 74), many of them emerging out of co-created technologies such as compatibility standards and platform technologies. A compatibility standard is the technical specification of an interface between interacting components. Examples include MPEG-2 digital video compression, Bluetooth wireless personal area networking, and RFID non-intrusive identification. Platform technologies are products or services that act as a foundation upon which an array of complementary products (e.g. software, movies or music) can be offered.[541] A well-known example is the DVD platform and the movies available on DVD discs. Technology platforms can incorporate multiple compatibility standards; the movies on DVD discs are compressed using MPEG-2 for the images and Dolby Digital for audio.[542] In the last decade, patent pools have expanded to new areas, unrelated to compatibility standards. Some examples include agricultural technologies such as the 'Golden Rice pool',[543] pharmaceuticals such as the Medicines Patent Pool which aims to facilitate the development of better-adapted HIV medicines (e.g. special formulations for children), and Librassay which provides a one-stop license for diagnostics and tools in support of personalized medicine and healthcare.[544]

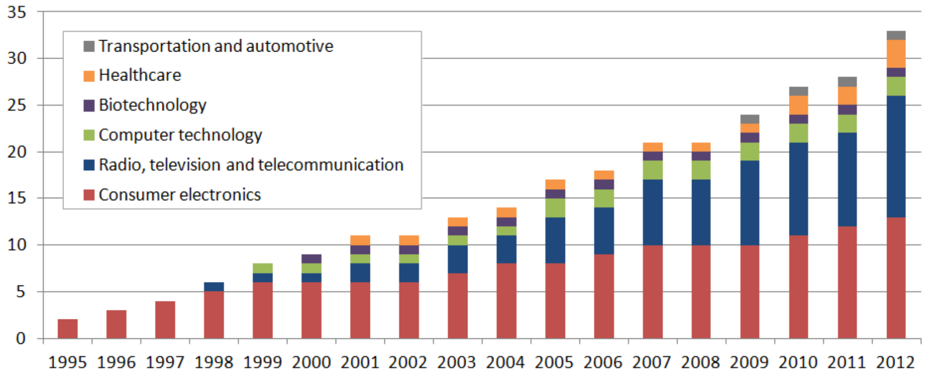



*Figure 74: Number of Patent Pools Established Since 1995.*[545]

Modern patent pools have the following characteristics: (i) all pooled patents are available to licensors participating in the pool, as well as to external licensees, (ii) licensees are offered standard licensing terms; usually a simple, coherent menu of 'patent packages' with prices and other terms, (iii) licensing fees are allocated to each member according to a pre-set formula or procedure, (iv) an independent party is involved to evaluate the essentiality of patents before they are included in the pool, (v) membership for licensors is voluntary, and most allow additional patent owners to join after formation of the pool, (vi) they include various adjustment mechanisms for adding new patents and recalibrating royalty shares.[546] Modern patent pools often bundle patents for a specific compatibility standard, because antitrust authorities require such pools to include complementary patents only, and patents that are essential for implementing a standard are by definition complementary. Pooling patents for technologies that directly compete is regarded as anti-competitive. In 2002, there was an initiative to establish a '3G platform pool' to pool patents into packages constituting five competing compatibility standards for 3G mobile telecommunications. Under pressure of the competition authorities, the proposal had to be changed to ensure that each standard would have its own pool, with independent decision and price setting structures.[547] Only for one of these standards a pool was actually formed.

### *7.1.1 Why firms engage in patent pools*

Managers in strategy and innovation are increasingly challenged to move beyond conventional thinking and need to compete on the basis of technology platforms.[548] Competitions between technology platforms are subject to network externalities: the technology with the largest number of users attracts providers of complementary products, which, in turn, increases the technology's utility to a customer.[549] These self-reinforcing feedback loops result in a virtuous cycle that often 'tips' a competition in favor of the technology that has the leading user base or complementary products that offer the most utility. These 'winner-take-all' markets demonstrate different competitive dynamics than markets in which competitors coexist relatively peacefully. A company does not need to have the best technology to achieve a dominant market share. Companies need to encourage innovation around their platforms at the broad industry level (i.e. create an ecosystem of businesses that support the platform) because the value of their platforms depends on the availability and innovativeness of complementary products and services.

In order to jump start the self-reinforcing feedback loop and outcompete technological alternatives, companies have started to collaborate in developing the platform's technology and then compete with each other in providing differentiated but compatible versions of the 'shared' platform.[550] However, involving multiple parties during technology development allows these to contribute their inventions and related IPR. The result is a 'patent thicket'; an overlapping set of patent rights requiring those that seek to commercialize new technology to obtain licenses from multiple patentees.[551] Circumventing the IPR by implementing alternate inventions is typically impractical, as it would preclude the manufacturer from claiming that its products are compliant and thus assuring consumers that they are fully compatible. Patent thickets lead to three problems: [552] (i) each individual patent holder may charge a royalty that seems reasonable when viewed in isolation, but together the royalties represent an unreasonable burden, (ii) even if other firms agree to license their patents at a modest rate, a hold-up problem may result if a single firm sets a high license fee for its technology, (iii) the very process of obtaining the required licenses may prove to be time consuming. The rapid growth in research and development expenditures[553], number of patents[554], patent holders, and their diversity is making it increasingly difficult to navigate through these thickets. This affects high-tech industries in general, including agriculture, pharmaceuticals, and personalized healthcare.

With such excessive property rights, co-created technologies are likely to be underused. However, in several cases (e.g. CD, DVD, Blu-ray and MP3) sponsors of co-created technologies have been effective in establishing an industry ecosystem by using patent pools to simplify the patent thicket. Patent pools create transparency, a level playing field, and facilitate market adoption. For licensees, patent pools function as a one-stop shop to access a technology's IPR. They offer lower transaction cost and a discounted royalty compared to concluding multiple individual licenses. These lower costs make the technology more attractive and are beneficial for its users. For licensors, patent pools lead to higher profits[15] due to the more effective and efficient licensing and collection of royalties. For example, AT&T has signed up 13 licensees for patents essential for implementing the popular H.264 / Advanced Video Coding (AVC) standard.[555] In contrast, the AVC patent pool, in which 29 other companies have united their essential patents, has attracted over 1,100 licensees.[556] Due to the increasing use of IT and telecommunications technologies as enabling technologies in larger systems, tomorrow's market will have to deal with many more diverged buyers, rendering bi-lateral licensing between patent holders increasingly ineffective. Examples include intelligent transport systems, where RFID tags now play a central role, and banking, with mobile payments. This trend will continue into many more areas, such as smart grids, personal health, and the 'internet-of-things'.

### *7.1.2 Difficulties in implementing patent pools*

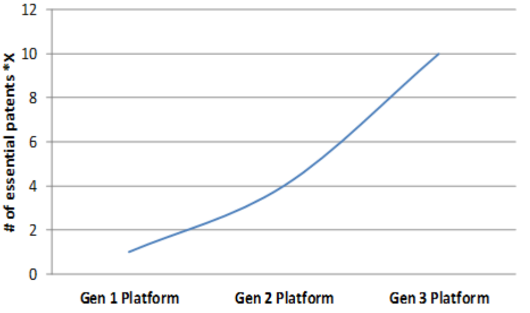
Establishing a patent pool is not easy, and its benefits are rarely realized to the full extent. Lerner and Tirole[16] identify several elements that restrict the formation of pools:

- **Negotiating cost**. Forming a pool involves a process with substantial legal expenditures. The benefits of forming a pool have to be compared with the resulting costs;

- **Asymmetric information**. Asymmetries in information (e.g. regarding the value of individual patents) can cause bargaining breakdown;

- **Self-imposed constraints**. Efficient bargaining requires sufficient flexibility to tailor patent pool conditions (e.g. license fee and royalty distribution) to individual needs and bargaining powers. Many pools go for an equal treatment of all members.

In addition, a patent pool can only be successful if it manages to obtain a critical mass of IPR. The more parties involved in the development of a co-created technology, the more IPR is fragmented among many owners. As Figure 75 illustrates the first generation of a technology platform or compatibility standard is often covered by relatively few patents, but as subsequent generations are developed and experience path dependency,[557] the number of patents and patent holders rapidly increases.[558] While a high number of patent owners makes one-stop shopping especially attractive, it is also more difficult to negotiate a patent pool arrangement.




| Above trend applies to: | | |
|---|---|---|
| CD (~100) | DVD (>400) | Blu-ray (~2000) |
| GSM (~100) | 3G/UMTS (~1000) | 4G/LTE (Not known yet) |
| MPEG-1 Video (~50) | MPEG-2 Video(~700) | MPEG 4 Video(~850) |

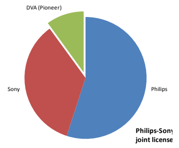
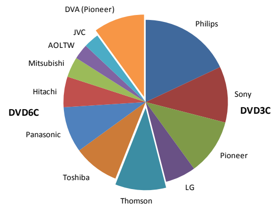
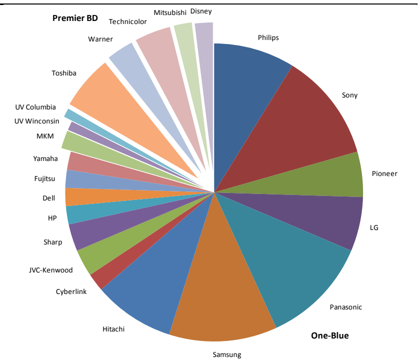
*Figure 75: Indicative Number of Essential Patent Families Associated with Subsequent Technology Generations in Optical Discs, Mobile Telecommunications, and Video Coding*[559]

In addition to the increasing number of essential patents per subsequent technology generation, there are two other trends that are enhancing the IPR fragmentation. Firstly, to facilitate customers to switch to a new platform, implementers often need to offer backwards compatibility by incorporating several technology generations into products: a Blu-ray player is expected to play older DVDs, and a 3G smartphone is expected to make calls on older GSM networks. Each of these technology generations comes with its own set of essential IPR and IPR owners. Secondly, there is an increased convergence of functionalities into devices and products. Whereas traditional technologies could often be exploited as a device or service in its own rights, today's devices often incorporate many different technologies. The evident example is the smartphone that includes a camera, a music player, an internet browser, GPS, and much more. A modern Blu-ray player will often include internet access, streaming video services, and Wi-Fi. As the level of complexity increases, patent pool formation becomes more demanding.

## 7.2 Patent pools in the optical disc industry

To demonstrate how companies can successfully manage their IPR on co-created technologies and deal with the increasing complexity, we describe the evolution of patent pools in the optical disc industry. The success of the first optical disc platform, the Compact Disc (CD), fostered several generations of shared platforms that became the market standard. These generations display different levels of maturity with regard to the number of essential patents, and the number of companies involved. The optical disc is one of the most successful industry platforms of all times. The related patent pools were among the first of the modern patent pools and their success has made them an example for others. Over time, the optical disc platforms also enveloped other areas such as video and computer data storage, thereby entering the domain of other companies with their own IPR interests. Nevertheless, most companies agreed to bring their essential patents into a patent pool. Table 25 shows an overview of three optical disc generations, their patent pools and the main characteristics of these pools.

Table 25: Overview of Three Optical Disc Generations and Main Characteristics of their Patent Pools[560]

<table>
<tr><th></th><th>CD Audio</th><th colspan="2">DVD Video</th><th colspan="2">Blu-Ray Video</th></tr>
<tr><td>Year of market introduction</td><td>1982</td><td colspan="2">1996</td><td colspan="2">2006</td></tr>
<tr><td>Billions of discs sold worldwide</td><td>100</td><td colspan="2">62</td><td colspan="2">2</td></tr>
<tr><td>Billions of players sold worldwide</td><td>2.8</td><td colspan="2">1.3</td><td colspan="2">0.1</td></tr>
<tr><td>Patents divided over owners</td><td>
</td><td colspan="2">
</td><td colspan="2">
</td></tr>
<tr><td>Patent pool</td><td>CD</td><td>DVD3C</td><td>DVD6C</td><td>One Blue</td><td>Premier BD</td></tr>
<tr><td>Administrator</td><td>Philips</td><td>Philips</td><td>Toshiba</td><td>One Blue LLC</td><td>Toshiba</td></tr>
<tr><td>Comfort letter</td><td>n/a</td><td>December 1998</td><td>June 1999</td><td>Mid 2011</td><td>March 2010</td></tr>
<tr><td>Original licensors</td><td>Philips, Sony (2)</td><td>Philips, Sony, Pioneer (3)</td><td>Hitachi, Matsushita, Mitsubishi Electric, Time Warner, Toshiba, JVC (6)</td><td>CyberLink, Hitachi, Panasonic, Philips, Sony (5)</td><td>Mitsubishi Electric, Thomson, Toshiba, Warner Bros (4)</td></tr>
<tr><td>Subsequent licensors</td><td></td><td>LG, HP (+2)</td><td>IBM, Samsung, Sanyo, Sharp (+4)</td><td>HP, JVC Kenwood, LG, Dell, Pioneer, Samsung, Yamaha, Taiyo Yuden, Fujitsu, Sharp (+10)</td><td>Disney, Columbia University (+2)</td></tr>
<tr><td>No. of licensees</td><td>118 (discs), 51 (players)</td><td>551</td><td>467</td><td>50</td><td>31</td></tr>
<tr><td>No. of essential patents</td><td>~100</td><td>263</td><td>608</td><td>83,000</td><td>n/a</td></tr>
<tr><td>Player royalties</td><td>2% of net sales price</td><td>3.5% of net sales price, minimum of $7.00 (dropped to $5.00 after 2000)</td><td>4% of net sales per unit, minimum of $4.00</td><td>$9.00</td><td>$4.50</td></tr>
<tr><td>Disc royalties</td><td>$0.03</td><td>$0.05</td><td>$0.075</td><td>$0.0725</td><td>$0.04</td></tr>
<tr><td>Royalty allocation method</td><td>Fixed</td><td>Fixed (based on amount of patents and contribution to the development of the platform)</td><td>Each patent weighs equally (per-patent basis)</td><td>Limited number of divisionals, differentiation on application and physical format, differentiation on market and manufacturing countries</td><td>n/a</td></tr>
<tr><td>Royalty collection</td><td>Post-netting principle</td><td>Post-netting principle, batch license, customs program</td><td>Post-netting principle</td><td>Pre-netting principle, batch license, mandatory participation in enforcement action, enforcement fund</td><td>n/a</td></tr>
</table>

### *7.2.1 The Compact Disc*

In 1979 Philips and Sony combined their technologies for optical discs in a shared platform, the Compact Disc (CD). Although both were major players in the consumer electronics industry, they realized additional market momentum was required to replace the installed base of the LP and Compact Cassette. Therefore, they decided to license the CD technology. To facilitate platform support and enable other parties to easily manufacture interoperable products, the specifications of the CD discs and players were described in the 'Red Book'. After the Red Book was finalized in 1980, other companies could access it to develop prototypes and evaluate the platform.

In order to make it easy for companies to obtain a license, Sony and Philips decided to jointly license their CD patents. Sony appointed Philips to act as the patent pool administrator, responsible for issuing licenses and collecting license fees. This role proved to be an effective solution. Philips had the licensing experience, only two companies were involved, the number of patents was relatively small, and the patent climate in the early 1980s was easy and benign. While, Philips and Sony held most of the patents on CD, there was also a third company, DVA. Their patents were related to optical storage technologies developed for LaserDisc, CD's failed predecessor that was co-created by Philips and DVA. DVA licensed its patents separately, and was later acquired by Pioneer.

The patent pool consisted of the patents essential for implementing the Red Book, and these were offered as 'patent packages' for the discs and players. This allowed the hardware manufacturers and record labels to take a license on the package they required. The licenses also included the use of a logo. The compliance logo showed consumers that the products were interoperable, but licensees could only use this after they were independently certified for adhering to the specifications in the Red Book. Because of this tight link between the logo, Red Book, and patent pool license, it was clear that every product with a logo was subject to license fees.

The approach of the Red Book and the joint licensing program proved to be very successful. Matsushita announced support for the CD format in January 1981, which meant that the three largest consumer electronics manufacturers supported the format. Other manufacturers followed suit and by March 1982 the format was supported by 30 CD player manufacturers. During the development of the CD, two major record labels, CBS/Sony and Philips's Polygram announced their support for the format. Nevertheless, due to the license fee demanded by Philips and Sony for the discs, the record industry threatened to become organized and offer almost unanimous resistance several months before Philips and Sony's 1982 product launch. In fear of being rejected by the music industry, Sony decided to drop its royalty claims for the discs[561] which left Philips as the sole recipient. As a result, any organized effort to resist this technology could face antitrust consequences. The threatened collective action did not occur, and many record companies decided to become licensees of the format instead. By August 1983, the format had 55 licensees; 39 were player manufacturers and 16 were disc producers who collectively offered 1,000 titles. With the successful market adoption of the CD, Philips had to take measures to counteract illegal manufacturing. It set up a dedicated team that proactively attended trade shows and approached parties without a license on the patents.

### *7.2.2 The Digital Versatile Disc*

After the success of CD audio, the platform was successfully leveraged as CD-ROM (Yellow Book) for the market of computer software distribution and as CD writeable and re-writeable (Orange Book) for the data copying market. The next step was to enter the market for video storage and distribution. Initially, Sony, Philips, Toshiba and Time Warner explored the possibility to enter this market with a shared platform, but this was unsuccessful and they split up in two camps. Sony and Philips developed the MultiMedia CD. Toshiba and Time Warner, joined by Matsushita, developed the SuperDensity Disc. With a platform competition looming, the computer and movie industry pressured the respective camps to merge their formats into a single platform. In 1995, agreement on a unified concept, the Digital Versatile Disc (DVD), was announced. With all the major consumer electronics companies and some of the major film studios supporting DVD, it quickly became popular and in six years it replaced VHS video tapes as the market standard. However, the uneasy merger of the two platforms was limited to pre-recorded discs. When the companies set out to extend the format to writeable and re-writeable discs, the competition flared up again and the two camps introduced their own formats (DVD+R and DVD-R). Both sides recognized the importance of creating a patent pool for DVD, but their competition led each to establish their own pool. Philips, Sony and Pioneer established the DVD3C pool, while Toshiba, Time Warner, Matsushita, Hitachi, JVC and Mitsubishi set up the DVD6C pool.

The patent pools were established in a few steps. First, the major DVD patent owners established small groups of companies that were interested to create a pool together. These groups internally discussed the main parameters of their patent pools:

- The companies of the DVD3C patent pool appointed Philips as license administrator, and the companies in the DVD6C pool appointed Toshiba as administrator.
- The license fees were defined as modest royalties. The main business of the patent holders was to market and sell products. Therefore, they were also licensees, and stood to benefit from reasonable fees.
- The pools chose the post-netting principle to calculate royalty payments. This meant that a licensee would make full royalty payments to the patent pool regardless of any licenses that the licensee already had on patents in the pool, for which refunds would have to be arranged outside the pool.
- The allocation of the royalties for DVD6C was based on the number of essential patents, multiplied by the number of countries in which the patents were filed. For DVD3C, there was a fixed allocation based on the number of essential patents and the contribution of the firms to the platform's development.
- If a company infringed on the patents in the pool, each individual firm in the pool could choose to make its patents available for an enforcement action.

Following agreement on these parameters, the two groups issued a call for other patent holders to join. The interested patent holders submitted their patents to an independent evaluator (a patent attorney or a law firm specialized in IPR) which determined if they were essential for implementing the platform. The last step in the process was compliance with international antitrust regulation. The initiators of the DVD3C and DVD6C patent pools collectively held a large market share in the consumer electronics industry, and their IPR could potentially be used to create entry barriers. To check whether the proposed patent pools were considered pro-competitive, the respective companies requested a comfort letter (also known as Business Review Letter), which is a statement of the DoJ's intentions not to challenge the pool. There are several must-haves for approval:[562] the patents should be essential for implementing the technology and complement each other, licensors should be permitted to license their patents outside the pool, and royalty rates must be reasonable and nondiscriminatory. DVD3C was the first to receive notification that the pool would not be challenged, and DVD6C received the same response in the following year. After the respective comfort letters were secured, the license administrators initiated the worldwide licensing effort. It took two years to complete the process of setting up the patent pools.

Once operational, the patent pools were open to new licensors who could add their essential patents to the joint license on the same terms and conditions as other patent holders. Licensees that owned essential patents were obliged to grant a license back to the other patent holders in the pool on comparable terms and conditions. The patent pool retained the right to suspend a license when a licensee defaulted on its commitments. Moreover, a patent owner was allowed to remove its patents from license coverage as to a particular licensee if that licensee brought a lawsuit for infringement of a related patent against the licensor.

The license for the DVD format and the essential patents license were separated. So in order to manufacture DVD discs or players, a licensee had to obtain the technical specification and a logo license from the DVD-Forum (a legal entity in which the DVD platform sponsors collaborated to promote the market adoption of the platform). Subsequently, they had to deal with two separate patent pools for DVD products, a number of individual DVD patent holders, various CD patent pools (not only on CD audio, but also on e.g. CD-ROM and CD-recordable) and additional CD licenses from individual companies. This fragmentation resulted in royalty stacking, and increased transaction costs for both licensors and licensees. Due to the large number of licensors, the playing field became more antagonistic. Each pool and individual company adopted its own strategy for enforcement. A trend developed in which some companies signed a license agreement, but deliberately failed to pay royalty fees. A licensee that does not pay royalties (or only a small portion) has a competitive advantage over licensees that do. While it is relatively easy to act against a non-licensee that infringes patents, legal action to force a licensee that is unwilling to pay is difficult and can take years. To tackle this problem for the DVD3C pool, Philips introduced a per-batch licensing system. This implies a license per shipment of products of DVD discs and player products, rather than for all products sold over a set number of years. The system directly tied the licensee's legal right to use patented technology to the payment of royalties.

### *7.2.3 Blu-ray*

Shortly after the market introduction of DVD, Sony, Philips and Panasonic initiated the development of Blu-ray, a next generation platform. They were quick to get other major consumer electronics companies on board such as Samsung, Pioneer, LG, Sharp, Hitachi, Mitsubishi and Thomson. The competing platform HD-DVD was developed by Toshiba, NEC and Sanyo. Blu-ray emerged victorious after most of the major film studios and major retailers announced exclusive support for the platform early 2008. In the competition between Blu-ray and HD-DVD, the importance of winning support from providers of complementary products (film studios) was greater than in previous platform competitions. The Blu-ray platform sponsors managed to attract more support than HD-DVD by acknowledging the preferences of the film studios. For example, they incorporated certain audio and video compression formats and content protection technologies in the platform. Some of these technologies were covered by IPR of complementary product providers, and these had different incentives for monetizing IPR than the major consumer electronics companies.

Sony, Panasonic and Philips started discussions for setting up a patent pool in September 2005, almost a year before the first Blu-ray players and discs were introduced on the market. By the end of 2009, Sony, Panasonic, Philips, CyberLink and Hitachi issued a public patent call. By August 2011, the One-Blue patent pool was launched. The sponsors of the HD-DVD platform had incurred severe losses[563], and were not ready to join One-Blue. Toshiba set up a competing patent pool, Premier BD, with Warner, Mitsubishi and Thomson.

In setting up the One-Blue patent pool, Blu-ray's main platform sponsors set out to reduce the huge efforts required in collecting royalty payments from non-compliant DVD licensees, as this led to an unlevel playing field and distorted competition. To counteract this and encourage platform implementers to become licensees, Blu-ray's main platform sponsors wanted to limit IPR fragmentation and make life easier for licensees. They decided to go beyond a 'DVD' type of patent pool and created a pool for all the patents required to implement the Blu-ray platform (i.e. including patents required for CD and DVD because Blu-ray was backwards compatible to these platforms), thereby reducing total royalties and transaction costs. As Figure 76 shows, One-Blue's founders managed to pool their patents on Blu-ray, most of the DVD patents and CD. The pool also included patents required for DVD-R, -RW, +R, +RW and CD-R which were required for Blu-ray recorders. They also tried to include the patents regarding some externally developed compatibility standards, but these efforts did not bear fruit.

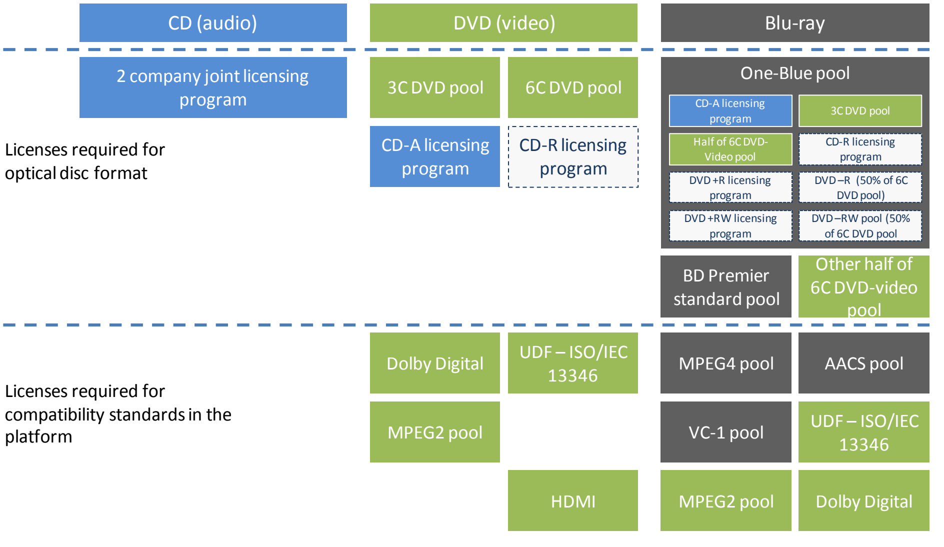



*Figure 76: Non-Exhaustive Overview of Licenses Required to Manufacture a CD, DVD or Blu-ray Player (packages with dotted lines represent additional licenses required for recorders)*

In October 2009, the founders of One-Blue established a separate legal entity, One-Blue LLC, as independent pool administrator with the sole task to act in the interest of the pool. The founders wanted to avoid the problems experienced in previous patent pools whereby one of the IPR owners regulated licensing and enforcement. When one of the IPR owners acts as pool administrator, it may need to deal with the backfire of enforcing the patents in the pool, hindering its capacity to operate effectively. An independent pool administrator has two main advantages: it mitigates the possibility or illusion of a conflict of interest, and the pool's stakeholders are better able to monitor the performance of the administrator and hold it accountable.

One of the key issues was how to allocate the royalties over the optical disc formats in the pool. The companies agreed on a fixed allocation, which will be adjusted over time to account for shifts in the weight of the patent packages related to the different optical disc formats. Considering that the DVD format was introduced in the market in 1997, and patents have a maximum lifetime of 20 years, one can imagine the shift in allocation that will occur in the coming years.

While Philips, Sony and Panasonic were setting up the patent pool, they held discussions with potential licensees to understand their views and expectations. One of the key requirements for these potential licensees was a true level playing field whereby the pool would ensure that all participants in the market for Blu-ray products would take licenses and would pay all royalties due. To achieve this, One-Blue had to find a way to protect licensees and licensors from companies that failed to pay royalties, and to be effective in engaging non-licensees. They decided to re-use the per-batch licensing system which was introduced for DVD discs, for all Blu-ray products. To make the system easier and avoid unnecessary cost, the pool initiators applied a pre-netting principle, whereby licensees only paid their net royalties to the licensors in the patent pool. The existing bilateral agreements between licensors and licensees and the related royalty payments are taken into account when calculating payments. Regarding the enforcement of patent rights, One-Blue applied mandatory participation in enforcement action. This was a response to the serious free rider problem in the existing patent pools, like MPEG-2 video, due to the voluntarily participation in enforcement actions. The members of One-Blue agreed that each licensor would make its patents available for use when One-Blue decided an enforcement action was warranted.

In One-Blue, the IPR owners moved away from the conventional and easy 'one patent one dollar' approach of valuing patents, because it encourages companies to apply for a high number of separate essential patents per invention. They achieve this by filing as many divisional- or continuation patents as possible for one invention covered by a parent patent. The only brake on this 'patents race' is the cost of filing and maintaining a patent. As long as these costs are lower than the income of an extra patent in the pool, a company has an incentive to file an extra divisional. However, if all patent owners adopt this tactic, everyone has higher costs. To stop this undesired practice, the founders of One-Blue decided that they would limit the number of divisionals or continuations for each parent patent. In addition, One-Blue differentiated the value of the patent based on the nature of its invention. Physical format patents were given more weight than application format patents, because physical format inventions require more costly research and are used in products all the time.

While the One-Blue patent pool was established fairly recently, the number of licensors quickly grew to 15 (including the major contributors to the Blu-ray platform) and as a result contains a large majority of all Blu-ray essential patents. The rapid increase in the number of licensees shows that the license conditions are considered appealing. This is not surprising when we consider the pricing and the efficiency that One-Blue offers over bi-lateral licenses. As Table 26 shows, the cumulative amount of separate licenses required to manufacture Blu-ray players is roughly \$25, whereas One-Blue offers the license at \$9. This constitutes a differential saving of 64%.

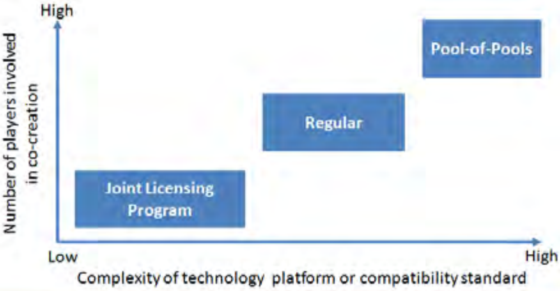
Table 26: Estimated Fees for Bi-lateral Licenses on a Blu-ray Player, instead of a License from One-Blue[564]

| Licenses included in One-Blue | Comparable Fees for Bi-lateral licenses |
|---|---|
| CD | <$1 |
| DVD 3C pool | $5 |
| DVD 6C pool[a] | $2 |
| Blu-ray | $17.25 (Philips $3.50, Sony $2.25, others $11.50) |
| | |
| Total per Blu-ray player | $25 |

a) about 50% of the necessary patents for the DVD 6C pool is included in the One-Blue license, remaining patents have to be licensed in addition

## 7.3 The evolution towards a 'pool-of-pools'

Based on the three generations of optical disc patent pools, we can distinguish three types of pools (as shown in Figure 77). The evolution of these patent pools was influenced by two elements; the number of parties involved in co-creating the technology, and the complexity of the technology platform. In order to cope with the increased number of parties involved in platform development and the increased platform complexity, the patent pools became more sophisticated and evolved towards the novel pool-of-pools.




| | Joint Licensing Program | Regular Patent Pool | Pool-of-Pools |
|---|---|---|---|
| Number of licensors | 2-3 | Multiple | Many |
| Open to new licensors | No | Yes | Yes |
| Number of technologies covered | 1 | 1 | Multiple |
| Time required to become operational | 1 year | 1-2 years | 3-4 years |
| Negotiating cost | Low | Medium | High |

*Figure 77: Three Patent Pool Models, Typical Features, and Elements Influencing the Choice of Patent Pools*

In a *Joint Licensing Program* (JLP), a few parties combine their patents and offer them to licensees at predetermined rates. JLPs are a relatively quick and cost-effective means of collaboration, and are often administered by the party which is most experienced in licensing. A JLP is especially suitable when few parties are involved in the development of the technology and when it is relatively simple. This is often the case when a radical innovation disrupts the industry. JLPs are seldom open to new members.

'*Regular' Patent Pools* are the most widely used type of patent pools.[565] This model is based on the MPEG-2 patent pool, which was the first modern patent pool to receive a comfort letter from the antitrust authorities and became very successful.[566] This model is a suitable solution when multiple parties are involved in technology co-creation and these are willing to collaborate in a joint license.

The novel *'pool-of-pools'* is the most sophisticated. It aims to facilitate the market adoption of complex products. This pool may encompass the patents of multiple generations of technology. Due to the large number of players involved in the co-creation, the success of this type of pool depends to a large extent on the willingness to collaborate. Compared to the other patent pools, the pool-of-pools has high negotiating cost and takes several years to become operational.

*7.3.1 Designing and managing patent pools*

Based on our observations, we have found that the lifecycle of patent pools passes through four phases; investigation, formation, gaining traction and maturity (Figure 78). Each phase comprises several activities which are important to the success of a patent pool.

Time

| Investigation | Formation | Gaining traction | Maturity |
|---|---|---|---|
| Determine scope and type of patent pool | Determine pool administrator | Actively market the license | Enforce contractual compliance (auditing) |
| Identify main patent holders | Determine the charter: pricing and structure of license fees , royalty collection, royalty allocation, IPR enforcement, licensor protection | Enforce non-authorized use of the IPR | Maintain up-to-date list of living patent rights in the pool |
| Investigate which have a common interest to establish patent pool | Issue call for patent pool formation | Continue submission, evaluation and inclusion of essential patents from new licensors | |
| | Determine essentiality of patents in the pool | Hold regular Administrative Committee meetings | |
| | (Letter from anti-trust authorities) | | |

*Figure 78: Phases in the Lifecycle of a Patent Pool*

Phase 1: Investigation

The lifecycle of a patent pool starts when a company takes the initiative to determine the scope of the pool and drives the process. The initiator can be one of the patent holders, a professional license administrator or a Standard Development Organization. In the case of the optical disc patent pools, the initiators were major patent holders that could provide the pool with the required critical mass. The scope is defined by the pool's mission and goals. Whereas patent pools in the field of consumer electronics and telecommunication generally aim to facilitate worldwide market adoption of a technology and to appropriate license income, patent pools in the field of agriculture and healthcare often serve a humanitarian goal by aggregating IPR on medicines or seeds and licensing this on royalty free basis in developing countries. The next step is to determine the patent packages that will be offered by the patent pool. The CD-Audio pool offered a package for CD-discs and for CD-players, whereas the Librassay pool offers many packages divided over eleven categories. The last consideration is the type of patent pool (joint licensing program, regular patent pool, or pool-of-pools), which has been discussed above.

When investigating which parties have a common interest to establish a patent pool, one can initially take an 'open' approach by extending a call to any party that may own an essential patent, or a 'closed' approach by selecting only a few major patent holders. To simplify negotiations and minimize associated costs, the initial groups that started the optical disc patent pools consisted of up to six major patent holders. For efficient follow-up discussions, it helps to establish a homogeneous group of companies, however the optical disc patent pools show there can be exceptions. Whereas both and open and a closed approach can work, the latter has most benefit when the group of patent holders is large and diverse, as is usually the case when creating a pool-of-pools.

Phase 2: Formation

In the formation process, the initial group has to determine whether the patent pool will be administered by one of the members, whether a new entity will collaboratively be established for this purpose, or to outsource this task to an established commercial license administrator.[567] For inexperienced parties, it can be helpful to enlist the services of a commercial license administrator to provide support in establishing a patent pool. When aiming to establish a regular patent pool or a pool-of-pools, the best practice from the optical disc industry is to let an independent license administrator manage the pool.

The next step is to determine the charter of the patent pool. Table 27 shows the charter's main parameters, considerations per parameter and associated lessons learned from the optical disc patent pools.

Table 27: Main Parameters of Patent Pool Charter, Considerations and Lessons from Optical Disc Patent Pools

| **Main parameter** | **Considerations** | **Lessons learned from optical disc patent pools** |
|---|---|---|
| Pricing / License fees | The license should reflect a balance of royalty, revenue, and administrative fee that gives a reasonable return to patent owners, and reasonable access for licensees. Pool licenses should be lower than the aggregate individual licenses of the companies that participate in the pool. | Use a fixed fee per device instead of a percentage of the net sales price. With the success of the platform, product costs decrease and put pressure on the minimum fixed fee. |
| Royalty collection | Which measures will the patent pool use to ensure a level playing field (e.g. batch licensing), and how are royalty payments settled among licensees and licensors in the pool (pre-netting vs. post-netting)? | Batch licensing works as an effective mechanism to ensure a level playing field. Pre-netting ensures that companies only have to pay once for the same license. |
| Royalty allocation | Will royalties be allocated on a 'fixed' or 'per-patent' basis? Will there be restrictions on the number of divisionals per parent patent? Will patents be weighted differently based on the type of patent (e.g. application or physical format), and how will the royalties be allocated over various technology generations? | Per-patent-basis is the easiest method. Variations can do more justice to the efforts of the companies and the type of patents but make negotiations more difficult. |
| IPR enforcement | Will the pool use mandatory or voluntary participation in enforcement actions? | Mandatory participation mitigates free rider behavior |

Once the charter has been defined, the group can issue a call, inviting other patent holders to join. Interested parties submit the patents that they deem essential to an independent patent evaluator.[568] The group with essential patents may consider requesting a comfort letter from the antitrust authorities. This is recommended when the patent pool is expected to meet scrutiny from antitrust authorities.

Phase 3: Gaining traction

After a patent pool has started, access to licenses is open and non-discriminatory, and it is important to create public transparency by making license rates and terms, licensors, licensees and the respective patents in the pool publicly available. The next step is to actively market the license, e.g. by visiting potential licensees and identifying parties that sell products based on the technology platform. To prevent unauthorized use of the patents in the pool, the administrator will have to enforce the patent rights.

While the patent pool is gaining traction, other patent holders may want to join. This requires an on-going process of patent evaluation and recalibration of the royalty allocation. To deal with these changes and the various other aspects, a patent pool may hold regular administrative committee meetings where all the licensors are invited to discuss ongoing business.

Phase 4: Maturity
In the maturity phase, the pool administrator will need to enforce contractual compliance by auditing its licensees. As patents are often granted for a period of twenty years, the pool administrator will need to monitor the expiration of patents and the countries in which they expire, recalibrate the royalty allocation and possibly adjust the license fees.

## 7.4 Discussion and conclusion

For modern technologies, access to IPR is often complex and sometimes problematic because it is fragmented among many owners. The bilateral licensing agreements that need to be concluded are time consuming, invoke considerable transaction costs, and can result in royalty stacking. Often it is in the interest of the technology sponsor to ease access to the required IPR, whether owned by himself or by other parties that are willing to cooperate. In the optical disc industry, patent pools have proven to be a useful way to achieve this goal. Over time, these patent pools have become more sophisticated. The small, relatively simple and closed Joint Licensing Program was succeeded by Regular Patent Pools that catered to a larger number of pool members and licensees. The latest development is the 'Pool-of-Pools', which addresses the increasingly occurring situation in which consumers demand devices that not only support a new technology, but also previous generation technologies.

Though our analysis has thus far been focusing on the optical disc industry, we believe that pools and pool formation (using the process described in Figure 5) can be equally well applied to other standards-based industries that face patent thickets, e.g. radio, television, telecommunications, computers, and automotive. We also see indications that pools are now being established in industries where technology platforms and compatibility standards are less prominent, such as in agriculture, pharmaceutics, and healthcare. The use of the novel pool-of-pools model is likely to be appealing specifically to industries with complex products that incorporate several technology generations. For instance, the IEEE 802.11 standard (popularly known as Wi-Fi[569]) has developed through as much as six generations, and devices usually incorporate several (if not all) of these generations. Currently, there is a modestly successful patent pool for the first three generations of this standard, and recently an initiative was started for a separate pool that covers the latest generations. Instead, the pool-of-pools model could be used as reference for a one-stop-shop of all generations. In the computer industry, the Ethernet standard (IEEE 802.3) and the related Power over Ethernet standard (IEEE 802.3af) also comprise of multiple technology generations and a patent thicket. Arguably, industries such as mobile telecommunications could also make a sensible case for pools of pools, because typical modern phones incorporate at least two or three technology generations. While earlier attempts to create pools in this industry have met only moderate success,[570] multiple new pool initiatives have been taken for the latest technology generation in that field, called 4G LTE.[571]

As noted earlier in this paper, there are several trends that make it increasingly difficult for companies to navigate through the patent thicket. We believe this will foster the adoption of future pools, as well as pools-of-pools, even in industries where this has been difficult. The first trend is the rapid growth in research and development expenditures, patenting intensity, and the typical number and diversity of patent holders for any specific technology. The second trend is increased convergence of functionalities into devices and products. Whereas traditional technologies could often be exploited as a device or service in its own rights, today's devices often incorporate many different technologies. The third trend is the increasing use of IT and telecommunications technologies as enabling technologies in larger systems including smart grids, logistics and transportation, personal health, and the 'internet-of-things', to name a few. These three trends have the effect that many of tomorrow's markets will have to deal with a more diverse and more fragmented IPR market, both in terms of sellers (patent owners) and buyers (technology implementers). This increases transaction costs and renders current practices of bi-lateral or cross licensing increasingly ineffective. As a result, we believe that patent pools will be more and more recognized as an attractive way to facilitate these IPR markets, benefiting technology developers and technology implementers alike.

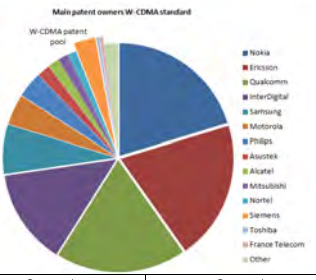
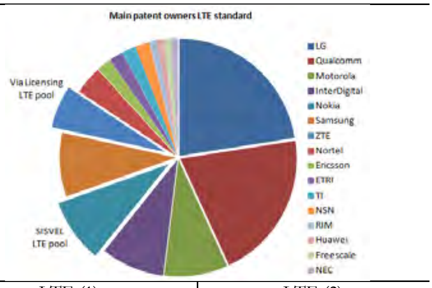
## 7.5 Epilogue

While the previous sections illustrated examples of successful patent pools, many attempts to pool patents have also failed. This can be illustrated by several cases in the telecommunications industry.

### *7.5.1. Patent pools in mobile telecommunication*

Although compatibility standards are different from technology platforms, they have just as much impact on our daily lives. Well known examples include WiFi, USB, GSM, 3G, LTE, RFID, MPEG-2 and MPEG-4. However, establishing a successful patent pool requires the right conditions regarding the technology and the industry. To contrast the three generations of the optical disc technologies and their patent pools, we illustrate the difficulties of establishing patent pools in the mobile telecommunications industry. Table 28 provides an overview of these patent pools.

Table 28 Overview of Two Generations of Mobile Telecommunication Standards and Characteristics of their Patent Pools[572]

| | **3G** | | **4G** | |
|---|---|---|---|---|
| Year of market introduction | 2001 | | 2009 | |
| Patents divided over main owners |  | |  | |
| Patent pool | W-CMDA | CDMA2000 | LTE (1) | LTE (2) |
| Starting date | September 2003 | June 2009 | October 2012 | November 2012 |
| Original licensors | France Télécom, Fujitsu, KPN, NEC, NTT, NTT DOCOMO, Panasonic, Sharp, Siemens, SK Telecom, Toshiba (3, +8) | France Télécom, NTT, NTT DOCOMO, KPN, Siemens (5) | AT&T, Clear Wireless, Deutsche Telekom, DTVG Licensing, Hewlett-Packard, KDDI, NTT DOCOMO, SK Telecom, Telecom Italia, Telefonica, ZTE (11) | Cassidian (EADS), CATT, ETRI, France Telecom, KPN, TDF, SISVEL (patents acquired from Nokia) (7) |
| Subsequent licensors | | SK Telecom (+1) | | |
| Royalties for terminals | Variable, ranging from $0.22-$2.00 per unit | $0.05 per patent family per unit, maximum of $0.50 | Variable, ranging from $2.10-$3.00 per unit | €0.99 per unit |
| Administrator | SIPRO LAB | SISVEL | Via Licensing | SISVEL |

The mass adoption of mobile telecommunications coincided with the implementation of the second generation standards GSM and CDMA. GSM was a co-created standard and became the dominant standard worldwide. CDMA was pioneered by Qualcomm, and became the dominant standard in the U.S. Access to the necessary GSM patents was problematic[573]. However, the major licensees were also the major patent owners (i.e. Ericsson, Nokia, Siemens, Motorola and Alcatel[574]), so these companies resolved the IPR issues through bi-lateral licensing agreements. The first patent pool was initiated during the development of GSM's successor.

In January 1998, the European Telecommunications Standards Institute (ETSI) set out to establish a close collaboration with standards bodies from several regions to develop a joint standard. This collaboration became known as the 3rd Generation Partnership Project (3GPP). Together they developed W-CDMA, in Europe known as UMTS. At an early point in the collaboration, IPR concerns were extensively addressed and the parties agreed to explore the feasibility of a patent pool for W-CDMA.[575] This task was taken up by the IPR Working Group[576].

Although it was clear that implementing such a task was not going to be easy, the exercise was taken seriously. In September 1998, the working group had 33 member companies. Many of the major mobile equipment suppliers (Nokia, Ericsson, Alcatel, Siemens, Motorola, and Sony) were actively involved. Various IPR approaches were studied, including several pool variants. At the same time a number of other, competing 3G standards were being developed. Five of them (W-CDMA, CDMA2000, TD-CDMA, EDGE and DECT) were recognized as such by the International Telecommunications Union (ITU) as a 'family of standards'.[577] Eventually, the working group decided to go forward with what it called a 'patent platform'. The idea was to create a menu of five patent packages, each containing the patents for one of the competing 3G standards, to facilitate multi-mode products. The central motivation of the participants was to restrict the cumulative royalty fees, whereby the maximum cumulative royalty rate should be in the 'single digit' range.[578]

A lot of work went into the various design parameters of the pool, including the royalty sharing scheme. To attract major IPR owners that were not vertically integrated, e.g. Qualcomm and InterDigital, it was considered to have a higher fee category for such companies. However, when it became clear that such mechanisms would not attract key companies in that category, the idea was abandoned. Another feature of the pool was the royalty exemption clause, which allowed for a pre-netting scheme that mitigated double royalty payments in case the licensee already has a bilateral license with one of the pool members.

The initiators sought comfort letters from antitrust authorities across the globe. Most authorities sent a favorable response within a short timeframe, however the Department of Justice (DoJ) was concerned that the model of a patent platform could lead to anticompetitive behavior. Eventually, the DoJ sent a positive response in November 2002, three years after the request was submitted. In its response, the DoJ firmly stressed that the group had to create an independent pool for each competing technology. Regardless of these important issues, large firms continued to underline the *raison d'être* of the pool. In September 2002, Ericsson, Nokia, Siemens, Sony and five more companies issued a joint press release, expressing desire to have the aggregate W-CDMA licensing royalty rate set at a low level, below 5%.[579]

When the patent pool became operational in September 2003, it focused on the W-CMDA standard in order to adhere to the requests of the DoJ. However, against expectations, only three minor players actually joined the pool. Pool membership gradually increased over the years – by late 2012 there were 11 members. Large players such as Nokia and Ericsson never signed up, despite their aforementioned letter supporting the main objective of the pool. Many other companies involved in the initiation phase of the pool also never signed up. While it would be incorrect to state that the pool was insignificant, it did not gain critical mass. Of the other 3G standards, the CDMA2000 standard was the only one for which an independent patent pool was established.

As successor of 3G, various parties started working on 4G technologies. The two main competitors were LTE and WiMAX. For both technologies there were many different companies that held essential patents. To accelerate the widespread adoption and deployment of WiMAX, Alcatel-Lucent, Cisco, Clearwire, Intel, Samsung, and Sprint announced in June 2008 the formation of the Open Patent Alliance (OPA). This alliance aimed to establish a WiMAX patent pool. Although the initiative showed potential in the beginning, little has been heard from it in the past years and we assume the negotiations have failed. From the two competitors, the most successful technology to date is LTE. In 2009, the Next Generation Mobile Network (NGMN) Alliance, a group of leading mobile network operators (representing more than half of all worldwide users) and equipment vendors (representing 90% of mobile wireless infrastructure) issued a call for information to parties that could act as licensing administrator for an LTE patent pool.[580] Three commercial patent pool administrators – MPEG LA, Via Licensing and SISVEL – responded to this call. They engaged in discussions with LTE's essential patent owners and issued calls for patents. While MPEG LA withdrew its pool imitative, Via Licensing and SISVEL continued. Late 2012, two different LTE pools became operational.

As of late 2012, the Via Licensing LTE pool comprised eleven members of which ZTE contributes the most essential patents. The SISVEL LTE pool has seven members, including SISVEL itself which acquired 47 patent families from Nokia late 2011 (these patent families comprise over 350 patents that are claimed essential for 2G, 3G and 4G standards). Although the two LTE pools have more mass than the WCDMA pool, they still only represent a modest part of the total number of patents.

While the roll-out of LTE is currently ongoing, we shall see how this market will develop and if the two LTE patent pools will become successful. An interesting recent development is the redistribution of the some of LTE's major essential patent holders (i.e. the acquisition of Nortel's patent portfolio by Apple, Microsoft, Sony and RIM in 2011, and the acquisition of Motorola by Google in May 2012).

### *7.5.2. 'Accessibility of intellectual property rights' in the integrative framework*

As the optical disc and telecommunications cases have shown, the more parties involved in the development of a technology, the more difficult it becomes for third parties to obtain access to the respective intellectual property rights, and the more difficult it becomes for the technology sponsors to make the joint intellectual property rights accessible. So the cases substantiate that an increase in the measure of collaborative technology development has a negative impact on the accessibility of the required intellectual property rights. The optical disc cases also show that by setting-up a patent pool, access to the intellectual property becomes easier, and a large organizational community that supports the technology can be established. However, the mobile telecommunication cases show that the lack of a patent pool does not preclude a sizeable organizational community to support a particular technology, nor does the fragmented ownership of intellectual property rights prevent a technology from becoming the de-facto standard. Further research is required to gain a more comprehensive understanding of the impact of accessible intellectual property rights on the size of a organizational community, and its effect on a technology's ability to become the de-facto standard.

*7.5.3. Reflection on limitations of the integrative framework*

As was found in Chapter 6, the findings from this Chapter show there are elements that influence the emergence of a de-facto standard which are unaccounted for in the integrative framework. In addition, with the identification and closer investigation of these elements, also new relationships to existing elements are found.

## References Chapter 7

[538] Some of the product names referred to in this paper are copyrighted or have registered trademarks, such as Android™, Windows Mobile® and Librassay®.

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# Chapter 8 - Cross case analysis

This chapter will first reflect on the use of the integrative framework on the cases. Thereafter, patterns across the cases will be investigated, and used to complement the integrative framework.

## 8.1 Reflection on the integrative framework

This section will start with a reflection on the separate aspects of the integrative framework, i.e. its elements, categories, first and second order elements, and phases. It concludes with a reflection on the integrative framework as a whole, and presents a revised integrative framework. The sections on the separate aspects will reflect on the assumptions made when developing the integrative framework in Chapter 2, and describe the new insights gained from the cases.

### *8.1.1. Elements*

Of the 45 elements that were identified in Section 2.1 and 2.2, 41 elements were confirmed by the three case studies. The following elements were not found in the three case studies:

- Installed base (in the 'firm' category)
- Technological performance trajectories
- Availability of imitators
- Product proliferation (in the 'market / industry' category)

Considering that the elements of 'installed base' and 'product proliferation' can be allocated to multiple categories, and were found in another category (installed base was found when related to the technology, and product proliferation was found when related to the firm), these elements should remain part of the integrative framework.

When reviewing the element of 'technological breakthroughs in subsystems', it became clear that it is actually encompassed by the element 'technological breakthroughs in subsystems'. Hence, it makes sense to combine the two. I will retain the element of 'technological breakthroughs in subsystems', and modify its description into: advances and breakthroughs in subsystems that enhance the technology's performance or utility.

Following the insights from the case studies, it has become apparent that the element of 'availability of imitators' is strongly related to 'appropriability'. In an embryonic market, there is always competition, and weak appropriability will enable companies to imitate a product, rather than become part of a technology sponsors' 'organizational community of supporters'. Hence, it makes sense to merge the two. I will retain the element of 'appropriability', and modify its description into: ability to protect the innovation from imitation by competitors and capture the profits generated by it. Dependent on solid intellectual property rights, a secure R&D and manufacturing environment, and the efficacy of legal mechanisms. Weak appropriability may enable imitators, enhancing the number of products or complements on the market.

In order to make the integrative framework more parsimonious, I reviewed the results of the case studies to verify if the individual elements contributed to understanding the emergence of a de-facto standard. While doing so, I found that:

- The element 'powerful rival technology sponsors' can be merged with the element of 'level of competition'. The description of level of competition (i.e. number of incompatible technological alternatives that are competing in the market for adoption and the strength, financially and in terms of market share, of their supporters) encompasses the point of 'powerful rival technology sponsors' and doesn't require modification.
- The elements of 'unclear assessment criteria' and 'hereto- or homogeneity of customer needs' can be merged with the element of 'market and industry characteristics'. The resulting description would need to be changed into: structure and dynamics of the market and technological field, e.g. excess inertia vs. insufficient friction, hetero- or homogeneity of customer needs, and maturity of assessment criteria for technology adoption.

While performing the case studies, three new elements were identified. Table 29 provides an overview of these new elements.

Table 29: Overview of new elements as identified in the individual cases

| Element | Chapter 3 High definition optical discs | Chapter 4 MP3 | Chapter 5 High definition audio discs | Chapter 6 | Chapter 7 |
|---|---|---|---|---|---|
| Subsidizing providers of complementary goods | X | | X | | |
| History of the industry | X | | X | | |
| Accessible intellectual property rights | X | X | | | X |

The element of subsidizing providers of complementary goods was found in both Chapter 3 and 5. It was not found in the case of MP3, which can be attributed to the lack of a need to involve content providers in the organizational community of supporters. Contrary to the cases of the optical discs, in the case of MP3 the users of the technology were also the content providers. Going back to the academic literature, two aspects appear to be relevant; firstly the literature on platforms (Subsection 1.1.3.) distinguishes between the 'supply network' (parties providing complementary goods) and the 'demand network' (customers), and secondly the literature on pricing (Appendix 1, no.25) notes that technology sponsors can subsidize customers by applying penetration pricing. Interestingly, the aspect of subsidizing providers of complementary goods fits well into the existing literature[581], however it had not yet been identified as such. As two cases support the relevance of this element, in accordance with Section 1.5, it should be included in the integrative framework. The findings of Chapter 3 and 5 indicate that this element falls in the 'firm' category, and it is subject to strategic decision making. This element has been found to influence the organizational community of supporters, but no other elements. Considering that the organizational community of supporters is a second order element, the element of 'subsidizing providers of complementary goods' should be positioned as a third order element in the framework.

Chapter 3 and 5 both show that events in previous technology competitions (i.e. the history of the industry) affect the new technology competition, especially with regard to the level of collaborative development; some technology sponsors may hold a grudge to each other and rather compete in the market than collaborate on a shared technology. This element was not found in the case of MP3; MP3 was a radical innovation that disrupted the existing linkages in the industry's value chain, and it was therefore not influenced by the history of the industry. As two cases support the relevance of this element, in accordance with Section 1.5, it should be included in the integrative framework. The findings of Chapter 3 and 5 indicate that this element falls in the 'market/industry' category. It has been found to influence the level of collaborative development, but no other elements. Considering that the level of collaborative development is a second order element, the element of 'history of the industry' should be positioned as a third order element in the framework.

Chapter 7 delved into the aspect of accessibility to intellectual property rights. It found that the greater the level of collaborative development, the more difficult it becomes to provide access to the intellectual property governing the technology. While multiple cases in Chapter 7 indicate that the accessibility to the required intellectual property has an influence on the organizational community of supporters, it does not provide insights regarding the measure and nature of this influence. This element also becomes apparent in Chapter 4, and it applies to the case of Chapter 3 as Blu-ray is one of the cases studied in Chapter 7. However, the effect of this element does not become apparent in these Chapters. Considering that multiple cases in Chapter 7 support the element of accessibility to intellectual property rights, the condition for analytic generalization (as provided in Section 1.5) is met and the element will be included in the framework. Chapter 7 shows that the initiative for a patent pool can come from a technology sponsor or from external parties. Therefore, this element can be categorized as both firm- and market/industry-related, and it is subject to strategic decision making. Considering that the organizational community of supporters is a second order element, the element of 'accessibility to intellectual property rights' should be positioned as a third order element in the framework.

*8.1.2. Categories of elements*

In Chapter 2, three categories of elements were defined: firm, technology and market/industry. The insights from the three cases support this distinction, and do not indicate a need for an additional category or that one of the three is redundant. Differentiating between three categories has provided the following benefits:

- Of the 34 elements, 10 were allocated to multiple categories. This proved important during the case studies, as it allowed for more accurate analysis. For example: if the case showed network effects, a differentiation was made if the network effects were related to the technology, which in the academic literature is known as direct network effects, or to the market / industry, which is known as indirect network effects.
- The categories helped to identify major shifts in the balance of the type of elements over the course of the emergence of a de-facto standard.
- Lastly, the firm-related elements led to identifying the elements that are subject to strategic decision making.

In Subsection 2.2.2., eight elements were found to be attributable to multiple categories. The cases confirmed six of these in the categories to which they were attributed. As noted in Section 8.1, two elements (installed base and product proliferation) were only found in one category. However, considering there is no compelling argument why those two elements should not be found in the other category in other cases, and considering our small sample size, the allocation of these elements in the integrative framework will not be modified.

Regarding the categorization of elements, it became apparent during the case of MP3 that the element 'level of collaborative development' could be attributed to the industry. While the case of MP3 is the only occasion where the initiative for collaborative development was found to come from the industry rather than from the technology sponsor, I will include it in the integrative framework because it is important to note that it can be an external event in which a technology sponsor can participate.

Lastly, in Subsection 2.2.3., 16 elements were identified as being subject to strategic decision making. Of the three newly identified elements, two are also subject to strategic decision making, resulting in a total of 18 elements that can be used to shape the odds of a technology emerging as de-facto standard. The results from the cases support that these 18 elements are indeed subject to strategic decision making and can be used to shape the odds. In the case of the high definition optical discs, all 18 elements were used. The two elements that proved decisive were the result of strategic decision making. In the case of MP3, 13 elements were used. Of the nine elements that were key in influencing the competition, five were subject to strategic decision making. So in this case strategic decision making played a significant role in the outcome. In the case of the high definition audio discs, 17 elements were used. Here strategic decision making was actively applied by both sides and resulted in a toe-to-toe competition, whereby the outcome was determined by external forces. The results from the cases confirm the notion that companies can indeed shape the odds of their technology emerging as de-facto standard through strategic decision making, however the outcome does not rely solely on strategic decision making.

### *8.1.3. First- and second order elements, and inter-element relationships*

At the beginning of Chapter 2, several starting points for the integrative framework were adopted. One of these was that the de-facto standard is determined by customers adopting a technology. In Section 2.3, the elements were divided into those with a first- and second order influence on the customer's decision to adopt a technology. This was done using the body of academic literature to identify the first order elements, and subsequently investigating the inter-element relationships.

When overlooking the insights from the three cases, it becomes clear that these are insufficient to verify the order of the elements. This can be attributed to several reasons. Firstly, while performing the case studies, no measures were included to test the causality of the individual first order elements on a customer's decision to adopt a technology (for example, no customers were approached to identify the elements which led them to adopt a particular technology). Therefore, the results from the case studies lack structured data to substantiate the distinction between first- and second order elements. Secondly, in the case of the high definition optical discs, a de-facto standard emerged because the industry tipped towards one technology. This outcome goes against the starting point in Chapter 2 that a de-facto standard is determined by customers adopting a technology. While the literature on platform technologies highlights the importance of both the network of customers and the network of companies providing complementary products (Subsection 1.1.3.), the literature on network effects only describes tipping on the customer side of the platform (Appendix 1). The case of the high definition optical discs adds the insight that tipping can also occur on the side of the companies providing complementary goods. Although the case of the high definition optical discs is the only known case where the network of complementors tipped, this shows that customers do not always determine which technology emerges as the de-facto standard. Considering that this is a single occurrence, there are insufficient grounds to justify the required substantial modification to the integrative framework. However, as 'tipping the network of complementors' may be encountered more often in the future, it would be interesting to investigate how this would impact the integrative framework. Thirdly, in the case of the high definition audio discs, none of the two rivals emerged as the de-facto standard because they were leapfrogged by a substitute. This case provided support for 'rate and type of technological change' as first order element. From the three case studies, the case of MP3 was the only one which clearly showed that the customer determined the emergence of the de-facto standard. Although the case does not provide insights that oppose the selection of first order elements, this single case and lack of data on the causality between the first order elements and a customer's decision to adopt a technology are insufficient to provide support to the selection of first order elements. This would require further research.

In order to review the inter-element relationships, as defined in Subsection 2.3.2., the set-up of the matrix as shown in Appendix 2 was re-used to note the inter-element relationships as found in the three case analyses (Figure 35 - Figure 39, Figure 50 - Figure 55, and Figure 63 - Figure 67). The results are shown in Appendix 3. The relationships that were found in the case of the high definition optical discs were labelled 'A', those from the case of MP3 were labelled 'B', and those from the case of the high definition audio discs were labelled 'C'. In order to make a good comparison of the two matrices, they were merged (Appendix 4). As noted in Subsection 2.3.2., 122 relationships were found from the academic literature. Appendix 3 shows that 66 inter-element relationships were found in the three case-studies. The combined findings, corrected for the merger of several elements in Subsection 8.1.1., provide 132 relationships. The inter-element relationships found in the three cases mostly support the relationships found in Chapter 2, and they complemented the earlier findings with 21 relationships.

As noted in Subsection 2.3.2., the relationships shown in the graphical representation were the one or two per element that had the highest concentration in the matrix shown in Appendix 2. With the insights of the three case studies, the concentration of the relationships in the matrix has changed. After reviewing Appendix 4, it became apparent that most relationships in the graphical representation could remain shown because the additions were mostly to those relationships that already had a high concentration. The following relationships were hidden or included in the graphical representation:

- The influence of 'entry timing' on the 'availability of complementary goods' was replaced by the influence of 'entry timing' on 'increasing returns to adoption', because this relationship overtook the other in terms of number of sources.
- The element of 'reputation and credibility' was noted to influence entry timing. Firms with a reputation for being innovative may feel pressure to be first to market with a new technology.
- The element of 'rate and type of technological change' was noted to influence the 'level of competition'. When there is a high rate of technological change, the industry will see many new entrants with their own technologies, thus increasing the level of competition.
- The element of 'type of technological innovation' was noted to influence 'appropriability'. A radical technology in general offers a technology sponsor more opportunity to claim intellectual property rights than when a technology is incremental.
- The influence of 'adapters and gateways' on 'backwards compatibility' was replaced by the influence of 'adapters and gateways' on 'switching and homing cost'. The new insights from the cases show that while backwards compatibility often needs to be designed into the technology at an early stage, in the later stages adapters and gateways may be provided to influence the switching and homing cost.
- The element of 'technological breakthroughs in subsystems' was noted to influence 'pricing'. Technological breakthroughs in subsystems often lead to an improvement of the performance or a reduction in the cost of a technology.

As mentioned in Subsection 8.1.1., three new elements were found that can be regarded as third-order elements. Chapter 3, 4 and 7 showed that the elements 'subsidizing providers of complementary goods' and 'accommodating to needs and requirements of providers of complementary goods' influenced the organizational community of supporters. Chapter 3 and 7 showed that the element 'history of the industry' influenced the level of collaborative development.

Lastly, the insights from the case studies (Figure 35 - Figure 39, Figure 50 - Figure 55, and Figure 63 - Figure 67) show that the inter-element element relationships are dynamic throughout the emergence of a de-facto standard: one element may influence another in a particular phase, this may dissolve in the next phase, and become active again in the phase thereafter. In addition, the results of Chapter 6 show that the relationship between elements can be very dynamic, and its nature (i.e. strong or weak influence, positive or negative effect) can change over time.

### *8.1.4. Phases*

When studying the emergence of MP3 as de-facto standard, I found that the five phases as defined by Suarez[582] did not completely fit with my observations. To accommodate for my observations, I added a phase in the process 'winning the mass market' (reflecting the phase when a technology has won from its direct rivals, but still needs to dislodge the existing de-facto standard) and renamed a few of the other phases. The resulting six phases were: R&D Build-up, Preparing for Market Entry, Initiating Market Adoption, Gaining Critical Mass, Winning the Mass Market, Post-Dominance.

Looking back at the emergence of Blu-ray as the de-facto standard, the case analysis stopped at the 'Post-Dominance' phase, while Blu-ray still had to overcome DVD as the de-facto standard. One could argue that Blu-ray could not have been considered as the de-facto standard at that point, and the process was actually in the phase of 'winning the mass market'. Therefore, a sixth phase process could have also been applied to the high density optical disc case, and would have provided a more accurate view by providing the understanding that the case was not in 'post-dominance' yet.

The case of the high definition audio discs shows the limitations of the phases. The six phases were applied, but as a substitute technology leapfrogged both SA-CD and DVD-A, the phase of 'winning the mass market' becomes moot and the transition from the phase of 'gaining critical mass' to 'winning the mass market' becomes debateable; this transition typically occurs when one of the technologies becomes dominant in its initial niche, but when this is caused by the rival's more rapid decrease in sales, it defeats the point. So while the six phases were applicable to this last case, the transition to the later phases becomes more apparent when a technology is successfully adopted.

Overall, it appears that defining the emergence of a de-facto standard as a six-phase process is applicable to all three cases, and adds an important insight to our understanding of the emergence of a de-facto standard; the technology competition initially focuses on the immediate technological rivals, and later transitions to a competition versus the incumbent de-facto standard and technological substitutes.

### *8.1.5. Integrative framework*

The case analysis tool as presented in Subsection 2.5.1. proved to be an important aid in performing the in-depth case studies. It helped to structure the insights gained from executing the initial desk research on a case, and to identify gaps in the case which could subsequently be addressed in the focused interviews.

The combination of the extensive list of elements and the phases of the emergence of a de-facto standard, allowed for a very detailed case description and more thorough understanding of how a technology became the de-facto standard. In the case of the high definition optical discs, 35 elements were identified. 26 elements were identified in the case of MP3, and 30 elements were identified in the case of the high definition audio discs. So by applying the case analysis tool, consistently more elements were found than in previous empirical studies shown by Table 3. In addition, on average 16 elements were identified per phase (the case of the high density optical discs had 89 influences over 5 phases, the case of MP3 had 77 influences over 6 phases, and the case of high definition audio discs had 88 influences over 5 phases). Lastly, the case analysis tool provided all cases with a common basis for the integrative framework and the subsequent case analysis.

When comparing the case analysis tool of each of the cases (Table 14, Table 17, and Table 21), these show that the three technology competitions display a unique pattern; each of the technology competitions show a different composition of elements per phase, and these compositions develop differently over the phases. This provides support to the notion that all technology competitions are unique, and therefore require a framework approach to support strategic decision making.

The integrative framework, in combination with the phases, has shown to provide a fine-grained view of the emergence of a de-facto standard. It takes the elements as found in the case evaluation tool, and graphically adds relevant contextual information such as their category (firm, technology, or market/industry related), the elements by which they are influenced or which they influence themselves, and if they have a direct or indirect influence on the customer's decision to adopt a technology. By applying the integrative framework on the case studies, per case five or six snapshots were generated of the emergence of a de-facto standard. These showed how each phase was comprised of a particular set of elements, how these developed over time, and provided insight in the major shifts in the balance of the type of elements over the course of the emergence of a de-facto standard. The insights gained from the integrative framework had a central role in the case analysis. In addition, in the cases of high definition optical discs and MP3, it led to identifying several elements that proved decisive in the technology competition (as noted in Section 3.7 and 6.6).

In Section 1.4 I noted that the framework should be able to cater to the variety and dynamics of technology competitions. The insights of applying the framework to the three cases confirm that the framework is indeed able to cater to the variety and dynamics of technology competitions. However, as noted in Section 7.8, during all phases it is important to closely monitor the incumbent de-facto standard and any substitute technologies that are also vying to become the de-facto standard. The integrative framework provides a relatively detailed view on a technology competition and offers a strong focus how the odds of technology adoption are shaped, as a consequence these 'higher level' market forces are taken insufficiently into account. Considering that these aspects require a different perspective ('market forces' rather than 'shaping the odds of technology adoption'), it may be wise to adopt an additional framework that can be used to complement to the integrative framework, rather than trying to incorporate these aspects in the integrative framework.

In Subsection 2.5.3., I proposed to score the elements. This turned out to be a valuable addition; whereas the integrative framework can be used to show which elements influenced the adoption of a technology, it does not show how one technology performs versus its rival. The scores provided an insight per phase on which elements the competing technologies had an advantage or disadvantage. In addition, elements that showed distinct advantages/disadvantages for each technology, or a change in the scores over the phases, served as an indicator regarding the importance of those elements to either rival (i.e. showing if both rivals focused on the same elements, or on different elements). As a result, it gave an insight (in hindsight) if the technology sponsors used similar or different strategies to establish their technologies as the de-facto standard. The scoring of the elements was also relevant when I evaluated how the losing side could have shaped the odds in its favour. When considering the scoring options as proposed in Table 10, my experience is that these sufficed; it would not have been beneficial to use fewer options, and it would have been impractical to use a wider range of scoring options because the level of detail for such fine-grained scoring is often not available.

### *8.1.6. Revised integrative framework*

Before moving to the integrative framework, it is relevant to revise the case evaluation tool in accordance with the outcomes of Subsections 8.1.1. to 8.1.5. Table 30 shows the revised case evaluation tool, which now includes six phases, the three additional (third order) elements, and the element of 'Level of collaborative development' as part of the 'market / industry' category.

Table 30: Revised case evaluation tool

| | | R&D Build-up | Preparing for market entry | Initiating market adoption | Gaining critical mass | Winning the mass market | Post-dominance |
|---|---|---|---|---|---|---|---|
| Firm | Reputation and credibility | | | | | | |
| | Installed base | | | | | | |
| | Pricing | | | | | | |
| | Entry timing | | | | | | |
| | Marketing and pre-announcements | | | | | | |
| | Availability of products | | | | | | |
| | Availability of complementary goods | | | | | | |
| | Killer application | | | | | | |
| | Size | | | | | | |
| | Complementary assets | | | | | | |
| | Technological knowledge and skill base | | | | | | |
| | Absorptive capacity | | | | | | |
| | Pre-empting scarce assets | | | | | | |
| | Level of collaborative development | | | | | | |
| | Organizational community of supporters | | | | | | |
| | Strategic partnerships | | | | | | |
| | Product proliferation | | | | | | |
| | Appropriability | | | | | | |
| | Subsidizing providers of complementary goods | | | | | | |
| | Accessible intellectual property rights | | | | | | |
| | Chance | | | | | | |
| | | | | | | | |
| Technology | Technological superiority | | | | | | |
| | Installed base | | | | | | |
| | Network effects | | | | | | |
| | Switching and homing cost | | | | | | |
| | Backward compatibility | | | | | | |
| | Increasing returns to adoption | | | | | | |
| | Technological breakthroughs in subsystems | | | | | | |
| | Type of technological innovation | | | | | | |
| | Adapters and gateways | | | | | | |
| | Chance | | | | | | |
| | | | | | | | |
| Market / industry | Market and industry characteristics | | | | | | |
| | Level of competition | | | | | | |
| | Rate and type of technological change | | | | | | |
| | Network effects | | | | | | |
| | Availability of products | | | | | | |
| | Availability of complementary goods | | | | | | |
| | Killer application | | | | | | |
| | Level of collaborative development | | | | | | |
| | Government intervention and industry regulation | | | | | | |
| | Product proliferation | | | | | | |
| | Appropriability | | | | | | |
| | History of the industry | | | | | | |
| | Chance | | | | | | |

Now, moving to the integrative framework, this can be revised using the outcomes of Subsections 8.1.1. to 8.1.5. Figure 79 shows the revised integrative framework. It shows much resemblance to Figure 27, but includes the additions of the third order elements, whilst overall being more parsimonious.

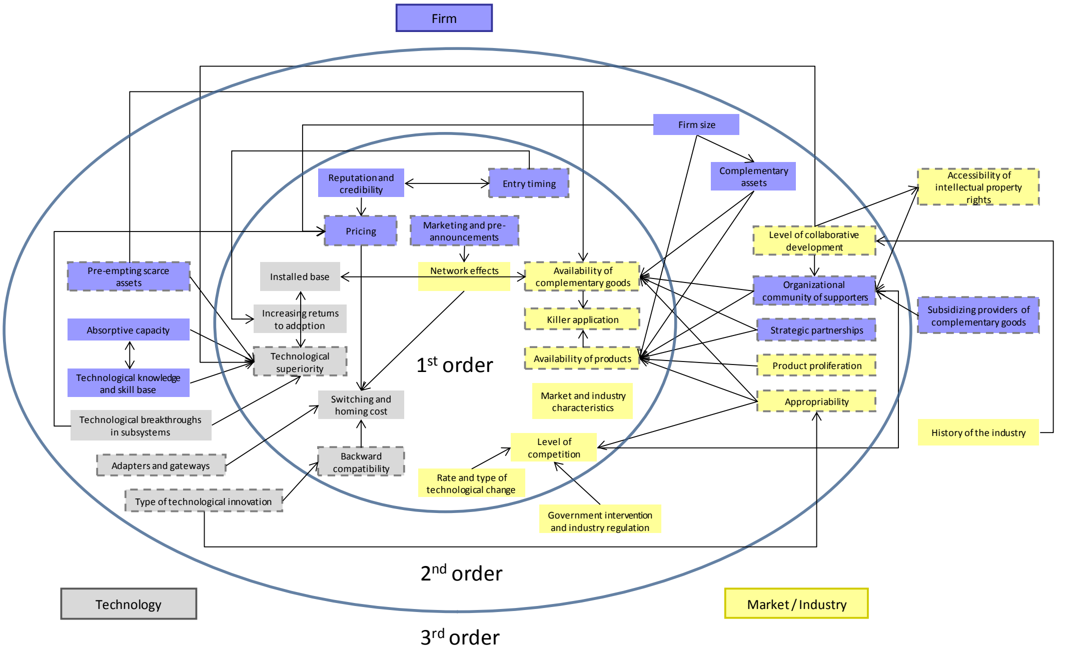



*Figure 79: Revised integrative framework*

Figure 79 needs to be used in conjunction with the phases and milestones of the emergence of a de-facto standard. Figure 80 shows the revised phases and milestones, based on Subsection 8.1.4. For clarification, I will provide a short description of the revised phases and milestones. The start of the R&D Build-up can be traced back to the moment when a pioneer firm or research group starts doing applied R&D aimed at the technological innovation. The appearance of the first working prototype based on that innovation marks the start of the Preparing for market entry phase. The phase of Creating the market is marked by the launch of a first commercial product of the new technology. This first commercial product is often aimed at a particular niche which fits well with the specific features and benefits that are offered by the new technology. After several technological rivals have entered that niche, the market starts showing a pattern in the adoption of the technologies. The phase of Gaining critical mass starts when this pattern shows a clear market preference for one of the technologies. This front runner has the best chance of winning the competition, as its larger market share tends to create a bias towards the technology. At some point, one technology may obtain a dominant market share in its initial niche (for Blu-ray this was the niche of high definition movies, and for MP3 this was the niche of music distribution over the WorldWideWeb), and the competition progresses to the next phase 'Winning the mass market' where it needs to dislodge the incumbent de-facto standard in the product category (for Blu-ray this was DVD, and for MP3 this was CD) while competing against technological substitutes. Once the technology manages to obtain widespread acceptance (>50% market share in the product category), it has become the new de-facto standard. This marks the beginning of the final phase of Post dominance.

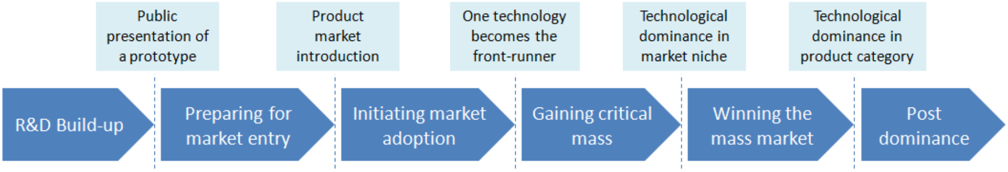


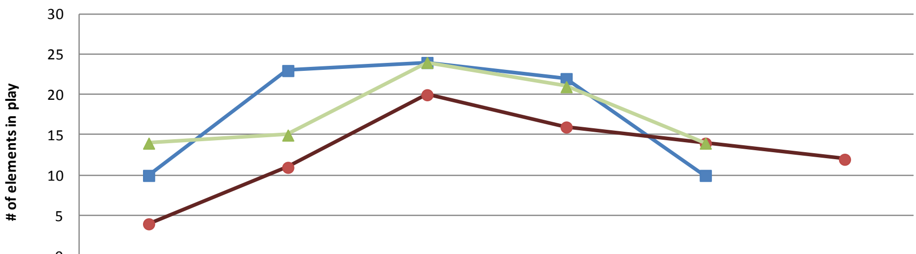

*Figure 80: Revised phases in the emergence of a de-facto standard*

As noted in Subsection 8.1.5., one can further enhance the insights from the integrative framework by scoring the elements.

## 8.2 Patterns across the cases

Although Subsection 8.1.5. points out that all cases display a unique pattern, this section investigates if there are certain patterns that can be found across the cases. These may complement the integrative framework and provide additional insights on how firms can shape the odds of their technology emerging as the de-facto standard.

Let's first look at how the number of elements developed over the phases in the three cases. Figure 81 shows the number of elements that were found per phase in each of the cases. It shows that early in a technology competition only a few drivers need to be taken into account. In the subsequent phases the number of elements expands cumulatively because the influence of an element often influences the technology competition during multiple phases. The number of elements culminates during the phase of Initiating market adoption, and slowly decreases thereafter.




| | R&D Build-up | Preparing for market entry | Initiating market adoption | Gaining critical mass | Winning the mass market | Post-dominance |
|---|---|---|---|---|---|---|
| Blu-ray vs. HD-DVD | 10 | 23 | 24 | 22 | 10 | |
| MP3 | 4 | 11 | 20 | 16 | 14 | 12 |
| SACD vs. DVD-A | 14 | 15 | 24 | 21 | 14 | |

*Figure 81: Number of elements in play per phase per case*

As noted in Subsection 8.1.5., each phase in the three case studies was marked by a different subset of elements, resulting in a different dynamic per phase. In addition, shifts in the balance of the type of elements were identified over the course of the emergence of a de-facto standard. However, following a close analysis of the commonalities between the three cases (shown in Appendix 5, main commonalities are highlighted per phase), I found they all share a common set of dynamics that govern technology competitions. This common set of dynamics is complemented by elements that make the technology competition unique and requires strategic decision making to shape the odds. An overview of the common dynamics per phase is shown in Table 31. The following sections provide a description of the common dynamics per phase.

Table 31: Common dynamics during the emergence of a de-facto standard

| Phase | Common dynamics |
|---|---|
| R&D build-up | Determine technological positioning and level of collaborative development |
| Preparing for market entry | Build the organizational community of supporters |
| Initiating market adoption | Jump starting increasing returns |
| Gaining critical mass | Tip the network of customers or complementors |
| Winning the mass market | 4 Ps of marketing, economies of scale, and incremental product improvements |
| Post dominance | Create lock-in and leverage to adjacent markets |

**R&D build-up: Positioning the technology and level of collaborative development**

In the R&D build-up phase, the technology sponsor needs to make several key trade-offs concerning the positioning of his technology. The trade-offs concern the technological superiority, pricing, backwards compatibility, and switching cost. These are themselves also influenced by the type of technological innovation, technological breakthroughs in subsystems, the firm's absorptive capacity, technological knowledge and skill base, the level of collaborative development, and strategic partnerships. Ideally, one would develop a technology to be (backwards) compatible, technological superior and with an attractive price level. However, technological superiority and (backward) compatibility tend to increase the price. The difficulty lies in finding a good balance, which needs to appeal to the customer and potential partners. The positioning can be used to distinguish a technology from its alternatives.

After the initial R&D, but before publicly presenting a prototype, the technology sponsor needs to consider 'if', 'at what point' and 'with whom' it would like to engage into collaborative technology development. It is a trade-off between letting other companies participate in refining the technology versus the risk of losing grip over the direction of technological developments and sharing potential license revenues. This decision can be based on an assessment of the chances of a firm to achieve dominance by itself (which is dependent on *firm size, complementary assets, reputation, installed base, and superiority of its technology*), the *market and industry characteristics* and the strategy of its rivals. This decision will influence the *level of competition* in the industry. The cases of high definition optical discs and high definition audio discs showed that starting the collaborative technology development during the phase of R&D build-up positively influences the *organizational community of supporters* at a later stage. However, the more parties involved in the collaborative process, the longer the time-to-market of a technology will be.

**Preparing for market entry: Build the organizational community of supporters**

While preparing for market entry, the technology sponsor needs to build-up the organizational community of supporters (i.e. complementors and/or competitors) in order to outperform its rivals regarding the availability of products and/or complementary goods when entering the phase of 'Creating the market'. As described in Appendix 1, the community of supporters can be built through licensing and OEM agreements. In addition, the organizational community of supporters can be stimulated by engaging into collaborative technology development, strategic partnerships, pre-empting scarce assets (identifying key companies and providing these with preferential treatment), subsidizing providers of complementary goods, accommodating to needs and requirements of providers of complementary goods (as noted in Subsection 8.1.7.). Organizations are more prone to support a particular technology when it is first to market, superior to its rivals, has an advantage in terms of installed base, the technology sponsor is a large firm that has a good track record in establishing de-facto standards, it believes the technology will become successful (perhaps due to perception, shaped by marketing), and when collaboration is common practice in the industry.  Alternatively, organizations are less prone to support a particular technology when there is much competition in the industry and when rival technologies are sponsored by powerful companies, or when the technological innovation requires a different skill set or complementary assets.

**Creating the market: Jump starting increasing returns**
Moving into the next phase, all three cases showed a shift from technology related elements to firm- and market/industry related elements. This is because the technology sponsor shifted their focus towards jump-starting the two processes with a positive feedback loop; increasing returns to adoption and network effects. The technology sponsors used the following elements to jump-start the increasing returns: entry timing, pricing, marketing and pre-announcements, availability of products, availability of complementary goods, and killer applications.

When combining the insights from the cases with the insights from the academic literature, one can state that the chance of successfully jump starting the increasing returns processes improves when a company is first to market, has a good reputation, applies penetration pricing, actively markets its technology and uses pre-announcements to shape expectations regarding the technology, uses its installed base to leverage clients towards the new technology, enables large availability of products and complementary goods, and the technology has a better match with customer requirements than the technological rivals, and is backwards compatible with the incumbent de-facto standard. Elements such as a high rate of technology change, heterogeneous customer needs and unclear assessment criteria will hamper technology adoption and the increasing returns.

**Gaining critical mass: Tip the network of customers or complementors**
In this phase one of the rival technologies competing for adoption has gained a front runner position (a lead in terms of installed base). In markets with strong increasing returns, this advantage will enhance the market adoption of the technology and attract more providers of complementary goods. In markets with weak network effects, or when the network of customers or complementors has not reached the critical mass required for tipping, a technology sponsor may provide stimuli. The cases and academic literature[583] provides the following elements to stimulate tipping:

- Tipping network of customers: product proliferation, influence market perception through marketing, penetration pricing, introduce a killer application.
- Tipping network of complementors: subsidizing providers of complementary goods, influence market perception through marketing.

Winning the mass market: 4 Ps of marketing, economies of scale, and incremental product improvements
Now that the technology has bested its rivals in the initial market niche, it has gained substantial momentum, a sizeable installed base, and an organizational community of supporters. In this phase the focus of the strategic efforts shifts towards conventional ways of market competition, known as the four Ps of marketing; product variety, price, place (channels, locations), and promotion.[584] Now that the technology has gained critical mass, manufacturing will start to benefit from economies of scale, which result in lower manufacturing cost and consequently lower prices. This will make the technology more attractive to the mass market, spurring adoption, and leading to further economies of scale. In addition, incremental improvements will make the technology more attractive to the customers. These dynamics coincide with those attributed to the transitional phase of Utterback and Abernathy's model of product and process innovation (Figure 7).

**Post dominance: Create lock-in and leverage to adjacent markets**

In the phase of Post dominance, it is important to create lock-in and leverage the strong market position to adjacent markets. The appearance of a de-facto standard shifts the competitive emphasis to cost efficiency.[585] If companies, specialized in low cost production, are able to copy the de-facto standard, they could potentially reap most of the benefits. This means that appropriability, on both the firm and industry level, becomes important in this phase. In addition, by tightly controlling its complementary assets, a technology sponsor creates entry barriers for potential competitors and can realize cost reductions.[586] In addition, the technology sponsor can evaluate if it can leverage its technology to adjacent markets, as was done very successfully with the Compact Disc.

The dynamics described above can complement the revised integrative framework (Figure 79) and provide insight regarding the focus areas for strategic decision making per phase of the emergence of the de-facto standard.

## References Chapter 8

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# Chapter 9 - Concluding remarks and contributions

This chapter will first reflect on the research questions of Section 1.4. Subsequently the theoretical and managerial contributions are summarized. Lastly, a critical reflection on the theoretical and methodological limitations is provided, including suggestions for future research.

## Main findings

The results from this dissertation show that every technology that emerges as de-facto standard displays a unique path. This provides support to the notion that all technology competitions are unique, and therefore require a framework approach to support strategic decision making. In addition, the results confirm that companies can shape the odds of their technology emerging as de-facto standard through strategic decision making, however the outcome does not solely rely on strategic decision making. Over the course of this dissertation, I developed and tested an integrative framework that adheres to the following requirements:

- Shall be able to support strategic decision making to shape the odds of a technology emerging as the de-facto standard;
- Shall provide an integral approach (covering the various aspects relevant for strategic decision making);
- Shall be able to cater to the variety and dynamics of technology competitions.

The result is presented in Section 9.2 as the primary theoretical contribution. The framework is the result of several research questions, of which the findings are summarized below.

### *9.1.1. What are the various elements of the emergence of a de-facto standard that we would need to incorporate in the framework?*

Following an extensive review of the academic literature, insights from three in-depth case studies, and evaluation of the relevance of the individual elements, in total 34 unique elements[587] were found to influence the emergence of a de-facto standard. An overview of these elements can be found in Figure 79.[588]

### *9.1.2. How to integrate the elements in a framework?*

Using the insights from the academic literature and the in-depth case studies, the 34 elements were first allocated to three categories: firm-, technology-, and market/industry related. 12 were found to be firm-related, seven were technology-related, five were market/industry related, and 10 could be allocated to multiple categories. Then they were divided into those with first, second and third order influence on a customer's decision to adopt a technology. This resulted in 16 first-order, 14 second-order, and three third-order elements. One, the element of chance, was applicable to all categories and level, and was therefore excluded from the framework. The result was nine groups of elements, which could be graphically represented by placing the customer in the centre and placing the respective elements around this centre in a layered approach. The academic literature and in-depth case studies also provided insight in the inter-element relationships. In total, 132 inter-element relationships were identified, of which the most important ones were included in the graphical representation of the framework. The final version of the framework is shown by Figure 79.

*9.1.3. Which phases and milestones can we identify in the emergence of a de-facto standard?*

Following a review of the academic literature, and insights from three in-depth case studies, I found that the emergence of a de-facto standard can be divided into six phases: R&D build-up, Preparing for market entry, Creating the market, Gaining critical mass, Winning the mass market, and Post dominance. These phases and their respective milestones are shown by Figure 80. The start of the R&D Build-up can be traced back to the moment when a pioneer firm or research group starts doing applied R&D aimed at the technological innovation. The appearance of the first working prototype based on that innovation marks the start of the Preparing for market entry phase. The phase of Creating the market is marked by the launch of a first commercial product of the new technology. This first commercial product is often aimed at a particular niche which fits well with the specific features and benefits that are offered by the new technology. After several technological rivals have entered that niche, the market starts showing a pattern in the adoption of the technologies. The phase of Gaining critical mass starts when this pattern shows a clear market preference for one of the technologies. This front runner has the best chance of winning the competition, as its larger market share tends to create a bias towards the technology. At some point, one technology may obtain a dominant market share in its initial niche, and the competition progresses to the next phase 'Winning the mass market' where it needs to dislodge the incumbent de-facto standard in the product category while competing against technological substitutes. Once the technology manages to obtain widespread acceptance (>50% market share in the product category), it has become the new de-facto standard. This marks the beginning of the final phase: Post dominance. My research confirms Suarez's[589] notion that each technology competition progresses through the same phases.

*9.1.4. How can the framework be applied to technology competitions?*

In order to address this research question, I selected three cases and applied the framework to these. For each case first the timing of the respective milestones and phases had to be defined. Subsequently, the relevant elements per phase could be identified using written documents, public announcements and focused interviews with key persons from companies involved in the respective technology competitions. The case analysis tool was used as a checklist, the integrative framework can be seen as the starting point, whereby an overview of the situation is gained by eliminating elements from the framework that are not applicable to the phase. This approach worked well for each of the cases, and especially for the technology competitions wherein a de-facto standard emerged; in one of the cases both competing technologies did not become the de-facto standard and this caused some difficulties in defining the milestones in the later phases. While working on the case analysis, the insights gained from the framework showed several advances over the existing academic literature:

- A much more comprehensive insight in technology competitions and the emergence of de-facto standards, leading to a better understanding of the dynamics and the differences / commonalities between technology competitions;
- It allowed for a better insight in the strategic approaches of the rival technology sponsors during the emergence of the de-facto standard;
- It enabled an analysis on how, in hindsight, the losing side could have shaped odds of its technology to emerge as the de-facto standard;
- Out of the comprehensive number of elements that were found to influence each of the technology competitions, a subset of key elements could be identified which proved to be decisive in the process. These decisive elements, and their number, differ per case.

## 9.2 Contributions, Implications & Discussion

*9.2.1. Theoretical contributions and implications*

The results of this dissertation have implications for the strategic-choice view in the literature on de-facto standards. The primary contribution of this dissertation is the integrative framework that can be used to support strategic decision making to shape the odds of a technology emerging as the de-facto standard. Figure 82 shows a graphical representation of the framework, which includes elements influencing the emergence of a de-facto standard (e.g. market mechanisms, models for creating a technological bandwagon, elements for shaping the odds of technology selection), scoring options, phases and milestones in the emergence of a de-facto standard, and dynamics which are typical for each of the phases. Although the framework draws upon many findings from the existing body of academic literature, the novelty lies in the way these are combined. This enabled new insights in accordance with the findings described in Subsection 9.1.4.

In addition, the approach of the framework is novel; it requires the researcher to delineate the timing of the start and end of the phases in the emergence of a particular de-facto standard, and to identify per phase which subset of the 33 elements influenced the technology competition. By combining the concept of phases with a 'menu' of elements, the result is a framework that is able to cater to the variety and dynamics of technology competitions. The literature provides static models which suggest a 'recipe for success' (Lee et al.[590], Gallagher and Park[591], Suarez[592]), but these are not robust as technology competitions in practice are all different and dynamic: my research confirmed that the emergence of every de-facto standard displays a unique 'path'. In addition, technology competitions require trade-offs: i.e. while one could recommend that a technology sponsor should be the first to market with a technologically superior product that is backwards compatible with the incumbent de-facto standard and conveniently priced, this neglects the issue that technological superiority requires a type of innovation is marked by a long development time, and results in relatively expensive products that may lack backward compatibility. Rather than providing a 'recipe for success', the framework aims to support the strategic decision maker through a series of questions:

- Which phases of the technology competition can be defined, and in which phase are we currently?
- Which elements are influencing the technology competition in each of the phases?
- When applying scores to those elements, what can be learnt regarding the position of a technology versus its rival?
- When considering the common dynamics, the elements in play and scores, which actions should be taken, and which elements for strategic decision making could be utilized?

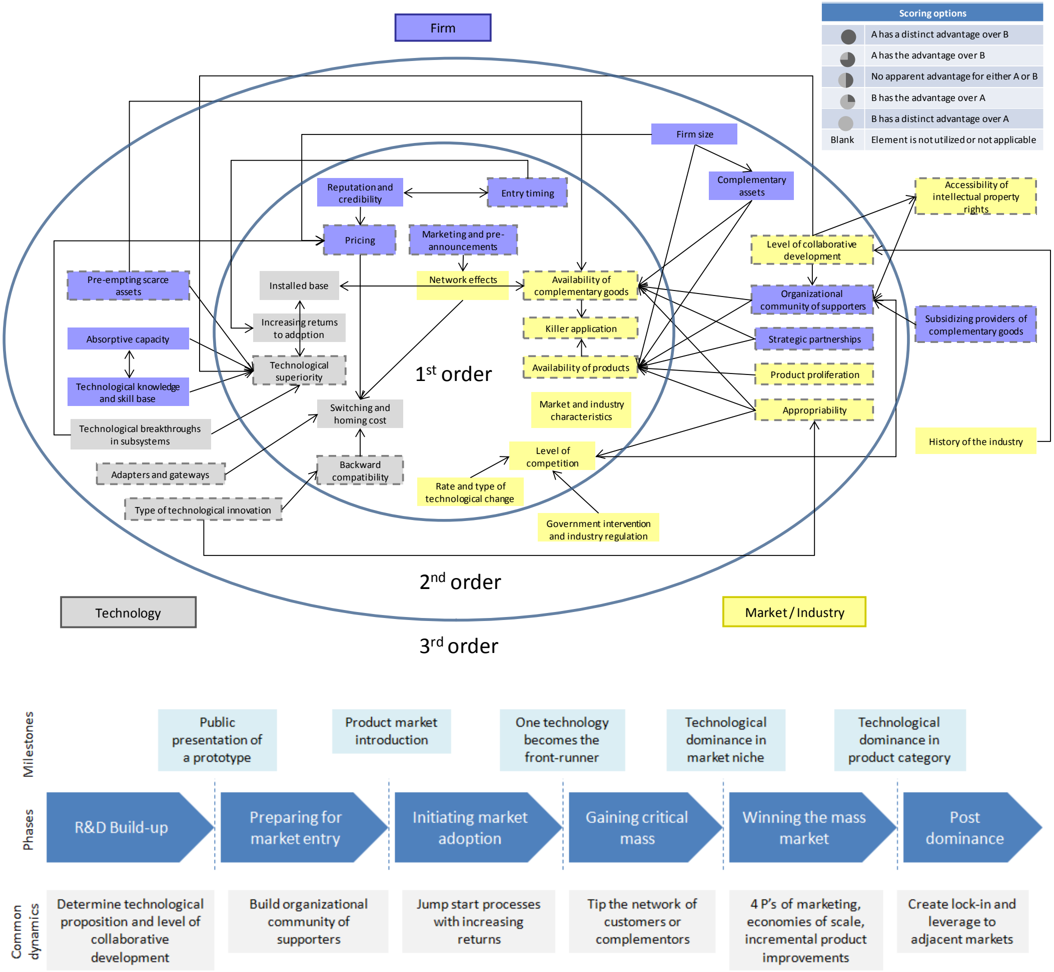


*Figure 82: Integrative framework, scoring options, phases and milestones of the process, and common dynamics*

The separate parts of the framework also contain contributions:

- My results suggest that the emergence of de-facto standards is better understood when adding a sixth phase (Winning the mass market), between Suarez's[593] fourth- and fifth phase (respectively 'decisive battle' and 'post dominance').
- Common set of dynamics that govern technology competitions. Although literature related to the strategic-choice view often provides suggestions regarding the elements that are important in the emergence of a de-facto standard (Grindley[594], Shapiro[595], Hill[596]), these do not take into account that the relevance of the elements may change during the emergence of the de-facto standard. Suarez[597] suggests that the relevance of the elements changes during the process. However, his 'key elements of success at each stage of the dominance process' lack empirical evidence. In order to advance this part of the literature, I studied the common patterns across the case studies. This resulted in identifying the main attention points per phase, providing guidance on the subset of elements that are especially relevant for each phase. These research findings complement Suarez's

‘key elements’ with new insights. Besides their theoretical contribution, they primarily have managerial relevance.

The results of my research also contribute to the field of network externalities. The body of literature (e.g. Arthur[598], Hill[599]) describes the notion of ‘tipping’, but only with regard to the customer network. The case of the high definition optical discs showed that it is possible to tip the network of companies providing complementary goods. In effect, it shows that two-sided tipping possible: a de-facto standard can emerge not only by customer-driven process, but also by industry-ecosystem driven process. This sheds new light on the element ‘size of the organizational community that supports a technology’. Although previous research has shown that this element is important,[600] my research has shown that it can be decisive in the emergence of a de-facto standard.

Another contribution concerns the elements that influence the emergence of a de-facto standard. In the body of literature, merely a few have undertaken an effort to provide a comprehensive overview of elements that influence the emergence of a de-facto standard. A notable, recent, effort was done by Van de Kaa et al. [601], whom studied 127 sources and identified 29 elements. In my research, I identified 34 unique elements, thereby extending the current state-of-the-art by five elements. Of these elements, three were newly found during the case studies, i.e. accommodating to needs and requirements of providers of complementary goods, subsidizing providers of complementary goods, history of the industry, and accessibility of intellectual property rights.

The results of my research also contribute to the field of inter-element relationships. Whereas previous studies have thoroughly studied the causality between a few elements (e.g. Katz and Shapiro[602], Farrell and Saloner[603]), in my research these were combined into a more comprehensive overview, complemented with insights from three case studies. In total, 132 inter-element relationships were identified: 114 relationships were deduced from the body of literature, the results from the case studies in this dissertation led to an additional 18 relationships. This constitutes a far more comprehensive overview than can be found in the current body of literature. The overview adds to our understanding about the interrelatedness of the elements, helps us to better understand what may cause the status change of an element, and which other elements may be affected when a status-change of a particular element occurs. In addition, the results show that inter-element relationships are dynamic: throughout the emergence of a de-facto standard the relationship between two elements may be intermittent, and the nature of the relationship (i.e. strong or weak influence, positive or negative effect) can change over time.

In the body of literature on de-facto standards, studies can be found that either provide an extensive number of elements (Van de Kaa et al.), provide a limited set of elements that directly influence the emergence of a de-facto standard (Suarez[604], Lee et al.[605]), or provide a model of elements which directly/indirectly influence a particular aspect of de-facto standards (Schilling[606], Gallagher and West[607]). Gallagher and Park[608] presented a framework that combines the latter two aspects. Their framework is comprised of 11 elements, and includes the notion that elements can have a direct and indirect influence on ‘competitive success’. They propose two first order-, seven second order-, and two third order elements. The integrative framework that resulted from my research comprised of 16 first order-, 14 second order-, and three third order elements. The integrative framework therefore provides a more comprehensive insight in the direct and indirect influences on a customer decision to adopt a particular technology, which allows researchers to better understand the outcomes of technology competitions.

If we focus on the elements with a first order influence on a customers' decision (i.e. the most relevant elements), there are two frameworks in the body of literature that approximate the overview of first order elements provided in this dissertation: one from Suarez[609] (shown in Figure 22), and one from Gallagher and West[610] (shown in Figure 13). Table 32 shows the list of first order elements in this dissertation, and a comparison with Suarez, and Gallagher and West. The number of first order elements in my integrative framework extends those of Suarez by six elements, and those of Gallagher and West by four elements. This translates into an increase of 60% and 33% respectively. In addition, the lack of second and third order elements, and phases in the process of the emergence of a de-facto standard, hampers their models' ability to clarify how the technology competition was shaped over time.

Table 32: Comparison of first order elements with frameworks from literature on de-facto standards

| Elements with first order influence | Suarez (2004) | Gallagher and West (2009) |
|---|---|---|
| Firm reputation and credibility | X | X |
| Entry timing | X | X |
| Pricing | X | X |
| Marketing and pre-announcements | X | X |
| Installed base | X | X |
| Availability of products | | X |
| Availability of complementary goods | | X |
| Killer application | | X |
| Network effects | X | X |
| Increasing returns to adoption | | |
| Technological superiority | X | X |
| Switching and homing cost | X | X |
| Backward compatibility | | X |
| Market and industry characteristics | X | |
| Level of competition | X | |
| Rate and type of technological change | | |

Out of the comprehensive number of elements that were found to influence each of the technology competitions, it was possible to identify a small subset of 'key elements' that proved decisive in the process. One could question if the elaborate integrative framework is required to identify the decisive elements: as noted in Subsection 3.8.2., Gallagher and West[611] managed to indentify the same two decisive elements in their study on the high definition video discs, using a model with 13 elements. However, as Section 6.6 shows, there were nine key elements in the case of MP3. Of these nine, there was one common element (killer application) between the two cases. Five of the elements are not part of Gallagher's framework, and would have likely been missed. The insights from the two cases indicate that the decisive elements, and their number, differ per case. As the decisive elements are a subset of the total number of elements that influence the emergence of a de-facto standard, an elaborate framework is required to ensure identification of all elements that may turn out to be decisive.

This dissertation contributes to extending the definition of 'de-facto standards', by providing an integral view of the concepts 'compatibility standard', 'dominant design', and 'platform'. One could say it is a pity that the academic field is fragmented in its terminology for studying de-facto standards, but this would not do justice to the underlying issue that the phenomenon of de-facto standards is multi-faceted: the three concepts actually highlight these different facets. Current literature, however, falls short in linking the three concepts together. This makes it difficult to combine the insights from the three fields, and to identify where they complement each other. To overcome this, I illustrated the overlap and boundaries between the concepts through 19 examples of de-facto standards (Figure 4). This integral view shows that technologies can be allocated to six distinct categories, whereby one needs to consider that market adoption of compatibility standards, platforms and product design specifications is governed by specific dynamics. The implications for academia are twofold. Firstly, it provides additional limitations to the generalization of case study results; while USB, the Ford Model-T and Google's web search engine are all examples of de-facto standards, whatever caused their success cannot be generalized to all de-facto standards. Secondly, for academics that perform multiple case study research in the field of de-facto standards, it is important to allocate their cases to the six categories in order to check if the fit between the cases is sufficiently close to support analytic generalization.

|  |  | Firm C and D |  |
|---|---|---|---|
|  |  | Lead | Follow |
| Firm A and B | Lead | (1,19)<br>(19,1)<br>(1,-1)<br>(-1,1) | (20,10) |
|  | Follow | (10,20) | (15,15) |

*Figure 83: 'Competition of the industry consortia' game*

The insights from this research can also be used to provide contributions to other fields, such as the literature on game theory (i.e. collective-action view). As described in Subsection 1.2.3, Grindley provides examples of two 'games'; 'Battle of the sexes' and 'Rather fight than switch' (Figure 15 and Figure 16 respectively). But when overlooking the optical disc technologies which were studied in this dissertation (i.e. CD, DVD, SA-CD and Blu-ray), a game as shown in Figure 83 provides a more accurate representation for industry consortia in winner-take-all markets. This can be explained based on the optical disc technologies. Starting with the parties involved, Firm A and B in Figure 83 could be substituted for Toshiba and Panasonic, and Firm C and D could be substituted for Sony and Philips. Let's assume that the potential revenue from a de-facto standard is '30' for all parties involved (please note that this is a fictitious number, and purposefully no measure is used). As this game has a 'winner-take-all' outcome, the revenue from the de-facto standard is optimal when all parties collaborate or when one side follows the other, i.e. they all support the same technology and differentiate on product implementations. In such a situation there is no confusion in the market, and the technology has significant industry support which will lead to rapid market adoption. The main difference is the distribution of the benefits; when all parties collaborate, the gains are shared (more-or-less) evenly, whereas the situations in which one side leads and others follow will results in more benefits to accrue at the leading side. These two situations can be illustrated by CD and DVD. In the case of CD, Toshiba and Panasonic followed Sony and Philips which led to a large market for the CD whereby all parties reaped the benefits. However, Sony and Philips reaped more benefits than others due to licensing income on the intellectual property rights. In the case of DVD, both sides merged their technologies before entering the market due to pressure from their customers (especially the PC industry). This unified format resulted in rapid market adoption of the DVD technology whereby the contributors benefitted (relatively) evenly. In the case of a technology competition (also known as 'standards battle' or 'format war') a situation as shown in the top-left quadrant will occur. In this situation, the competition will hamper market adoption of the new technologies, the incumbent de-facto standard will maintain its market position for a longer time, and therefore the total potential revenues from the de-facto standard will be '20' for all parties involved. However, an alternate scenario is possible, whereby the sponsors of both technologies lose, which results in a total value of '0'. These two situations can be illustrated by SA-CD and Blu-ray. In the case of SA-CD vs. DVD-A, Sony and Philips had a lot to lose (they were benefitting from their lucrative position in CD). So when Toshiba and Panasonic announced the development of DVD-A, Sony and Philips were reluctant to give up their position and invested in developing a competing technology. As a result, both technologies came on the market and competed for adoption. This competition hampered the market adoption, but nonetheless both sides invested heavily to obtain an outcome as displayed top left (1,19) or (19,1). However, the technologies were leapfrogged by an alternative (MP3), and the outcome was a result as displayed in the bottom of the top-left quadrant (-1,1). DVD-A was removed from the market, and its sponsors had to take a loss while having no possibility to recoup it. SA-CD remained on the market but made little return-on-investment. In the case of Blu-ray, Sony and Philips were the first to announce the development of a new technology, and they made an effort to involve other parties. As the move represented merely a shift from the lower-right quadrant (DVD) to the top-right quadrant, Sony and Philips were quite successful in obtaining support for their technology (e.g. from Panasonic). However, Toshiba aimed to defend its position in DVD and invested in the development of a competing technology, HD-DVD. The resulting competition slowed down the market adoption of both technologies, and both sides aimed for the outcome in the top-left quadrant. After a few years, Blu-ray emerged as the victor, and Toshiba had to take a significant loss. Toshiba is nowadays a member of the Blu-ray Disc Association and offers its own Blu-ray products to recoup its losses.

Lastly, my research provides a methodological contribution. The body of literature lacks guidelines or tools for performing case studies on de-facto standards, which limits the measure to which case studies can be compared to each other. This dissertation presents a framework for studying the emergence of de-facto standards, called 'the case evaluation tool'. Instructions are provided on how to use this framework, so other researchers can use it to systematically collect all the relevant details, and obtain the required in-depth insights.

### *9.2.2. Implications for practice*

Although one could argue that any contribution to the 'strategic-choice view' has practical relevance, this section will focus more specifically on how the theoretical contributions translate into practical implications.

First, the results of this dissertation support that executive teams need to treat the emergence of a de-facto standard as a highly dynamic game between multiple technologies that compete for market adoption. To provide an accessible explanation how executive teams need to approach the emergence of a de-facto standard, I will provide an explanation based on a commonly known game. Based on the insights of this dissertation, I believe the emergence of a de-facto standard can be compared to the game of chess. In chess, many different situations are possible, but the game is comprised of several phases (i.e. the opening, mid-game, and end game). For each phase there are generic guidelines that serve as heuristics to help the player to determine its moves. Each player has 16 chess-pieces on the board which he can use as instruments to influence the game. When playing a move, a player takes into account his own strategy and the need to respond to the actions of the opponent.

Instead of three phases, my research shows that the emergence of a de-facto standard can be regarded as a six-phase process whereby transitions are marked by milestones. As in chess, there are generic guidelines that apply for each phase. These function as heuristics that provide guidance to the executive teams regarding the relevant matters to address in any particular phase of the technology competition, and to consider the strategic decisions that need to be made in the next phase. As analogy to the 16 chess-pieces, in total 40 elements were found to influence the emergence of a de-facto standard, whereby my research identified 19 to be subject to strategic decision making. Of these, eight have first order-, eight second order-, and three a third order influence on the decision of a customer to adopt a particular technology. Of the elements that are subject to strategic decision making, the eight first order elements (i.e. pricing, entry timing, marketing and pre-announcements, availability of products, availability of complementary goods, killer application, technological superiority, and backward compatibility) exert most influence on the customers' decision. Hence, these are naturally the ones which require an executive teams' closest consideration. But considering that the first, second, and third order elements are interrelated, the second and third order elements should not be forgotten. Instead, they should be considered as a means to obtain an advantage in all first order elements, even those outside a firms' scope of control. The cases of high density optical video discs and compressed audio files show that by using these elements, executive teams are capable of shaping the odds of technology selection. However, the case of high definition audio discs shows that the outcome of a technology competition can be heavily influenced by matters outside a firms' scope of control. Per phase the studied technology competitions showed a different composition of elements that influenced the competition. The composition of elements throughout the phases of the emergence of the de-facto standard was unique for each of the studied technology competitions. The three in-depth case studies have also shown that the technology competitions have an action-response dynamic; the technology sponsors respond to each others' moves. The matters above are captured in a framework (Figure 82) that can be used by executive teams to assess the technology competition and provides guidance by asking the right questions.

The case studies of the high density optical video discs, compressed audio files, and high-definition audio discs (Chapter 3-5) provide examples of technology competitions, which in itself are useful for executive teams that aim to establish their technology as the de-facto standard. Again, drawing the analogy to chess; by studying recorded matches, one can gain insights regarding the tactics and moves that have worked well, or did not work well, in the past. When facing a specific situation that requires strategic decision making, executive teams may use their repository of knowledge of previous technology competitions to generate reference points.

In Chapter 6, the research focused on the relationship between 'collaborative technology development' and the 'organizational community of supporters', and bared several practical implications. Firstly, the outcome of technology competitions is influenced by the amount of industry support for the respective technologies, including their willingness to use the technology in their products, therefore it is important to involve a variety of manufacturers and in some cases also professional customers in the development of the technology. This includes adapting the standard to meet their requirements, if necessary. Involving other parties can be done before they belong to the network, in order to persuade them to join, but also once they have joined (i.e. by providing opportunities to propose modifications to the technology). Secondly, the timing of incorporating changes is important for success. The results suggest that it is appropriate to start with just a few actors who possess essential know-how. The network can then be gradually extended further to enable a large and diverse group, which is essential for broad market acceptance and to avoid that essential stakeholders join a competing alliance. The required speed also depends on what the competing standards alliances, if any, do. Creating a layered network structure in which contributors are differentiated from adopters in terms of privileges and voting rights keeps the processes manageable.

Lastly, the research in Chapter 7, which focused on the role of 'accessibility of intellectual property rights' in the framework, resulted in a managerial contribution; a novel model for patent pool lifecycle management (Figure 77, Figure ***78***, and the corresponding explanation in Section 7.3). This model is applicable for technologies that have been developed through a collaborative effort, whereby an executive team can utilize it to establish and manage a patent pool. When establishing a patent pool, the team needs to select a patent pool model (i.e. a joint licensing program, a regular patent pool, or a pool-of-pools). In addition, it needs to manage a patent pool through the four stages of its lifecycle (i.e. investigation, formation, gaining traction, and maturity). A patent pool can provide potential supporters with easy access to the technology's intellectual property rights, and therefore enable a larger organizational community of supporters.

## 9.3 Limitations and further research

*9.3.1. Theoretical limitations*

Although my research addressed the research questions as set out in Section 1.4, it also has its limitations. The following sections will reflect on these limitations, and will discuss these per research question (i.e. which elements to incorporate in the framework, how to integrate the elements in the framework, which phases and milestones in the emergence of a de-facto standard, how can the framework be applied to technology competitions).

**Elements to incorporate in the framework**

In this dissertation, four new elements were found (i.e. accommodating to needs and requirements of providers of complementary goods, subsidizing providers of complementary goods, history of the industry, and accessibility of intellectual property rights). Based on the insights of the cases in this dissertation, these elements were allocated to the level of 'third order influence'. However, this allocation was based on a small number of findings. Future research is required to find out more about these elements and their relationships with other elements. If these new insights would show that an element directly influences the customers' decision, or directly influences a first order element, it would need to be upgraded to the first or second order respectively.

In addition, there may be other, non-identified, elements. As this research showed, new case studies lead to the identification of new elements, and therefore we cannot exclude that additional case studies will again lead to new elements. Next to this, I cannot guarantee that all elements noted in the literature on de-facto standards have been taken into account. Firstly, the literature research was based on a non-exhaustive set, and secondly it is possible that elements were overlooked during the content analysis (this latter point will be discussed in more detail in the next section on methodological limitations). It is, however, interesting that the newly identified elements were merely third order elements, which may indicate that the most important (i.e. first and second order elements) have already been identified.

In Section 1.2 a synthesis of the literature on de-facto standards was provided, whereby the literature was divided into four quadrants; natural-selection view, collective-action view, system-structural view', and strategic-choice view. In constructing the integrative framework, literature from the strategic-choice view and specific elements from the natural-selection view, collective-action view, and system-structural view were taken into account (these elements were listed in Section 1.5). This raises the question if relevant insights were missed by omitting parts of the literature from the integrative framework.

Looking back at the three case studies, additional insights regarding the case of high definition audio discs could have been gained by applying the literature on game theory (i.e. collective-action view). In this case, the technology sponsors of SA-CD and DVD-A invested heavily in the success of their formats. It led to a 'bidding war', which is similar to the 'Rather fight than switch' game described in Subsection 1.2.3. However, as both sides were focused on outcompeting each other, the market adoption of both technologies was delayed, which provided sufficient time for another (outsider) technology to enter the market and become the de-facto standard. Hence, both sides had to incur significant losses on their respective investments. By including game-theory in the framework, academics and executive teams could gain a better insight in the motives of companies to either develop their own technology, support a competing technology, or to collaborate on a technology.[612] In addition, it helps to understand why companies choose to compete whereas cooperation appears to render an overall better result for all parties involved, as discussed in Subsection 9.2.1.

**Integration of the elements in the framework**

Using the academic literature, a sub-set of the total number of elements was defined as having a first order influence on a consumer's decision to adopt a particular technology. However the empirical results are insufficient to verify this selection of elements. Further research, focused on testing the causality of the first order elements on a customer's decision to adopt a technology, is required to determine the validity of the selection of first-order elements. The recent cases described in this dissertation would lend itself for such research.

In constructing the integrative framework, an approach was taken whereby the elements were organized based on their influence on a consumer's decision. There are, however, also other approaches to constructing a framework. A particularly elegant alternative approach is the one taken by Gallagher and West[613], which use a model depicting increasing returns as a positive feedback loop as basis and extend this (shown by Figure 13). By focusing on a key mechanism that often determines the outcome of a technology competition, the resulting framework can be both accessible and comprehensive at the same time. Figure 84 shows how the elements identified in my research would fit in a framework with the same approach. Further research is required to compare the approaches and understand if one renders more insight than the other.

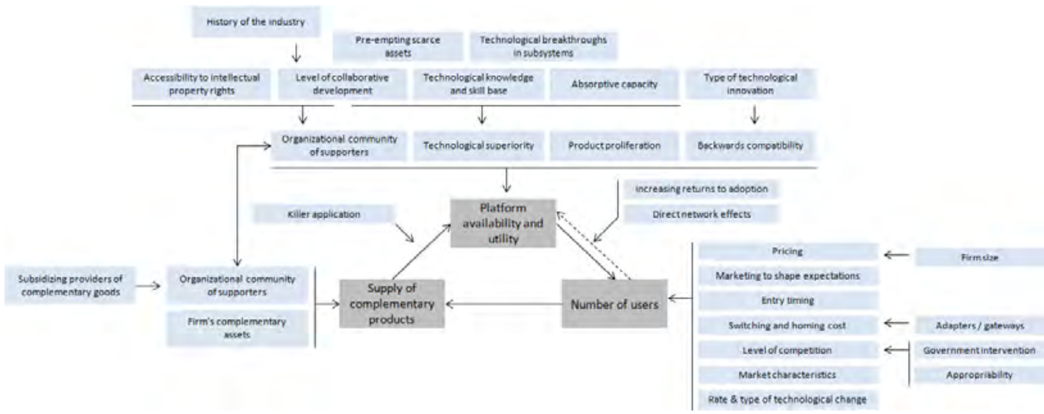


*Figure 84: Extended technology adoption model incorporating positive feedback*

As Chapter 6 and 7 show, the constructs and variables captured in the integrative framework are not exhaustive. The integrative framework itself merely provides a high level abstraction of the constructs and variables. Each inter-element relationship is based on several academic papers that have studied it in more detail. In addition, the body of literature researching these relationships is expanding, of which Chapter 6 is an example. In this dissertation, I synthesized the relationships between elements which have been identified in the body of literature, but did not summarize the findings themselves regarding each relationship. Research on this has been limited, with exceptions being Srinivasan et al.[614] and Van de Kaa et al.[615] This area could benefit from additional research efforts.

**Phases and milestones in the emergence of a de-facto standard**

Regarding the phases in the process of the emergence of a de-facto standard, Subsection 8.1.4. shows that the phases and milestones are well suited for cases where a de-facto standard emerges, however in technology competitions which do not result in a de-facto standard it becomes difficult to identify the milestones in the later stages of the competition. In order to test and improve the robustness of the phases and milestones, future research could test these on more technology competitions that did not result in a de-facto standard. Additionally, the current phases and milestones have only been applied on cases in the consumer electronics industry. The robustness of the phases could be further tested by applying it to cases from other industries.

**Applying the framework to technology competitions**

Although the goal for this thesis was to provide a framework that could be used to support strategic decision making, this framework has only been applied at the end of the technology competition. At this point the outcome was known, and the researcher had the possibility to overlook the whole technology competition and reconstruct the events. The main test for the framework, however, would be during a technology competition; would a technology sponsor, during a technology competition, with the information available at that time, be able to use the framework to enhance their insight in the technology competition and support strategic decision making to shape the odds. Such research would require a longitudinal, action research approach.

The integrative framework as it is presented in this dissertation is complex, and can be difficult to use for executive teams engaged in strategic decision making. It requires further research to find out if and how the framework can be simplified into something that is more accessible.

The cases that were selected were all related to the consumer electronics industry. The robustness of the framework should be further tested by applying it to cases from other industries.

As noted in Subsection 8.1.5, the idea of scoring the elements was a valuable addition to the framework. However, the scoring was done in hindsight, based on in-depth knowledge from both competing technologies. In order to learn more about the added value of assigning scores to the elements, future research should look into applying scores at ongoing technology competitions. The scoring could only be applied to two of the three case studies. The two cases that allowed for scoring were technology competitions whereby there were two main rivals that competed over multiple phases, whereas the case that did not allow for scoring was a technology competition whereby one technology faced different rivals over time. This raises the thought that there might be two distinct types of competitions; one with two main rivals, and one whereby a technology faces multiple rivals over time.  Future in-depth case studies can be used to further substantiate if there are indeed two types of technology competitions, or perhaps even more.

The common dynamics during the emergence of a de-facto standard, as presented in Section 8.2, are mainly based on the insights from three in-depth case studies. While this is sufficient basis for an emergent theory, further in-depth case studies are required to test if the 'common dynamics' hold for a wider variety of technology competitions.

While Figure 79 and Figure 80 constitute the main integrative framework, the insights in Subsection 8.1.3. suggest there could be an alternate version of Figure 79 which takes into account that tipping can occur on both the customer and complementor network. Figure 85 shows how the integrative framework could be modified to emphasize the cluster of elements influencing the organizational community of supporters. Not all relationships could be captured in the graphical representation. From Appendix 4 we can see that in total 16 elements were found to influence the organizational community of supporters (this is excluding the two third order elements which also influence the organizational community); technological superiority, entry timing, appropriability, government intervention and industry regulation, marketing and pre-announcements, installed base, reputation and credibility, strategic partnerships, level of competition, level of collaborative development, market and industry characteristics, firm size, powerful rival technology sponsors, type of technological innovation, availability of imitators, and pre-empting scarce assets. At this point, Figure 85 should be considered as an alternate version of the integrative framework, of which the merits and demerits versus Figure 79 require further research.

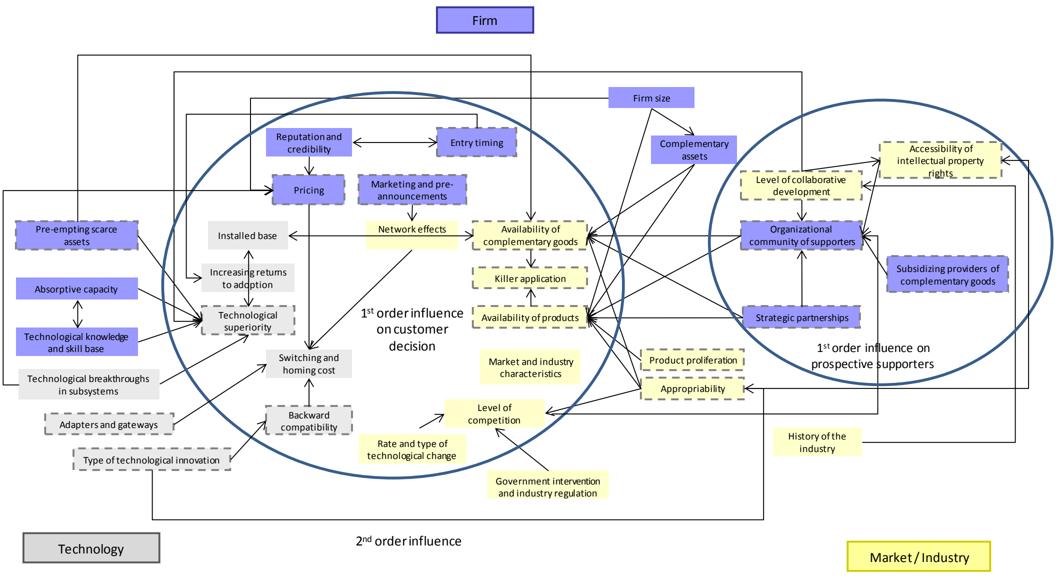


*Figure 85: Alternate integrative framework that accounts for tipping in the networks of customers and technology supporters*

As noted in Subsection 8.1.5., the integrative framework lacks a ‘market forces’ perspective, which requires a higher level view of the industry dynamics. The body of management literature provides several frameworks that are used to study industry dynamics. Considering the available frameworks, I believe one of the classics, Porter’s five forces framework[616] (Figure 86), could serve as basis for an applicable framework.

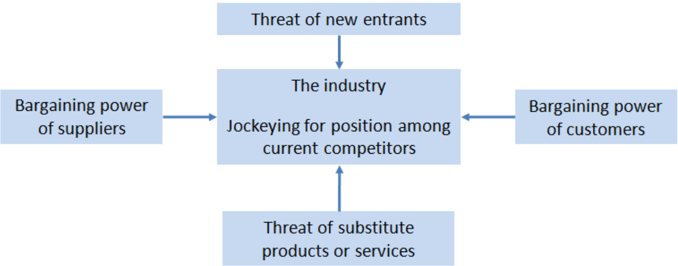


*Figure 86: Porter’s five-forces framework*

Figure 87 provides a suggestion for a slightly modified version of Porter’s five forces framework, which can be used to monitor market forces in conjunction with the integrative framework. The modifications include the replacement of ‘threat of new entrants’ by ‘embeddedness of existing de-facto standard’, and the bargaining power of customer and complementors has been swopped to reflect Figure 85. As a result, this framework reflects the forces regarding the incumbent de-facto standard, technological substitutes, and the networks on both sides of a platform; the customers and complementors. To some extent, one can regard Figure 87 as an abstract (higher level) version of Figure 85, with the inclusion of the forces regarding the existing de-facto standard and the technological substitutes. Further research is required to understand if this framework can be used, and if it indeed provides valuable 'higher level' market force insights regarding e.g. the incumbent de-facto standard and threats from substitute technologies.

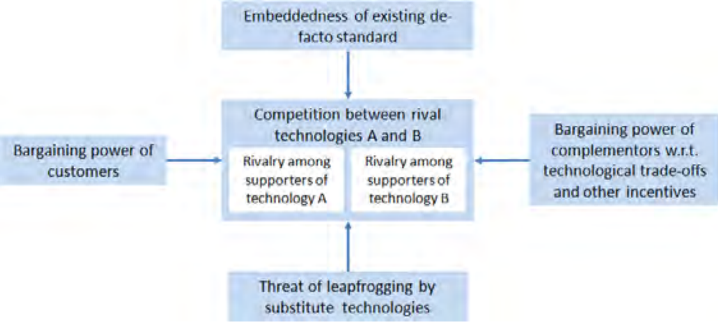


*Figure 87: Framework for monitoring market forces*

*9.3.2. Methodological limitations*

The methodology and research approach were also marked by some limitations, which will be discussed in this section. As in the previous section, the limitations will be addressed per research question.

**Elements to incorporate in the framework**

The overview of elements was derived from the existing body of literature on de-facto standards. There are three methodological limitations regarding the overview of elements. Firstly, the overview was generated through content analysis of the existing body of academic literature. Content analysis is an inherently a subjective research method. To provide an example; although my content analysis resulted in 36 elements that influence the emergence of a de-facto standard, Van de Kaa et al.[617] found 29 elements during their content analysis, and of these we have 19 elements in common. This means that 10 elements of Van de Kaa et al. were not included in my content analysis, and 17 of my elements were not identified in their content analysis. This can be attributed to combining several elements (i.e. the elements 'current installed base' and 'previous installed base' of Van de Kaa et al. is represented in my results as 'installed base') or by omitting elements that I deemed to be a moot point for the emergence of de-facto standards (e.g. the elements 'commitment' or 'antitrust laws' of Van de Kaa et al.). Secondly, the content analysis was applied on a limited set of sources. In my research, I reviewed 47 sources, whereas for example Van de Kaa et al. reviewed 127 sources, and Narayanan and Chen[618] reviewed 89 sources. Thirdly, the content analysis was performed by a single researcher (albeit with ad-post review by the supervisor), which makes the content analysis subjective. Additional measures could have been taken to compensate for the subjectivity of the content analysis, for example by involving academic peers to review the overview of elements and provide feedback.

A drawback of the inductive coding method is that the research findings result from multiple interpretations made from the raw data by the researchers who code the data. Therefore, inevitably, the findings are shaped by the assumptions and experiences of the researchers conducting the research and carrying out the data analyses. Different researchers are likely to produce findings which are not identical and which have non-overlapping components. A range of techniques can be utilized to assess the trustworthiness of the findings. I opted to assess the trustworthiness by triangulation within the project as part of the second stage of my research (the case studies). To be more specific, for each case the applicable elements were identified and incorporated into a case report. These case reports were checked by the respondents, 35 in total. Many of these respondents can be considered corporate experts in standardization. In addition, two case reports (high definition optical discs and MP3) were used for academic papers that were checked by co-authors and anonymous reviewers. These can be considered academic experts in standardization. As noted in Subsection 8.1.1., the case studies confirmed most of the elements that were identified in the content analysis of the academic literature. Hence, the confirmation of the corporate and academic experts can be regarded as validation of the identified elements.

**Integration of the elements in the framework**

After an overview was created of elements that influence a customers' decision to adopt a technology, these were differentiated based on their direct or indirect influence on the customers' decision. This differentiation was done based on a content analysis of the academic literature, but this differentiation was not tested on actual customers. Conjoint analysis should have been performed to better understand the trade-offs that are made by customers when adopting a technology, in order to verify the selection of first order elements. This matter requires further research. However, those who would undertake this research will have to take into account in their research approach that there are many attributes (40 elements) which can provide the issue of information overload. In addition, as de-facto standards are typically global phenomena, one would need to account for national or regional differences in customer trade-offs.

**Phases and milestones in the emergence of a de-facto standard**

In this research, the phases and milestones as proposed by Suarez[619] were adopted as a starting point. I did not perform a comparative study with phases and milestones as proposed by other authors (i.e. the three phases proposed by Utterback and Abernathy[620], or the two phases proposed by Tushman and Anderson[621]). Considering that the phases and milestones by Suarez build on the works of Utterback and Abernathy, and Tushman and Anderson, I believe the phases and milestones proposed by these others could be equally applicable. However, as the phases and milestones of Suarez provide more detail, they allow for a more thorough insight in the emergence of a de-facto standard.

**Applying the framework to technology competitions**

Another limitation of this study was its exploratory nature. As such, I performed in-depth case studies. In my efforts to generalize findings from the cases through a cross-case analysis, analytic generalization was applied. This method has several limitations:

- The results from this approach need to be considered as 'working hypotheses' (analytic generalizations requires carefully constructed arguments which must be resistant to logical challenge). Confidence in such hypothesizes can build as new studies continue to produce findings in support of the hypotheses.
- The generalization of these results is limited to cases of which the context has a good fit with the context of the cases studied in this dissertation (Guba, 1981). In accordance with Lincoln and Guba,[622] sufficient descriptive information has been provided regarding each case to allow other persons wanting to transfer the findings to assess the degree of similarity between the contexts.

Future research should validate the findings with large-scale empirical research.

As noted in Subsection 8.1.5, the idea of scoring the elements was a valuable addition to the framework. However, the scoring was done by the researcher, which makes the scores themselves very subjective.

Future research could investigate if scoring by multiple parties renders more accurate insights in the dynamics of the emergence of a de-facto standard.

## References Chapter 9

587 With 'unique elements' I mean that I do not take into account that nine elements can be allocated to multiple categories and therefore may be regarded as separate elements

588 Figure 79 does not show the element of 'chance' as explained in Subsection 9.1.2.

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# Appendix 1: Description of elements influencing the odds of technology selection (in alphabetical order)

**1. Absorptive capacity**

Absorptive capacity reflects the firm's ability to recognize the value of new information, to assimilate it, and to apply it to commercial ends.[623] Low investment in learning can lead to failure in anticipating shifts in customer requirements and makes companies less able to respond to technological change and emerging opportunities.[624]

**2. Adapters and gateways**

Technical interconnection of incompatible technological systems can be realized by developing adapters that enable the conversion from one side to the other, also known as gateway technologies (David et al.[625], Katz and Shapiro[626], Baake and Boom[627]). As such, gateway technologies may provide compatibility without constraining variety or innovation.[628] Gateway technologies can be developed to facilitate conversion in one or two directions. Even though a gateway technology that works in two directions can be perceived as 'neutral', it can tip the balance of market competition decisively in favor of on one of the technological systems. A gateway technology may provide the user of a certain network access to an alternative network. In the case of video game consoles, the company Coleco marketed an adapter that allowed its game console to play the broad range of video games developed for a competing game console.[629] Adapters and gateways can be hardware (e.g. the rotary converter in electricity supply networks)[630] or software (an emulator)[631]. However, gateway technologies can be expensive and/or inefficient (David et al.[632]; Farrell and Saloner[633]).

**3. Appropriability**

Appropriability refers to the ability of a technology sponsor to protect its innovation from imitation by competitors[634] and capture the profits generated by it.[635] Appropriability is dependent on solid intellectual property rights (patents, copyrights or trademarks), a secure research, development and manufacturing environment, and the efficacy of legal mechanisms to enforce the property rights. Different business environments have different degrees of appropriability, which have strong implications for the technology competition. According to Srinivasan et al.[636], appropriability for a product category may be represented along a continuum extending from a tight (closed) regime where firms are able to appropriate most or all innovation rents, to a weak (or open) regime where firms are able to appropriate little or no rents. A tight appropriability regime will favour firms with superior technology, because it allows them erect barriers to imitation.[637] High barriers to imitation may also provide a firm with a period of time free from competition, in which it can build an installed base sufficient to jump start an increasing returns mechanism.[638] However, it is often difficult to erect high barriers to imitation. Enforcement using legal instruments such as patents and/or copyrights takes a long and costly process with an uncertain outcome. Hill[639] mentions a large sample study of patent protection cases that found that 60% of patented innovations were invented around within four years.

**4. Availability of complementary goods**

Complementary goods are products or services that increase the utility of a technology, and are generally dubbed 'software'.[640] Examples include pre-recorded DVDs for DVD players, and charging stations for electric vehicles. Especially platform technologies are hardly useful or desirable without an associated set of complementary goods.[641] Goods are complementary to a technology when they adhere to a common compatibility standard. Adhering to a common compatibility standard enables independent development of myriad complementary goods, and allows complementary assets to be employed on a wide range of platform implementations. Given adequate resources, firms may choose to vertically integrate downstream from their platform and provide their own complements. Even if firms produce their own complements, they often enable other companies to provide complementary goods, often unique innovations that the platform sponsor did not anticipate. Two types of complementary goods can be defined: the goods that are essential for a technology to function/become commercially feasible (such as a computer and an operating system) and the goods that add functionality to the technology (such as software programs for the operating system of a computer). These technologies need not be separate, but can be a sub-technology of the core technology (for example when Matsushita developed the 8mm video camera it also needed to develop the recording heads), as such core technology and sub-technology need to be developed in parallel.[642] According to Arthur[643] these technological products exist within local groupings of products that support and enhance them, and as such form mini-ecologies. The effect of this interdependence is that the success of a technology also depends on the availability of complementary goods and attracting companies to develop these. Suppliers of complementary goods will want to supply to a large market, so their supply decisions are affected by their expectations about the future size of a network.[644] The possibilities a consumer has with a platform depend for a large part on the amount of available complementary goods, to realize a larger installed base than a competing technology it is thus important to influence the supply of complements.[645] When consumers use products which have many complementary products it becomes difficult for them to switch to another technology because of the incompatibility of the complementary goods with the other technology.[646]

**5. Availability of products**

The availability of products can be defined as the extent to which products based on a particular technology are available to the customer. Prospective customers have to see the product (either tangibly or in catalogs or websites), in order to purchase it.[647] The market for potential de-facto standards is often a 'mass' market of global nature. Such markets are often serviced by large companies that market their products under one or several brands, and have access to efficient mass production capacity and broad distribution channels.[648] When a technology sponsor sets out to establish an organizational community of supporters, this can be regarded as a race for distribution rights. The more 'shelf space' is filled by products based on a technology, the more a customer perceives the technology as successful.

**6. Availability of imitators**

Technology supporters may face companies imitating the new technology or its complementary products (Besen and Farrell[649]; Wade[650]). The effects of second sources entering an industry are twofold. They increase competition in the industry, and are likely to reduce the market share of the original technology sponsor. But in a technology competition, attracting imitators increases the organizational community of supporters, the amount of products and complementary goods in the market. Technology sponsors may be able to ward off imitators when it has strong intellectual property rights and the industry has a strong appropriability regime.

**7. Backward compatibility**

A technology is backwards compatible when it is designed to be interoperable with, or accommodate products from, the previous technology generation. This often requires a product based on the new technology to be compliant with compatibility standards from the previous technology generation. In the case of platforms, this may hold for the platform itself or for the complementary goods. In the case of an optical disc format, a new generation of the technology may feature a new player that can play discs from the previous generation or it may feature a new disc that can be used in the player of the previous generation (hybrid disc). Backward compatibility lowers switching cost, and facilitates the migration of a technology's installed base to the next generation technology.[651]

**8. Chance**

According to Arthur[652], in technological trajectories with (strong) network externalities many outcomes are possible; insignificant circumstances (small random events) such as unexpected successes in the performance of prototypes, whims of early developers, and political circumstances, become magnified by positive feedback to 'tip' the system into the actual outcome selected (Arthur[653]; Besen and Farrell[654]). These random events resemble 'chance' and 'luck', and can tip a market very rapidly.

**9. Entry timing, window of opportunity and first-mover advantage**

Entry timing refers to the point in time when the first product based on a particular technology enters the market. For the timing of entry to the industry Suarez[655] and Schilling[656] state that an early market entry has several important effects in a technology battle; it helps to build a larger installed base (because an early entrant has more time to promote, deploy, and improve its technology) and creates reputation effects. Early entry in systematic R&D activities creates important learning effects and provides more time to experiment with different technological alternatives (McGrath et al.[657]; Suarez[658]). The earlier in the evolution of a technology the firm enters, the more easily it is able to garner influence over distributors, suppliers and customers.[659] Early entry does, however, lock firms into particular technological trajectories that are potentially not consistent with the resulting dominant design. And while it pays to hit the market first, the initial lead can easily be taken by a competitor if the installed base is not built fast enough[660] or if it does not have control over the required complementary assets.[661] A later entrant can also capitalize on the research and development of the first mover, fine tune the product to customer needs as the market becomes more certain and avoid mistakes made by the first mover.[662] Anderson and Tushman[663] even state that first versions of a new technology do not become industry standards because they do not adhere to a broad set of customer needs, since customer needs are in an early industry stage unknown.

According to Schilling[664] there is a U-shaped relationship between entry timing and technological lock-out (the technology trajectory sponsored by the company does not become the dominant design), graphically represented by Figure 88. The U-shaped model of Schilling gives rise to the belief that there is a window of opportunity[665] during which it is optimal to enter the market. This window of opportunity implies that

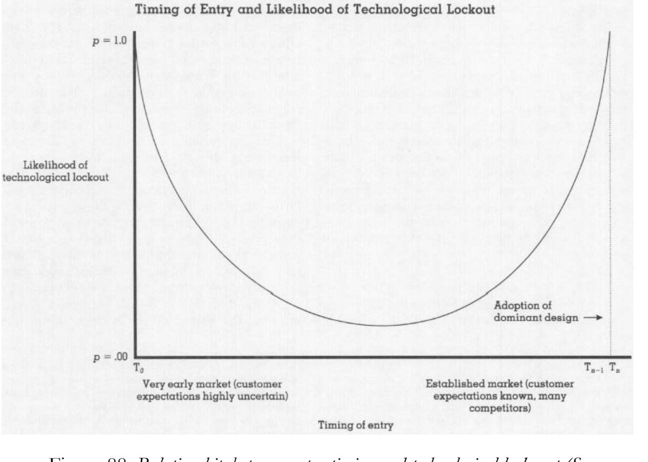


Figure 88*: Relationship between entry timing and technological lock-out (Source: Schilling, 1998)*

there is a specific time frame during which a firm should enter the industry. Schilling states that in very early market stages a technology may be underdeveloped, its fit with customer needs is unknown, necessary complementary goods and services may not be developed yet. As such the chances are low that the technology introduced in a very early market becomes the dominant design. Over time, knowledge of the technology and customer expectations will improve, thus increasing the likelihood that technologies will possess a set of attributes meeting customer demand. If the technology proves to be valuable, over time competitors will also enter the market. If competing technological designs enter too late, another design might have become so entrenched that the new designs have little chance of capturing market share. The deflection point and strength of the U-shaped relationship is moderated by the intensity of the industry's network effects, barriers to competitive entry and the margin of improvement the new technology offers over previous technologies competing for the same market.

**10. Firm's complementary assets**

A firm's complementary assets are particular capabilities or resources which, in addition to the technological knowledge, support the commercial success of a technology (for example manufacturing facilities, distribution channels, marketing, etc.). This relates to the extent to which a firm is vertically or horizontally integrated. Complementary assets are often required for bringing an innovation to the market and can be used to overtake the head start of a competitor. Possessing the required complementary assets is a reason why imitators sometimes outperform the original innovators. In general, a better set of complementary assets will cause a higher likelihood of emerging as de-facto standard, other things being equal.[666] The most valuable company assets are specialized and co-specialized assets. Specialized assets are unique elements accessible to the firm. To the extent that the assets (tacit or in tacit) are scarce or available only to the firm (such as a specific location) competitors will not be able to duplicate the firm's offering without the asset. Co-specialized assets are assets a firm possesses for other productive purposes, and which competitors therefore simply do not possess, but which can be deployed to enhance the product offering.[667] Integrating or developing these assets is expensive. Contracting relationships with firms that own these assets provides relatively cheap access, but may not be possible due to scarcity of the asset.[668]

**11. Firm size**

Financial resources, number of industries and geographical markets in which the technology sponsor has a presence and its market share in these. Technology sponsors with substantial financial resources can apply these to rapidly create an installed base through penetration pricing and extensive marketing.[669] Large firms often have access to relevant specialized and co-specialized assets required to support for a technology (Teece[670]; Suarez and Utterback[671]). If the technology sponsor has experience in adjacent markets, it may be able to easily target the new market with its existing knowledge and skill base, or existing technology portfolio (Schilling[672]; Gallagher and Park[673]). A technology sponsor with an existing business in an adjacent market may be able to leverage its existing customer base and complementary assets such as distribution networks.[674]

**12. Government intervention and industry regulation**

There are four relevant aspects of government intervention: government may act as an early adopter of a particular technology, provide subsidies to promote adoption or erect trade barriers, subject a technology sponsor to antitrust scrutiny, or mandate the use of a particular technology. In high tech industries, it is not uncommon that a branch of government (military, space or public health department) acts as an early adopter. Government purchases of a technology in the early stages may, however, tilt the balance in its favour and enhance the odds to become the de-facto standard.[675] An often mentioned example concerns the role of the US Navy in early nuclear reactor construction contracts, which favoured the early development of light-water reactors).[676] Military and space programmes may also operate as a focussing mechanism during a particular technological trajectory, while at the same time providing financial support to R&D and guaranteeing public procurement.[677] Klepper and Simons[678] note that in the television receiver industry, the Japanese government managed to limit foreign competition by placing tariffs and restrictions on foreign direct investment. In addition, they subsidized R&D and exports, and provided preferential access to capital. Rosenbloom and Cusumano[679] note that the Japanese Ministry of International Trade and Industry (MITI) provided subsidies to firms willing to develop a domestic version of a videotape recorder. An example of the third aspect can be found in the video-game console market; Gallagher and Park[680] found that around 1991 Nintendo removed the prohibition on licensees making their games available to competing game consoles because they were under threat of antitrust investigation. Lastly, sometimes a government will intervene directly to mandate the use of a particular technology.[681] This has often been the case for the utilities such as the telecommunications and television industries.[682] In these cases the consumer welfare benefits of having compatibility in technology have warranted government regulation.

**13. Hetero- or homogeneity of customer needs**

Markets differ on the hetero- or homogeneity of customer needs. According to McGrath et al.[683], markets can be composed of unevenly concentrated groups of customers that have different preferences regarding a product category. Markets with homogenic customer needs are prone to 'tipping' under network externalities, whereas markets with heterogenic customer needs are more likely to sustain multiple technologies.[684] The extent to which a technology may envelop groups of customers in a heterogenic market is dependent on its level of superiority. In many cases a new technology initially meets the specific requirements of a niche market, which allows it to build-up an initial installed base.[685] Through subsequent returns to adoption, a technological development will enhance its performance, and enable it to address an increasing amount of customer groups until it reaches its mass market potential.

**14. Increasing returns to adoption**

An important effect to obtain and retain technological superiority are the increasing returns to adoption or 'learning curve effects' (Schilling[686]; Abernathy and Clark[687]; Besen and Farrell[688]; Suarez and Utterback[689]). Complex technologies often exhibit increasing returns to adoption in that the more they are adopted, the more they are improved.[690] This is also called 'learning by using'. Revenues generated by the technology adoption can be used to further develop and refine it. As the technology is adopted, greater knowledge and understanding of the technology accrues as a by-product, which may enable improvements in the technology and in applications of the technology. Increasing returns to adoption will also enable better understanding of what customers want.

**15. Installed base**

Installed base is a multifaceted term, of which the applicable definition is case-dependent. It can be defined as the number of users applying a technology at a certain moment in time,[691] the number of users applying products of a particular firm, or the number of products in use. A larger installed base is associated with higher rates of adoption of a technology, and as such heightens the chance that customers will choose the technology.[692] Because the installed base becomes locked into the technology, it is difficult for the technology to be displaced by a superior and cheaper alternative. The size of the installed base is in industries with network effects also directly related to the benefits a consumer derives from using the technology.[693] For these reasons it is important for a firm to quickly build an installed base in industries with strong network effects. If an established company sponsors a new technology, it can offer the technology to its existing installed base in order to realize fast market adoption.[694]

**16. Killer application**

Market adoption of a new technology can be accelerated by a 'killer application'.[695] A killer application is an application of the technology that possesses a set of attributes meeting customer demands. Killer applications can refer to the product in which the technology is implemented (e.g. a PDA; Schilling[696]), a service enabled by the technology (e.g. electric lighting; David and Bunn[697]) or complementary goods (e.g. popular games for video game consoles; Gallagher and Park[698]; Schilling[699]).

**17. Level of collaborative development**

Extent to which a technology sponsor engages into a collaboration with its competitors to develop a shared technology. Such cooperation can take place in an industry alliance, or under the auspices of a standard development organization such as IEEE. Collaborative development allows merging technology features, spreading development cost, ensures adequate manufacturing capacity and distribution, and typically lowers the number of competing technologies.[700] Hill[701] notes that collaborative development may be able to produce a superior technology by combining the best aspects of several independent technology streams. The level of collaborative development also refers to the timing of a technology sponsor to engage into a collaboration with competitors; shared development can start at any moment during the technological development process.

Van den Ende et al.,[702] show that when a technology sponsor involves other parties in the development of a technology and its extensions, this enhances the amount of support and ensures that the technology incorporates features which are important to the different types of parties in the industry. While the development of technologies can be open or closed, it rarely occurs fully open or fully closed.[703] It is a trade-off between letting other companies participate in refining the technology vs. risk of losing grip over direction of technological developments and sharing potential license revenues (Cusumano et al.[704]; Shapiro and Varian[705]; Lee et al.[706]). Technologies that result from a collaborative process often have a longer time-to-market. Following collaborative development, the technology sponsors may opt to further extend the amount of supporters building an organizational community by licensing the technology to competitors and/or complementors.

**18. Level of competition**

The level of competition in a technology competition is based on the number of incompatible technological alternatives that are competing in the market for adoption and the strength (financially and in terms of market share) of their supporters. Competition between incompatible technologies in markets governed by strong network effects are not just a matter of better products or lower costs, small differences can be magnified into a substantial lead, resulting in a de-facto standard.[707] Technology competitions may delay market growth by causing market confusion which encourages buyers to wait for the outcome. Companies can choose to compete for the market with several incompatible technologies, or to compete within the market and agree to make their products compatible and subsequently compete in different dimensions such as price, service, and product features.

**19. Market and industry characteristics**

This element refers to the structure and dynamics of the market and technological field.[708] Every market has specific dynamics (e.g. excess inertia or insufficient friction, market size and growth), rules of engagement and information sharing practices which cut across organizations and can be described as an industry's value system. A company can make use of this value system, or review the various market segments for its technology and introduce it in a market with favourable dynamics, to affect the technology competition. Smit and Pistorius[709] indicated a certain conservatism in the mining industry that caused resistance to technological change. Overcoming this conservatism and building the necessary confidence in a new technology took considerable time.

**20. Marketing and pre-announcements**

This element refers to creating market awareness regarding the availability of a technology, informing the customer of its strengths,[710] and influencing customer and industry perception regarding its potential success.[711] As incumbents will try to knock down the viability of new technologies that emerge, those very entrants will strive to establish credibility. Arthur[712] refers to the management of expectations as psychological positioning; in industries with network effects rivals will back off in a market if they believe it will be locked in by someone else (since appearances may count as much as reality does if the installed base can only be imperfectly observed). Psychological positioning can take place through preannouncements, threatened alliances, parades of announced products (vapourware), etc. According to Shapiro and Varian[713] the most direct way to manage expectations is by assembling allies and making grand claims about the technology's current or future popularity. This discourages competitors from taking on a potentially dominant rival. Not all companies like to manage expectations through means such as vapourware and prefer a stick-to-the-facts approach.[714]

**21. Network effects**

Network effects (i.e. increasing returns, network externalities, bandwagon effects) in markets are a result of consumption complementarities whereby the utility of a technology to a customer increases with the number of customers that use the technology.[715] We distinguish two types of network effects; direct and indirect network effects. Direct network effects arise from the mere fact that when the *n*th customer joins a network, a network connection is created for all existing customers. As such the network becomes more valuable (the utility that a user derives depends upon the number of users) to a user the more users become connected.[716] Indirect network effects arise as a result of increased demand for complementary products or services (such as specialized training, etc.). The platform with the largest installed base attracts the largest supply of complementary products, which, in turn, further increases the platforms popularity with customers and this its attractiveness to providers of complementary products.[717] These positive (self-reinforcing) feedback loops will result in a virtuous cycle that will inevitably "tip" a platform competition in favour of the platform that has the leading installed base. However, the process of increasing returns needs to be jump-started in order to create momentum behind a technology. There are several company strategies for jump starting[718] or igniting[719] the increasing returns process: early entry, technological superiority and penetration pricing have positive effects on building an installed base. The effect of a firm's strategic manoeuvring is enhanced by network effects, this makes strategic manoeuvring a powerful force driving the emergence of a de-facto standard. While some argue that strong network effects result in strong selection pressures to choose a dominant design (Besen and Farrell[720]; Schilling[721]; Shaprio and Varian[722]), others (Srinivasan[723]) show that a dominant design is more likely to arise under weak network effects. Shankar and Bayus[724] show that network effects are a function of network size (size of installed customer base) and network strength (marginal impact of a unit increase in network size on customer demand). A firm with a smaller customer network, but a higher network strength than the firm with the larger customer network is able to overtake the sales of a firm with a larger network size because of higher customer loyalty.

**22. Organizational community of supporters**

In order to best a competitor in terms of availability of products and complementary goods, a technology sponsor can build a network of competitors and/or complementors that support its technology (i.e. creating an organizational community that has some degree of hardware and/or software compatibility[725]). A prime example is the case of the video recorders, whereby JVC enabled its VHS technology to win from the competing Betamax technology by being very successful in building an ecosystem of competitors and complementors that supported VHS.[726] Determinants of the ecosystem are the amount of parties, diversity, and market shares. According to Arthur[727] companies building 'webs' (alliances of companies organized around a mini-ecology) to amplify positive feedback to the base technology. The density of the network (the amount of possible links within the networks) and the strength of relationships between actors in the network influence the performance of the actors in the network. The strength of the relationships depends on the type of relationship between the actors. This can reach from a simple arms-length licensing contract to a joint venture in which the companies that have contributed technology take a share in the joint venture (this aspect is highlighted separately in 'level of collaborative development'). Larger groups often suffer from problems related to control and coordination. Van de Kaa et al.[728] state that these ecosystems are often organized in a core-periphery structure. The core can consist of a single sponsor with key complementors or an alliance of sponsors.

The ecosystem of supporters can be built through licensing and OEM agreements. Hill[729] identifies two licensing strategies; passive multiple licensing (which involves licensing to all comers and letting the licensees build the market for the technology) and aggressive multiple licensing (which involves licensing to as many firms as possible while remaining the dominant supplier of the technology). It is also possible to keep the core technology proprietary and make the knowledge of the interfaces of the technology public, this allows complementors (even rivals) to participate in developing the technology, but under own terms determined by the technology owner.[730] Licensing facilitates wide distribution and may co-opt competitors.[731] The resulting momentum will create a disincentive for competitors to invest in the development of their own technology. Success in persuading other enterprises to enter into licensing agreements sends a positive signal to the suppliers of complementary products, which are more likely to invest in the development of complementary products if a technology has gained substantial momentum. A liberal licensing strategy comes at the price of increased competition of licensees which make improvements on the technology and a certain loss of control over the technology's path of development, and may result in prices being bid down below the rate that would prevail in a monopoly situation.

In addition, OEM agreements can be useful when a brand owner is interested to offer a product under its brand, but is not willing to invest in technology-specific manufacturing facilities until the market has obtained sufficient volume. In order to accommodate these licensees, a technology sponsor (which needs to invest in a manufacturing facility anyways), could offer to manufacture products on OEM basis for its licensees. In order to effectively build the ecosystem of supporters, a technology sponsor needs to discover which requirements it has to fulfil in order to obtain support, and make a trade-off to what extent it is willing to accommodate licensee needs and requirements.

**23. Powerful rival technology sponsors**

Competing technology sponsors that have the resources required either to imitate a technology, even in the face of high barriers to imitation, or to develop their own, possibly superior, technology.[732] In addition, these competitors may have a substantial installed based (and thereby market share) which could be leveraged towards the competing technology. The existence of Powerful rivals places more urgency on rapidly building an installed base, thereby increasing the attractiveness of licensing arrangements and entering into strategic alliances. Technology sponsors faced with powerful rivals may be well advised to persuade them into a strategic alliance or collaborative development. A powerful rival may also help to build an organizational community of supporters; in the case of the Java programming environment, the threat of Microsoft entering the market with its Blackbird technology caused many smaller parties to support Sun Microsystems' Java technology.[733]

**24. Pre-empting scarce assets**

By anticipating on the path of technological development, companies can preserve future rights to scarce assets (e.g. materials, specific distribution channels or complementary products and intellectual property).[734] This can be done by pre-emptively contracting or integrating co-evolutionary partners, and will enable the company to have access to crucial resources once these are needed. For example, in the video game console industry, the companies that were first to market were also the first to obtain exclusive rights to games based on popular arcade games (e.g. Space Invaders) and their characters such as Donkey Kong.[735]

**25. Pricing**

Pricing is a key variable in the demand of a product, but it has particular relevance in the emergence of de-facto standards. Early aggressive pricing lowers switching cost and leads to a larger installed base, which in turn makes it more likely that a firm's technology will become dominant.[736] Penetration pricing often requires a dedicated technology sponsor with significant financial means, because the company must be able to bear substantial short-run losses in pursuit of longer run gains from economies of scale, learning effects, and establishing the technology as a standard. There are three ways to recoup the investments on penetration pricing:

- Once sufficient volume has been built up, substantial unit cost reductions may be forthcoming from learning effects and scale economies, which lead to significant profit margins.[737]
- Provide a discount to the first-movers in order to jump-start increasing returns, and remove the discount when the increasing returns mechanism kicks in.
- In the case of platform technologies a firm may apply penetration pricing on the platform (for example a game console) and charge high margins on the complementary assets (video games).[738]

**26. Product proliferation**

Product proliferation involves serving as many niches in the market as feasible by customizing the product offering to appeal to different users.[739] This maximizes the potential size of the market, and the rate of growth of the installed base. By designing a product or technology in such a way that it can easily be adapted to appeal to different users, the rate of installed base growth is optimized. Some indicators of product proliferation are a large number of new product introductions, wide product variety and extensive product lines.[740]

**27. Rate and type of technological change**

The rate of technological change is defined as the speed of introduction of subsequent innovations, i.e. the pace of technological change in the industry. The type of technological changes influences the pace of obsolescence. The rate of change and possibility of obsolescence affects the willingness of suppliers and buyers to invest in a technology and influences the desirability of committing to a specific technology. Henderson and Clark[741] constructed a framework for defining the type of technological changes (see Figure 89). This model bears similarities to the model of Abernathy and Clark[742] displayed earlier, however the model of Henderson and Clark focuses on innovation on product level, while Abernathy and Clark focus on innovation on industry level. In this model incremental innovation refines and extends an established design. Improvement occurs in individual components, but the underlying core design concepts, and the links between them, remain the same. Modular innovation is characterized by changes in the relationships between the core concepts of a technology. Radical innovation establishes a new set of core concepts embodied in components that are linked together in a new architecture (a substitute technology). Architectural innovation is defined as the reconfiguration of an established system to link together existing components in a new way. It creates new interactions and new linkages with (other) components, however the core design concept behind each component and the associated scientific and engineering knowledge remain the same.

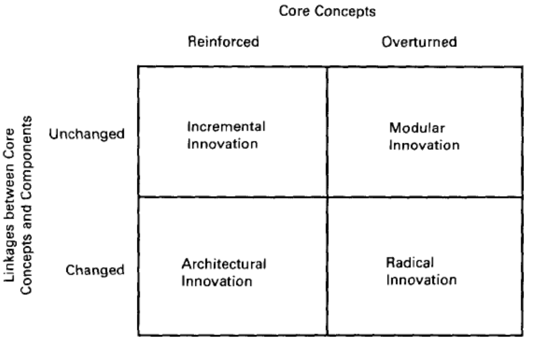


Figure 89*: Type of technological changes (Source: Abernathy et. al, 1985)*

**28. Reputation and credibility**

A firm's reputation is based on the public evaluation of a firm relative to other firms.[743] A good reputation and credibility have a positive influence on the establishment of a de-facto standard, especially in network markets where expectations are important.[744] Previous victories and a recognized name give customers some certainty that they are investing in a technology that has a good possibility of winning the competition. Consumers' knowing that a firm will act to preserve its reputation will raise consumer expectations about the future network size.[745] This is one of the reasons smaller companies are often eager to form an alliance with established companies.[746]

**29. Strategic partnerships**

A technology sponsor may establish a contractual relationship with providers of complementary goods and distributors to more rapidly deploy the technology,[747] or gain access to new technologies.[748] The sponsor may be able to negotiate joint promotion of the new technology with other (complementary) goods or a strategic bundling relationship. A well known example is provided in the case of the microcomputer industry, whereby IBM chose to sell its first Personal Computer in a bundle with Microsoft's PC-DOS operating system. This facilitated a timely market introduction of IBM's Personal Computer and led to a large installed base of consumers using Microsoft's DOS.[749] A strategic partnership can bring the required mass production skills, financial resources, broad distribution networks and added credibility,[750] especially if the sponsor is relatively unknown and the partner is established and reputable.[751]

**30. Switching and homing cost**

Switching costs are the costs that customers incur to move from one technology to another,[752] including the cost of specialized or co-specialized complementary goods. Switching costs affect a firm's ability to attract customers and build or retain its installed base.[753] As customers invest in technology specific training and complementary assets they become locked in a technology and the switching costs increase. The higher the switching costs, the more difficult it is for a firm to steal customers away from rivals and the more "loyal" is its own customer base. Homing costs include all the expenses incurred by technology users.[754] When homing costs are low, customers can easily choose to adopt multiple technologies.

**31. Technological breakthroughs in subsystems**

When a new technology is shown to be feasible in the form of a prototype, it is often not yet commercially feasible because some of its components or subsystems are not ready for (mass) production. Advances and breakthroughs in these subsystems can enable the technology to move from prototype to commercially feasible product. In the case of the video game console the creation of large-scale integrated circuits (transistors and microprocessors) enabled console systems to have sufficient processing speed at an acceptable price.[755] Other examples include Sony's electronic correction system in the CD-player architecture, high energy density batteries in PDA's and cell phones, microprocessors for personal computers.

**32. Technological knowledge and skill base**

The ability of a firm to enter a new market and develop a superior technology is dependent on its technological knowledge and skill base.[756] For example, Sony's know-how for magnetic recording equipment enabled it to replicate a videotape recorder in three months and use this as the basis to develop its Betamax technology.[757] When a firm invests in the development of a new technology (or purchases access to this knowledge) it expands its existing knowledge and skill base. What the firm can hope to do technologically in the future is often narrowly constrained by what it has been capable of doing in the past.

**33. Technological performance trajectories**

The impact of certain kinds of technological innovations on a given industry can be explained by the concept of technological performance trajectories.[758] Bower and Christensen[759] state that disruptive innovations are often not superior to existing technologies (the reason the mainframe-computer market is shrinking is not that personal computers outperform mainframes), but can create other important attributes that enable the whole technological architecture to change and open up new markets (which value these different attributes). Once disruptive technologies or technological architectures become established in their new (niche) markets, sustaining radical and incremental innovations can raise the architecture's performance along steep trajectories (as Bower and Christensen found in the disk-drive industry), so that the performance from the architecture soon satisfies the needs of customers in established (mass) markets. In effect, a technology which is confined to a particular niche market today, may very well migrate to mass markets tomorrow. When facing a technological performance trajectory, it is important for the current and future installed base that the product road map offers a smooth migration path to the ever improving technology.[760]

**34. Technological superiority**

A technology is superior when it has features that allow it to outperform competing alternatives.[761] These features comprise of the pure effect of technology (e.g. picture quality of video storage media), and differentiating features (e.g. the amount of video that can be recorded on a video tape). These differentiating features may enable a technology to better 'fit' in the context in which it will be used.[762] The technological features can be myriad, and their relative importance in a technology competition depends on the preferences of the major customer segments. If we take audio storage, these features can encompass the level of audio playback quality, portability (e.g. size and shock resistance), amount of storage capacity, ease of navigating between audio files/tracks, etc. Other things being equal, the better a technology performs with respect to competing technologies, the higher the likelihood of adoption. While it pays to have a superb technology, this does not guarantee success.[763] Even more so, the technology that is superior often does not become the industry standard.[764] Grindley[765] emphasizes the importance of developing an 'adequate' technology aimed at 'satisfying' users rather than optimal performance. Suarez[766] states that while technological superiority does not always play a significant role in platform competitions, it is in general reasonable to expect that technological superiority will play a greater role when there are large performance differences between a technology and its competing alternatives. According to Schilling[767] and Smit and Pistorius,[768] a large performance difference is often a prerequisite to overthrow the entrenched de-facto standard and fend off substitutes. Arthur[769] specifically claims that the new technology should be 'two to three times better in some dimension - price, speed, convenience'.

In the case of compatibility standards, the extent to which a technical specification (and compliance certification) ensures interoperability is part of its technological superiority, and affects the extent to which a sponsor will be able to harness the benefits of network effects.

**35. Type of technological innovation**

In accordance with the framework of Henderson and Clark[770], a technology sponsor can develop a technology based on an incremental innovation, modular innovation, architectural innovation, or a radical innovation. This type of technological innovation impact the superiority of the technology, its backward compatibility, appropriability, ability to engage in collaborative development, and ability to build-up an organizational community to support the technology.

A radical innovation typically offers better technical performance than an incremental innovation. However, an incremental innovation is inherently more likely to be backward compatible than a radical innovation.[771] Regarding the appropriability, a radical innovation often provides possibilities to create intellectual property rights. This enables a technology sponsor to erect barriers to imitation. Fourthly, if a technology sponsor wants to engage in collaborative technology development, it needs to find a competitor that has a similar perspective on the required innovation (if the perspectives are opposing, the lack of a shared view will hamper the collaboration). Lastly, when a technology sponsor develops an architectural or radical innovation, it will find it harder to attract industry incumbents in an organizational community of supporters, because such firms are generally not inclined to support a technology that requires a different skill set or complementary assets.

**36. Unclear assessment criteria**

In the early stages of a new industry, or with the introduction of a radical new technology, customers often face ambiguity regarding the features that they value and require in a new technology. This is cause by unawareness of the capabilities of the new technology or a need to explore its functionalities.[772] In the stage when customer requirements are fluid, it is difficult to implement the technology in such a way that it meets customer requirements and gains traction in the market. This is an important determinant for a firm's entry timing in the market, and can be resolved through increasing returns to adoption.

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# Appendix 2: Overview of relationships between elements

**Influenced elements** (columns) / **Influencing elements** (rows)

| The numbers in this table are codes that correspond with academic papers listed in Table 4 | Technological superiority | Entry timing | Network effects | Availability of complementary goods | Appropriability | Pricing | Organizational community of supporters | Government intervention and industry regulation intervention | Marketing and pre-announcements awareness and manage expectations | Installed base | Firm's complementary assets | Switching and homing cost | Reputation and credibility | Strategic partnerships | Level of competition | Technological knowledge and skill base | Level of collaborative development | Availability of products | Absorptive capacity | Increasing returns to adoption | Chance | Market and industry characteristics | Rate and type of technological change | Firm size | Backward compatability | Powerful rival technology sponsors | Type of technological innovation | Adapters and gateways | Availability of imitators | Pre-empting scarce assets | Unclear assessment criteria | Technological breakthroughs in subsystems | Technological performance trajectories | Killer application | Hetero- or homogeneity of customer needs | Product proliferation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Technological superiority | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Entry timing | | | | 16, 36 | | | 46 | | | | | 42 | 10, 17, 35, 42 | | 6, 30, 33, 35 | | | | | 6, 32, 35, 38 | | | | | | | | | | 10, 17, 19, 35, 42 | | | | | | |
| Network effects | | 42 | | 18 | | 18 | | | | | | 16, 42 | | | | | | | | | | | | | | | | | | | | | | | | |
| Availability of complementary goods | | | 19, 21 | | | 21, 27 | | | | | | 16 | | | | | | | | | | | | | | | | | | | | | | 16, 17, 27, 36 | | |
| Appropriability | | | | 40 | | 23, 40 | 40 | | | | | | | | 21, 33 | | | | | | | 46 | | | | | | | 5, 16, 33, 40, 46 | | | | | | | |
| Pricing | | | 21 | | | | | | | | | 36 | | | | | | | | | | | | | | | | | 27 | | | | | | | |
| Organizational community of supporters | | | 21 | 4, 5, 10, 16, 20, 21, 24, 25, 30, 36 | | | | | | | | 20 | | | 20, 21 | | | 5, 10, 14, 20, 21, 22, 26, 32, 46 | | | | | | | | | | | | | | | | | | |
| Government intervention and industry regulation | | 42 | | | | 31 | 10, 22 | | | | | | | | 33, 42 | | 22 | | | 2, 3 | | | | | | | | | | | | | | | | |
| Marketing and pre-announcements | | | 21 | 17 | | | | | | | | | | | 4, 10 | | | | | | | | | | | | | | | | | | | | | |
| Installed base | | | 14 | 3, 4, 10, 11, 17, 20, 21, 22, 23, 24, 28, 33, 34, 35, 36, 37, 42, 46 | | | | | | | | 42 | | | | | | | | 2, 3, 33 | | | | | | | | | 46 | | | | | | | |
| Firm's complementary assets | | | | 17, 28, 36 | 43 | 10, 17, 43 | | | | | | | | | | | | 20, 36, 39, 43 | | | | | | | | | | | | | | | | | | |
| Switching and homing cost | | | | 17 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reputation and credibility | | | | 36 | | 27 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Strategic partnerships | 15 | 43 | | 5, 9, 10, 21, 24, 33, 36 | 43 | | | | | | | | 43 | | | | | 16, 26, 36 | 43 | | | | | | | | | | | 15, 25, 33 | | | | | | |
| Level of competition | | | | | | | 19, 20, 34, 46 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Technological knowledge and skill base | 26, 44 | | | | | | | | | | | | | | | | | | 33 | | | | | | | | | | | | | | | | | |
| Level of collaborative development | 5, 10, 21 | 14, 43 | | 21 | | 14 | 19, 21 | | | | | 14 | 43 | | 5, 10, 14, 21 | | | 21 | 43 | | | | | | | | | | | | | | | | | |
| Availability of products | | | | | | 5, 14, 21 | | | | | | | | | | | | | | | | | | | | | | | | | | | | 12, 34 | | |

**Influenced elements**

**Influencing elements** (rows)

| The numbers in this table are codes that correspond with academic papers listed in Table 4 | Technological superiority | Entry timing | Network effects | Availability of complementary goods | Appropriability | Pricing | Organizational community of supporters | Government intervention and industry regulation intervention | Marketing and pre-announcements awareness and manage expectations | Installed base | Firm's complementary assets | Switching and homing cost | Reputation and credibility | Strategic partnerships | Level of competition | Technological knowledge and skill base | Level of collaborative development | Availability of products | Absorptive capacity | Increasing returns to adoption | Chance | Market and industry characteristics | Rate and type of technological change | Firm size | Backward compatability | Powerful rival technology sponsors | Type of technological innovation | Adapters and gateways | Availability of imitators | Pre-empting scarce assets | Unclear assessment criteria | Technological breakthroughs in subsystems | Technological performance trajectories | Killer application | Hetero- or homogeneity of customer needs | Product proliferation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Absorptive capacity | 18 | 16 | | | | 16 | | | | | | 42 | | | | 33 | | | | | | | | | | | | | | | | | | | | |
| Increasing returns to adoption | 2, 3, 6, 8, 32, 33, 35, 44 | | | | | 1, 38 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Chance | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Market and industry characteristics | | 35 | | | | | 10 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Rate and type of technological change | | | | | | 26 | | | | | 44 | | | | 28 | | | | | | | | | | | | | | | | | | 31 | | | |
| Firm size | | | | | | 17, 20 | | | 17 | | 17, 26, 43 | | | | | 16, 36 | | 17, 32 | | | | | | | | | | | | | | | | | | |
| Backward compatability | | | | 36 | | | | | | | | 18, 21, 36, 38 | | | | | | | | | | | | | | | | | | | | | | | | |
| Powerful rival technology sponsors | | | | | | | 19 | | | | | | | | 14 | | | | | | | | | | | | | | | | | | | | | |
| Type of technological innovation | | | | | 30, 43 | | 46 | | | | | | | | | | | | | | | | | | 38 | | | | 46 | | | | | | | |
| Adapters and gateways | | | | 16 | | | | | | | | 17 | | | 12, 38 | | | | | | | | | | 20 | | | | | | | | | | | |
| Availability of imitators | | | | 16 | | | 27 | | | | | | | | 46 | | | 27, 40, 46 | | | | | | | | | | | | | | | | | | |
| Pre-empting scarce assets | 15, 30 | | | 16 | 30 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Unclear assessment criteria | 31 | 33, 35 | | | | | | | | | | | | | | | | | | | | 31, 33, 34 | | | | | | | | | | | | | | |
| Technological breakthroughs in subsystems | 36 | | | | | 27, 36 | | | | | | | | | | | | | | | | | 27 | | | | | | | | | | | | | |
| Technological performance trajectories | 6, 31 | | | | | 31 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Killer application | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Hetero- or homogeneity of customer needs | | | 24 | | | | | | | | | | | | | | | | | | | 29, 30 | | | | | | | | | | | | | | |
| Product proliferation | | | | | | | | | | | | | | | | | | 9, 20, 21 | | | | | | | | | | | | | | | | | | |

# Appendix 3: Overview of relationships between elements in case studies

The letters in this table are codes that correspond with case studies, as described in Subsection 8.1.3

**Influenced elements** (columns) / **Influencing elements** (rows)

| | Technological superiority | Entry timing | Network effects | Availability of complementary goods | Appropriability | Pricing | Organizational community of supporters | Government intervention and industry regulation intervention | Marketing and pre-announcements awareness and manage expectations | Installed base | Firm's complementary assets | Switching and homing cost | Reputation and credibility | Strategic partnerships | Level of competition | Technological knowledge and skill base | Level of collaborative development | Availability of products | Absorptive capacity | Increasing returns to adoption | Chance | Market and industry characteristics | Rate and type of technological change | Firm size | Backward compatability | Powerful rival technology sponsors | Type of technological innovation | Adapters and gateways | Availability of imitators | Pre-empting scarce assets | Unclear assessment criteria | Technological breakthroughs in subsystems | Technological performance trajectories | Killer application | Hetero- or homogeneity of customer needs | Product proliferation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Technological superiority | | | | | | | A | | | | | | | | | | A | | | | | | | | | | | | | | | | | | | |
| Entry timing | | | | C | | | | | | | | | A | | | | | | | A | | | | | | | | | | | | | | | | |
| Network effects | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Availability of complementary goods | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | B | | |
| Appropriability | | C | | B | | | | | | | | | | | A | | | | | | | | | | | | A, C | | | | | | | | | |
| Pricing | | | | | | | | | | | | A, C | | | | | | | | | | | | | | | | | | | | | | | | |
| Organizational community of supporters | | | | A, B, C | | | | | | | | | | | | | | A, C | | | | | | | | | | | | | | | | | | |
| Government intervention and industry regulation | A | | | B | | | | | | | | | | | | | B | | | | | | | | | | | | | | | | | | | |
| Marketing and pre-announcements | | | A, C | | | | A, C | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Installed base | | | | A, B, C | | | A | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Firm's complementary assets | | | | A, C | | | | | | | | | | | | | | A, C | | | | | | | | | | | | | | | | | | |
| Switching and homing cost | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reputation and credibility | | A | | | | A | C | | | | | | | | | | A | | | | | | | | | | | | | | | | | | | |
| Strategic partnerships | | | | B | B | | A | | | | | | | | | | | A | B | | | | | | | | | | | | | | | | | |
| Level of competition | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Technological knowledge and skill base | A, B, C | | | | | | | | | | | | | | | | | | B | | | | | | | | | | | | | | | | | |
| Level of collaborative development | A, B, C | | | | | | A, C | | | | | | A | | | | | | | | | | | | | | | | | C | | | | | | |
| Availability of products | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | A | | |

**Influenced elements**

| The letters in this table are codes that correspond with case studies, as described in Subsection 8.1.3 | Technological superiority | Entry timing | Network effects | Availability of complementary goods | Appropriability | Pricing | Organizational community of supporters | Government intervention and industry regulation intervention | Marketing and pre-announcements awareness and manage expectations | Installed base | Firm's complementary assets | Switching and homing cost | Reputation and credibility | Strategic partnerships | Level of competition | Technological knowledge and skill base | Level of collaborative development | Availability of products | Absorptive capacity | Increasing returns to adoption | Chance | Market and industry characteristics | Rate and type of technological change | Firm size | Backward compatability | Powerful rival technology sponsors | Type of technological innovation | Adapters and gateways | Availability of imitators | Pre-empting scarce assets | Unclear assessment criteria | Technological breakthroughs in subsystems | Technological performance trajectories | Killer application | Hetero- or homogeneity of customer needs | Product proliferation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Influencing elements** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Absorptive capacity | B | | | | | | | | | | | | | | | B | | | | | | | | | | | | | | | | | | | | |
| Increasing returns to adoption | A | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Chance | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Market and industry characteristics | | | | | B | | A | | | | | | | | | | B | | | | | | | | | | | | | | | | | | | |
| Rate and type of technological change | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Firm size | | | | | | A, C | C | | | | A, C | | | | | | | A, C | | | | | | | | | | | | | | | | | | |
| Backward compatability | | | | | | A | | | | | | A, C | | | | | | | | | | | | | | | | | | | | | | | | |
| Powerful rival technology sponsors | | | | | | | A, C | | | | | | | | A, C | | B | | | | | | | | | | | | | | | | | | | |
| Type of technological innovation | A, C | | | | A | A, C | | | | | | | | | | | | | | | | | | | A, C | | | | | | | | | | | |
| Adapters and gateways | | | | | | | | | | | | A, C | | | | | | | | | | | | | | | | | | | | | | | | |
| Availability of imitators | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Pre-empting scarce assets | A | | | | | | A | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Unclear assessment criteria | | | | | | | | | | | | | | | | | | | | | | C | | | | | | | | | | | | | | |
| Technological breakthroughs in subsystems | A, B | | | B | | A | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Technological performance trajectories | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Killer application | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Hetero- or homogeneity of customer needs | | | | | | | | | | | | | | | | | | | | | | A | | | | | | | | | | | | | | |
| Product proliferation | | | | | | | | | | | | | | | | | | A, C | | | | | | | | | | | | | | | | | | |

# Appendix 4: Merged overview of relationships between elements

**Influenced elements** (columns); **Influencing elements** (rows)

| The numbers and letters in this table are codes that correspond with academic papers listed in Table 4 and case studies as described in Subsection 8.1.3. | Technological superiority | Entry timing | Network effects | Availability of complementary goods | Appropriability | Pricing | Organizational community of supporters | Government intervention and industry regulation intervention | Marketing and pre-announcements awareness and manage expectations | Installed base | Firm's complementary assets | Switching and homing cost | Reputation and credibility | Strategic partnerships | Level of competition | Technological knowledge and skill base | Level of collaborative development | Availability of products | Absorptive capacity | Increasing returns to adoption | Chance | Market and industry characteristics | Rate and type of technological change | Firm size | Backward compatability | Type of technological innovation | Adapters and gateways | Pre-empting scarce assets | Technological breakthroughs in subsystems | Killer application | Product proliferation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Technological superiority | | | | | | | A | | | | | | | | | | A | | | | | | | | | | | | | | |
| Entry timing | | | | **C**, 16, 36 | | | 46 | | | | | 42 | **A**, 10, 17, 35, 42 | | 6, 30, 33, 35 | | | | | **A**, 6, 32, 35, 38 | | | | | | | | 10, 17, 19, 35, 42 | | | |
| Network effects | | 42 | | 18 | | 18 | | | | | | 16, 42 | | | | | | | | | | | | | | | | | | | |
| Availability of complementary goods | | | 19, 21 | | | 21, 27 | | | | | | 16 | | | | | | | | | | | | | | | | | | **B**, 16, 17, 27, 36 | |
| Appropriability | | C | | **B**, 16, 40 | | 23, 40 | 27, 40 | | | | | | | | **A**, 21, 33 | | 46 | 27, 40, 46 | | | | 46 | | | | A, C | | | | | |
| Pricing | | | 21 | | 27 | | | | | | | **A**, **C**, 36 | | | | | | | | | | | | | | | | | | | |
| Organizational community of supporters | | | 21 | **A**, **B**, **C**, 4, 5, 10, 16, 20, 21, 24, 25, 30, 36 | | | | | | | | 20 | | | 20, 21 | | | **A**, **C**, 5, 10, 14, 20, 21, 22, 26, 32, 46 | | | | | | | | | | | | | |
| Government intervention and industry regulation | A | 42 | | B | | 31 | 10, 22 | | | | | | | | 33, 42 | | **B**, 22 | | | 2, 3 | | | | | | | | | | | |
| Marketing and pre-announcements | | | **A**, **C**, 21 | 17 | | | A, C | | | | | | | | 4, 10 | | | | | | | | | | | | | | | | |
| Installed base | | | 14 | **A**, **B**, **C**, 3, 4, 10, 11, 17, 20, 21, 22, 23, 24, 28, 33, 34, 35, 36, 37, 42, 46 | 46 | | A | | | | | 42 | | | | | | | | 2, 3, 33 | | | | | | | | | | | |
| Firm's complementary assets | | | | **A**, **C**, 17, 28, 36 | 43 | 10, 17, 43 | | | | | | | | | | | | **A**, **C**, 20, 36, 39, 43 | | | | | | | | | | | | | |
| Switching and homing cost | | | | 17 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reputation and credibility | | A | | 36 | | **A**, 27 | C | | | | | | | | | | A | | | | | | | | | | | | | | |
| Strategic partnerships | 15 | 43 | | **B**, 5, 9, 10, 21, 24, 33, 36 | **B**, 43 | | A | | | | | | 43 | | | | | **A**, 16, 26, 36 | **B**, 43 | | | | | | | | | 15, 25, 33 | | | |
| Level of competition | | | | | | | **A**, **C**, 19, 20, 34, 46 | | | | | | | | | | B | | | | | | | | | | | | | | |
| Technological knowledge and skill base | **A**, **B**, **C**, 26, 44 | | | | | | | | | | | | | | | | | | **B**, 33 | | | | | | | | | | | | |

**Influenced elements**

| The numbers and letters in this table are codes that correspond with academic papers listed in Table 4 and case studies as described in Subsection 8.1.3. (Rows: **Influencing elements**) | Technological superiority | Entry timing | Network effects | Availability of complementary goods | Appropriability | Pricing | Organizational community of supporters | Government intervention and industry regulation intervention | Marketing and pre-announcements awareness and manage expectations | Installed base | Firm's complementary assets | Switching and homing cost | Reputation and credibility | Strategic partnerships | Level of competition | Technological knowledge and skill base | Level of collaborative development | Availability of products | Absorptive capacity | Increasing returns to adoption | Chance | Market and industry characteristics | Rate and type of technological change | Firm size | Backward compatibility | Type of technological innovation | Adapters and gateways | Pre-empting scarce assets | Technological breakthroughs in subsystems | Killer application | Product proliferation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Level of collaborative development | **A**, **B**, **C**, 5, 10, 21 | 14, 43 | | 21 | | 14 | **A**, **C**, 19, 21 | | | | | 14 | **A**, 43 | | 5, 10, 14, 21 | | | 21 | 4 3 | | | | | | | | | | | C | |
| Availability of products | | | | | | 5, 14, 21 | | | | | | | | | | | | | | | | | | | | | | | | | |
| Absorptive capacity | B, 18 | 16 | | | | 16 | | | | | | 42 | | | | **B**, 33 | | | | | | | | | | | | | | | |
| Increasing returns to adoption | **A**, 2, 3, 6, 8, 32, 33, 35, 44 | | | | | 1, 38 | | | | | | | | | | | | | | | | | | | | | | | | | |
| Chance | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Market and industry characteristics | 31 | 33, 35 | 24 | | B | | **A**, 10 | | | | | | | | | | B | | | | | | | | | | | | | | |
| Rate and type of technological change | | | | | | 26 | | | | | 44 | | | | 28 | | | | | | | | | | | | | | 3 1 | | |
| Firm size | | | | | | **A**, **C**, 17, 20 | C | | 17 | | **A**,**C**, 17, 26, 43 | | | | | 16, 36 | | **A**, **C**, 17, 32 | | | | | | | | | | | | | |
| Backward compatibility | | | | 36 | | A | | | | | | **A**, **C**, 18, 21, 36, 38 | | | | | | | | | | | | | | | | | | | |
| Type of technological innovation | **A**, **C**, | | | | **A**, 30, 43, 46 | A, C | 46 | | | | | | | | | | | | | | | | | | **A**, **C**, 38 | | | | | | |
| Adapters and gateways | | | | 16 | | | | | | | | **A**, **C**, 17 | | | 12, 38 | | | | | | | | | | 20 | | | | | | |
| Pre-empting scarce assets | **A**, 15, 30 | | | 16 | 30 | | A | | | | | | | | | | | | | | | | | | | | | | | | |
| Technological breakthroughs in subsystems | **A**,**B**, 6, 31, 36 | | | B | | **A**, 27, 31, 36 | | | | | | | | | | | | | | | | | 27 | | | | | | | | |
| Killer application | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Product proliferation | | | | | | | | | | | | | | | | | | **A**, **C**, 9, 20, 21 | | | | | | | | | | | | | |

# Appendix 5: Overview per phase of commonalities between cases

| | R&D Build-up | | | Preparing for market entry | | | Initiating market adoption | | | Gaining critical mass | | | Winning the mass market | | | Post-dominance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Blu-ray vs. HD-DVD | MP3 | SACD vs. DVD-A | Blu-ray vs. HD-DVD | MP3 | SACD vs. DVD-A | Blu-ray vs. HD-DVD | MP3 | SACD vs. DVD-A | Blu-ray vs. HD-DVD | MP3 | SACD vs. DVD-A | Blu-ray vs. HD-DVD | MP3 | SACD vs. DVD-A | MP3 |
| ***Reputation and credibility*** | | | x | x | | x | x | | x | | | | | | | |
| **Installed base** | | | | | | | | | | | | | | | | |
| **Pricing** | x | | x | x | | x | x | x | x | x | x | x | x | x | x | x |
| **Entry timing** | | | | x | | | x | x | x | | | | | | | |
| **Marketing and pre-announcements** | | | | x | | x | x | x | x | | x | x | | | | |
| **Availability of products** | | | | | | | x | x | x | x | | x | | | x | |
| **Availability of complementary goods** | | | | | | | x | x | x | x | | x | | | x | |
| **Killer application** | | | | | | | x | x | | x | | | x | | | |
| Size | | | | x | | x | x | | x | x | | | | | | |
| Complementary assets | | | | x | | x | x | | x | x | | x | | | | |
| Technological knowledge and skill base | x | x | x | | x | | | x | | | | | | | | |
| Absorptive capacity | | x | | | x | | | | | | | | | | | |
| Pre-empting scarce assets | | | x | x | | x | | | | x | | | | | | |
| Level of collaborative development | x | | x | x | x | x | | | | | | | | | | |
| Organizational community of supporters | | | x | x | | x | x | x | x | x | x | x | x | x | x | x |
| Strategic partnerships | | x | | x | x | | | x | | x | | | | | | |
| Product proliferation | | | | x | | | x | x | | x | | x | | | x | |
| Appropriability | x | | x | | x | | | x | | | x | | | x | | x |
| Chance | | | | | | | | x | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| ***Technological superiority*** | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| **Installed base** | | | | | | | x | x | x | x | x | x | x | x | x | x |
| **Network effects** | | | | | | | | x | | | x | | | x | | x |
| **Switching and homing cost** | | | x | x | | x | x | | x | x | | x | | | x | |
| **Backward compatibility** | x | | x | x | | x | x | | x | x | | x | | | x | |
| Increasing returns to adoption | | | | x | | | | | | | | | | | | |
| Technological breakthroughs in subsystems | x | | | x | x | | | x | | | x | | | | | |
| Type of technological innovation | x | | x | x | | | | | | | | | | | | |
| Adapters and gateways | | | | | | x | x | | x | | | x | | | x | |
| Chance | | x | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| ***Market and industry characteristics*** | x | | | x | x | | x | x | x | x | x | x | | x | | x |
| **Level of competition** | | | x | x | x | x | x | x | x | x | x | x | | x | | x |
| **Rate and type of technological change** | | | | | | | | | | x | | x | x | | x | |
| **Network effects** | | | | | | | x | | x | x | x | x | x | x | | x |
| **Availability of products** | | | | | | | x | | x | x | | x | x | | x | |
| **Availability of complementary goods** | | | | | | | x | x | x | x | x | x | x | x | x | x |
| **Killer application** | | | | | | | | | | | x | | | x | | |
| Government intervention and industry regulation | | | | x | x | | | | | | x | | | x | | |
| Product proliferation | | | | | | | | | | | | | | | | |
| Appropriability | | | x | x | | x | x | x | x | | x | | | x | | x |
| Chance | | | | | | | | | x | | | | | | | |

## Summary

The emergence of a technology towards de-facto standard is a complicated, dynamic process whereby often many companies are involved. De-facto standards are established by market selection. However, the time required to move from research and development to becoming the de-facto standard can easily span more than ten years, challenged by changing customer preferences and a changing industry.

Currently, research in the field of technology- and innovation-management has identified many elements that influence the process of de-facto standard emergence. Whereas some academics have generated comprehensive overviews of these elements, others have proposed simplified models, composed of several elements, aimed at clarifying how these interact and influence the success of a technology. The main shortcomings are 1) that elements itself do not provide insights in the dynamics of de-facto standard emergence, and 2) the simplified models (although they have merit) address only a part of the total picture and are therefore incomplete.

This dissertation proposes an integrative framework and corresponding methodology for understanding the process by which a technology becomes the de-facto standard. This framework can be used to gain better insight how strategic decision making can shape the odds of a technology emerging as the de-facto standard. It thereby advances the 'strategic-choice view' that has been advocated by institutional economists and focuses on strategic behaviours of firms to establish their technology as the de-facto standard.

The framework was developed by creating a concept from a directed content analysis of the existing body of scientific literature. This integrated insights from different streams of literature. The concept was tested and improved through a multiple case study approach on technology competitions. The following technology competitions were studied: Blu-ray versus HD-DVD (high definition optical discs), MP3 (music storage and distribution), and Super Audio CD versus DVD-Audio (high definition audio discs).

This research resulted in the following main findings:

- Every technology that emerges as de-facto standard displays a unique path. This provides support to the notion that all technology competitions are unique, and therefore require a framework approach to support strategic decision making.
- The results confirm that companies can shape the odds of their technology emerging as de-facto standard through strategic decision making, however the outcome does not solely rely on strategic decision making.
- The emergence of a de-facto standard can be influenced by 34 unique elements (e.g. market mechanisms, models for creating a technology bandwagon, elements for shaping the odds of technology selection). Of these elements, 17 were found to be subject to strategic decision making. Companies can utilize these to shape the odds of their technology emerging as the de-facto standard.
- The 34 elements can be divided into nine groups by first allocating them to three types of categories (i.e. firm-, technology-, and market/industry related), and subsequently segmenting them into those with a first, second and third order influence on a customer's decision to adopt a technology. These

nine groups form the basis for the integrative framework. Of the 34 elements, 12 were found to be firm-related, seven were technology-related, five were market/industry related, and 10 could be allocated to multiple categories. In terms of influence on a customer's decision to adopt a technology, 16 elements have a first-order, 14 a second-order, three a third-order influence. One, the element of chance, could be attributed to all categories and levels, and was therefore excluded from the framework.

- Many elements influence each other. In total 132 inter-element relationships were identified.
- The emergence of a de-facto standard can be divided into six phases: R&D build-up, Preparing for market entry, Creating the market, Gaining critical mass, Winning the mass market, and Post dominance. My research confirms that each technology competition progresses through these phases.
- When testing the integrative framework on several case studies, this provided a more comprehensive insight in technology competitions and the emergence of de-facto standards, leading to a better understanding of the dynamics and the differences / commonalities between technology competitions. In addition, it allowed better insight in the strategic approaches of the rival technology sponsors during the emergence of the de-facto standard. Lastly, the framework enabled an analysis on how, in hindsight, the losing side could have shaped odds of its technology to emerge as the de-facto standard
- Out of the comprehensive number of elements that were found to influence each of the technology competitions, it was possible to identify a small subset of 'key elements' that proved decisive in the process. These decisive elements, and their number, differ per case.

The research led to the following main contributions:

- The primary contribution is the integrative framework that can be used to support strategic decision making to shape the odds of a technology emerging as the de-facto standard. Its contribution is twofold:
  - Firstly the composition of the framework: the framework is comprised of 33 elements influencing the emergence of a de-facto standard, scoring options, phases and milestones in the emergence of a de-facto standard, and dynamics which are typical for each of the phases. Although the framework draws upon many findings from the existing body of academic literature, the novelty lies in the way these are combined. This enabled new insights in accordance with the findings described above.
  - Secondly the approach: the research in this dissertation confirmed that the emergence of every de-facto standard displays a unique 'path', therefore the integrative framework is designed to cater to the variety and dynamics of technology competitions. It does so by combining the concept of phases with a 'menu' of elements. Rather than providing a 'recipe for success', the integrative framework supports the strategic decision maker through a series of questions.
- Sixth phase in the process of de-facto standard emergence. Suarez[1] claimed that de-facto standards emerge through five phases. This hypothesis is tested in my case studies, and these indeed support the

[1] Suarez, F.F., Battles for technological dominance: an integrative framework, *Research Policy,* 33 (2), 2004, pp.271-286

five phases, but also that there is a sixth phase, Winning the Mass Market, that was previously not identified.

- Common set of dynamics that govern technology competitions. By studying patterns between the case studies, the main attention points per phase were identified, providing guidance on the subset of elements that are especially relevant for each phase of the emergence of a de-facto standard.
- Possibility of two-sided tipping. Academic literature has shown that de-facto standards emerge as a customer driven process, but the case of Blu-ray versus HD-DVD showed that a de-facto standard can also emerge through selection by manufacturers of complementary goods. In other words, 'tipping' caused through network effects does not only occur in the customer network, but also in the complementor network. Therefore, two-sided tipping is possible.
- In my research, 34 unique elements were identified, thereby extending the current state-of-the-art by 5 elements. Of these elements, three were newly found during the case studies, i.e. subsidizing providers of complementary goods, history of the industry, and accessibility of intellectual property rights.
- Comprehensive overview of inter-element relationships, and a first glance on how they develop during the emergence of a de-facto standard. The research in this dissertation identified 132 inter-element relationships, of which 114 from the body of literature and 18 from the case studies. This represents the first time that inter-element relationships have been thoroughly mapped. It adds to the field of the 'strategic choice view' by providing a better understanding how various elements influence each other, and provides insight how the status of an element can be altered. In addition, the results show that inter-element relationships are dynamic: throughout the emergence of a de-facto standard the relationship between two elements may be intermittent, and the nature of the relationship (i.e. strong or weak influence, positive or negative effect) can change over time.
- Integral view of the concepts 'compatibility standard', 'dominant design', and 'platform'. The phenomenon of de-facto standards is multi-faceted, whereby the concepts of 'compatibility standard', 'dominant design' and 'platform' highlight these different facets. The overlap and boundaries between the concepts is illustrated through 15 examples of de-facto standards.

# Samenvatting

Een technologie welke de positie van marktstandaard verovert legt een pad af dat gepaard gaat met complexiteit en dynamiek. Dit wordt mede ingegeven doordat vaak meerdere bedrijven hierbij betrokken zijn. Marktstandaarden komen tot stand door marktselectie, oftewel de voorkeur van de klant. Het proces om de positie van marktstandaard te veroveren neemt vaak lang in beslag, vanaf de initiële onderzoeksfase kan dit gemakkelijk meer dan tien jaar zijn. Gedurende deze tijd moeten bedrijven rekening houden met ontwikkelingen in klantvoorkeuren en wijzigingen in de industrie.

In het academische veld van Technologie- en Innovatiemanagement is te zien dat academici vele factoren hebben geïdentificeerd welke de totstandkoming van een marktstandaard beïnvloeden. Sommigen hebben deze factoren samengevoegd tot complete overzichten, terwijl anderen een selectie van factoren in een versimpeld model hebben gevat. Dit alles om een beter inzicht te verkrijgen hoe het kan dat de ene technologie wel door de massamarkt wordt geaccepteerd, terwijl de andere faalt of slechts door een select aantal klanten wordt geaccepteerd. De belangrijkste tekortkomingen van de voorgaande studies zijn enerzijds dat de factoren op zichzelf niet in staat zijn om inzicht te geven in de dynamiek van een technologiestrijd, en anderzijds dat de versimpelde modellen een incompleet beeld geven.

In dit proefschrift wordt inzicht gegeven hoe een technologie zich kan ontwikkelen tot marktstandaard. Dit gebeurt aan de hand van een raamwerk en een bijbehorende methodiek voor toepassing ervan. Door middel van het raamwerk kan beter inzicht worden verkregen hoe bedrijven strategische keuzes kunnen inzetten om de kans te vergroten dat hun technologie de positie van marktstandaard veroverd. Hierdoor kunnen de grenzen van het 'strategische-keuze'-veld worden verlegd. Dit veld wordt aangehangen door institutionele economen, en richt zich op het vraagstuk hoe bedrijven door strategisch manoeuvreren hun technologie tot marktstandaard kunnen promoveren.

Het raamwerk is tot stand gekomen door eerst, middels een studie van de academische literatuur, een concept te ontwikkelen. In dit concept zijn inzichten van verschillende stromen uit de academische literatuur met elkaar verenigd. Vervolgens is dit concept getoetst en verbeterd door het toe te passen op een aantal gevallen waarin technologieën in onderlinge concurrentie strijden om de voorkeur van de klant. De volgende gevallen zijn bestudeerd: Blu-ray versus HD-DVD in de markt voor videodragers en -spelers, MP3 in de markt voor muziekopslag en -distributie, en Super Audio CD tegen DVD-Audio in de markt voor muziekdragers en -spelers.

Het onderzoek heeft tot de volgende bevindingen geleid:

- Elke technologie welke de positie van marktstandaard verovert legt een uniek traject af. Deze bevinding ondersteunt de aanname dat niet een model, maar een raamwerk gebruikt moet worden om strategische keuzes te kunnen ondersteunen.
- De resultaten van het onderzoek bevestigen dat bedrijven door middel van strategische keuzes de kans kunnen vergroten dat hun technologie de positie van marktstandaard verovert, maar laten ook zien dat de uitkomst niet enkel door strategische keuzes bepaald wordt.

- In totaal zijn 34 individuele factoren gevonden welke de totstandkoming van een marktstandaard beïnvloeden. 17 van deze factoren zijn onderhevig aan strategische keuzes.
- De 34 factoren kunnen onderverdeeld worden in negen groepen, namelijk als factoren die toebedeeld kunnen worden aan eigenschappen van de firma, de technologie, en de markt/industrie, en die anderzijds een eerste-, tweede- of derde-orde-invloed op klantbeslissingen hebben. Deze negen groepen vormden de basis voor het verdere raamwerk. Van de 34 factoren zijn er 12 gerelateerd aan eigenschappen van de firma, zeven aan eigenschappen van de technologie, vijf aan eigenschappen van de markt/industrie, en tien factoren konden aan meerdere categorieën worden gerelateerd. In termen van klantbeïnvloeding, bleken 16 factoren een eerste-orde-invloed te hebben, 14 een tweede-orde-, en drie een derde-orde-invloed. Eén factor, namelijk de factor 'toeval', bleek op alle categorieën en ordes van toepassing. Zodoende is deze factor niet opgenomen in het raamwerk.
- Veel factoren beïnvloeden elkaar onderling. In totaal zijn 132 relaties tussen de factoren gevonden.
- Technologieën welke de positie van markt-standaard veroveren gaan door een proces bestaande uit zes fases: technologie-ontwikkeling, voorbereiding op marktintroductie, creëren van de initiële markt, versnellen van de marktadoptie, overtuigen van de massa, en tot slot de fase na totstandkoming van de marktstandaard. Het onderzoek in dit proefschrift bevestigt dat elke technologiecompetitie deze fases doorloopt.
- Tijdens het testen van het raamwerk bleek dat deze het mogelijk maakt om een fijnmazig beeld te verkrijgen van technologiecompetitie uit het verleden. Deze fijnmazigheid bleek noodzakelijk om de dynamiek van de technologiecompetities te begrijpen, en daarmee te kunnen verklaren waarom de ene technologie wel succesvol was terwijl de andere heeft gefaald. Bovendien heeft het raamwerk geholpen om de verschillen en overeenkomsten tussen de bestudeerde gevallen te identificeren. Daarnaast bleek dat het mogelijk was om de strategieën van de concurrerende partijen te achterhalen. Dit heeft ons een beter beeld gegeven van de strategische mogelijkheden, en hoe deze zich gedurende de technologiecompetitie kunnen ontwikkelen. Vanwege het holistische beeld dat dankzij het raamwerk verkregen werd, was het mogelijk om achteraf te analyseren welke opties de verliezer mogelijkerwijs had om zijn situatie te verbeteren, en op welk moment deze opties ingezet konden worden.
- In elk van de bestudeerde gevallen werd een groot aantal factoren geïdentificeerd welke de totstandkoming van een marktstandaard beïnvloeden, maar het opmerkelijke was dat het telkens mogelijk was om achteraf enkele factoren aan te wijzen welke hierin doorslaggevend waren. Deze doorslaggevende factoren, en hun aantal, bleken echter per geval verschillend.

Daarnaast heeft het onderzoek tot de volgende bijdragen aan het academische veld geleverd:

- Het raamwerk is de voornaamste bijdrage aan het academisch veld, aangezien dit gebruikt kan worden om beter inzicht te geven hoe bedrijven strategische keuzes kunnen inzetten om de kans te vergroten dat hun technologie de positie van marktstandaard veroverd. De bijdrage van het raamwerk is tweeërlei:

    - Compositie van het raamwerk: het raamwerk is opgebouwd uit 34 factoren die invloed hebben op de totstandkoming van een marktstandaard, zes fases en bijbehorende mijlpalen, en een indicatie van de zaken die per fase van belang zijn. Hoewel een groot deel van de componenten individueel al in de literatuur te vinden is, zit de noviteit in de combinatie van al deze componenten en de wijze waarop deze gecombineerd zijn. Dit maakte de hierboven beschreven nieuwe bevindingen mogelijk.

  - De aanpak: de resultaten uit het onderzoek hebben bevestigd dat elke technologie welke de marktstandaard wordt een uniek traject doorloopt, zodoende is het raamwerk zodanig flexibel ontwikkeld dat het recht doet aan de grote variëteit en het dynamische proces waaraan technologiecompetities onderhevig zijn. Dit wordt gedaan door de gebruiker de juiste vragen op het juiste moment voor te leggen, in plaats van een "succesformule" te presenteren zoals academici in het verleden dikwijls hebben gedaan

- De identificatie van een additionele fase in de totstandkoming van een markt-standaard. In 2004 stelde Suarez[2] dat er vijf fases onderscheiden kunnen worden in de totstandkoming van een marktstandaard. Het onderzoek bevestigt deze vijf fases, maar heeft daarnaast een nieuwe fase gevonden: overtuigen van de massa.
- Generieke vraagstukken in de fases van de technologie competitie. Na afloop van de drie bestudeerde technologiecompetities zijn de bevindingen naast elkaar gelegd en geanalyseerd. Hierbij zijn patronen gevonden die erop wijzen dat elke fase een aantal onderliggende vraagstukken kent. Deze dienen correct geadresseerd te worden wil een bedrijf de kans vergroten dat zijn technologie de marktstandaard wordt. Dit resulteerde in een overzicht van de voornaamste aandachtspunten per fase, en de daaraan gekoppelde factoren in het raamwerk.
- Niet alleen de klant, maar ook de industrie kan de uitkomst van een technologiecompetitie bepalen. De industrie kan de uitkomst van de technologiecompetitie bepalen doordat zo veel bedrijven zich achter een technologie scharen dat de hele markt overgaat. De literatuur over de technologiecompetities die in dit proefschrift centraal staan gaat ervan uit dat de uitkomst bepaald wordt door de klant, bijvoorbeeld de consument. Deze maakt een keuze op basis van bepaalde voorkeuren, waarbij de technologie welke het meest gekozen wordt als winnaar uit de strijd komt. In de markt voor consumentenelektronica was het inderdaad typisch de consument die de keuze maakte voor de ene technologie of de andere. Het onderzoek in dit proefschrift laat echter zien dat de keus niet alleen bij de klant ligt, maar dat het aantal bedrijven dat zich achter een technologie schaart ook de doorslag kan geven.
- Zoals eerder genoemd zijn 34 individuele factoren gevonden die de totstandkoming van een marktstandaard beïnvloeden. Hiermee wordt het tot nu toe meest complete overzicht met vijf factoren overschreden. Drie van deze elementen zijn geïdentificeerd tijdens het empirische deel van het onderzoek, en daardoor nieuw: (1) subsidiëren van partijen die aanpalende producten en diensten leveren, (2) geschiedenis van de industrie (bijvoorbeeld 'oud zeer' tussen bedrijven), en (3) toegankelijkheid van intellectueeleigendomsrechten.
- Inventarisatie van relaties tussen factoren en een eerste beeld hoe deze zich gedurende de technologiecompetitie ontwikkelen. Veel voorgaande studies hebben zich gericht op het nauwkeurig vaststellen van een relatie tussen twee, of een paar, factoren. In dit proefschrift is deze schat aan inzichten bij elkaar gebracht, en gecomplementeerd met de inzichten uit de technologiecompetities die in het kader van dit proefschrift bestudeerd zijn. Dit resulteerde in een inventarisatie van 132

[2] Suarez, F.F., Battles for technological dominance: an integrative framework, *Research Policy,* 33 (2), 2004, pp.271-286

relaties, waarvan 114 afkomstig uit de literatuur en 18 uit de bestudeerde technologiecompetities. Door deze inventarisatie is een beter beeld verkregen hoe de 34 factoren op elkaar inspelen, en aan welke knoppen bedrijven kunnen draaien om een bepaalde factor te beïnvloeden. Daarnaast hebben de resultaten aangetoond dat de relaties tussen de factoren niet statisch zijn, maar zich gedurende de technologiecompetitie ontwikkelen. Zo kunnen twee factoren elkaar in de ene fase beïnvloeden, en in de volgende fase niet meer. Daarnaast kan de invloed sterker of zwakker worden, of zelfs omslaan van een positief naar een negatief effect.

- Integratie van de begrippen 'compatibiliteitsstandaard', 'dominant ontwerp', en 'platform' die in de academische literatuur elk verwijzen naar het begrip 'markt-standaard'. Deze drie begrippen zijn echter wezenlijk verschillend, wat het lastig maakt om inzichten vanuit de hieraan gerelateerde gebieden met elkaar te verenigen. Dit proefschrift laat zien dat het concept 'marktstandaard' meerdere facetten heeft, en de genoemde begrippen belichten elk een ander facet. Dit is gedaan door de overeenkomsten en verschillen tussen de drie begrippen te illustreren aan de hand van 15 voorbeelden van marktstandaarden.

## About the Author

Simon den Uijl was born on March 11, 1982 in Pijnacker, The Netherlands. Simon's engagement with Rotterdam School of Management started in 2000, when he started his studies in Business Administration. In 2003 he obtained his BSc. Early 2004, Simon interrupted his studies to start Epyon, a company focused on developing electronics to fast-charge devices. After two year of bootstrapping the company, Simon handed over the position of Managing Director to his co-founders, and pursued obtaining his MSc. degree. This is when he came in touch with Dr. Ir. Henk J. de Vries. Dr.Ir. De Vries challenged Simon to write a thesis on how Epyon's fast charging technology could be established as de-facto standard. This challenge was well aligned with Simon's interest to understand why particular technologies managed to become a global success, whereas others failed. Simon finalized his thesis in several months and obtained his MSc. degree. Following this event, Simon did not return to Epyon,[3] but decided to pursue a career as entrepreneur by starting Q Professionals, a company focused on IT recruitment. In its first year, the company did well and expanded aggressively, however it soon faced the economic recession and was not able to differentiate itself from competitors.

Based on his experiences with Epyon and Q Professionals, Simon learned his passion was to get a technology from idea to market successfully. In order to gain more experience in this field, Simon took a position at the Energy Research Centre of the Netherlands (ECN), where he performed the Technology Transfer. ECN is the largest research centre in the Netherlands in the field of energy. Its 400 researchers focus on performing applied research on a large variety of technologies. In his position, Simon was responsible for commercialization of 12 technologies, whereby he reported to the COO / Director of R&D. At the same time, Simon decided to take-up an opportunity offered by Dr.Ir. De Vries to start a PhD on de-facto standards, in parallel to his regular job.

After four years at ECN, and realizing multiple technology licenses, Simon found an opportunity to take his passion to the next level. At the end of 2011 he joined Royal Philips as Standardization Manager in the Intellectual Property & Standardization department of Philips Group Innovation. In this position Simon currently supports Philips' Lighting business in establishing standardized interfaces with external partners, and facilitating the market adoption of these standardized interfaces. In his position at Philips, Simon has been involved in establishing The Connected Lighting Alliance, an industry consortium focused on promoting the use of wireless connected lighting solutions. This alliance is currently comprised of 31 members, including the leading lighting companies worldwide. Due to the efforts of the alliance, the lighting industry is converging on the ZigBee protocol for residential wireless lighting solutions (e.g. wireless connected light bulbs a.k.a. smart bulbs), resulting in an increasing number of interoperable wireless connected lighting products. Within this alliance, Simon fulfills the position of Secretary General. Next to

[3] After bootstrapping for four years, the company managed to obtain its first funding round. Several more followed, and in 2011 the company was acquired by Swiss multinational ABB. It is currently one of the leading companies worldwide in the field of fast-charging infrastructure for electric vehicles.

The Connected Lighting Alliance, Simon has initiated Philips Lightings' activities on lighting based indoor positioning. He is currently still involved in this activity, where he is responsible for developing an industry ecosystem and partnerships for the platform.

In terms of academic achievements, Simon has published his work in California Management Review, Organization Studies, Business History, and International Journal of IT Standards and Standardization. Simon has presented his work at international conferences such as the International Conference on Standardization and Innovation Technology, and the EURAS Annual Standardization Conference. Besides his research, Simon has supervised the Master thesis of four students (i.e. Deniz Bayramoglou, Chris Ismyrloglou, Tim Riegman, and Cathy Tran), and has provided several lectures to Master students.

Simon is married to Marcia. Together they have a young daughter, Anna.

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## THE EMERGENCE OF DE-FACTO STANDARDS

Increasingly, companies compete on technologies that bring together groups of users in two-sided networks. Examples include smartphones and on-line search engines. Industries governed by such platform technologies commonly show one emerging as the de-facto standard. This is because these industries are prone to network externalities (i.e. when the benefit that can be derived from a technology increases exponentially with the number of users). Competitions for the de-facto standard are high-stakes games. These ‘winner-take-all’ markets demonstrate very different competitive dynamics than markets in which many competitors can coexist relatively peacefully, as they often have a single tipping point which shifts market adoption to one particular technology. The academic field lacks a robust clarification on how firms can shape the odds of their technology emerging as the de-facto standard.

This study develops an integrative framework and corresponding methodology for understanding the process by which a technology becomes the de-facto standard. By applying the framework to several technology competitions, insight is provided in how firm-, technology- and market-related elements influence technology competitions. Results indicate that the emergence of every de-facto standard displays a unique path. This path can be divided into six phases, and can be influenced by 34 unique elements, of which 17 are subject to strategic decision making. Patterns between technology competitions indicate a common set of focal points per phase.

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Design & layout: B&T Ontwerp en advies (www.b-en-t.nl) Print: Haveka (www.haveka.nl)