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Co-opetition in standard-setting: the case of the Compact Disc

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Abstract

The success of the CD has (partly) been attributed to the ability of Sony, Philips and Matsushita to cooperate in the run-up to the DAD conference in 1981, where the technological standard was set. We model the situation leading up to the conference in a simple game with technological progress and the possibility of prelaunching a technology. We identify players' tradeoffs between prelaunching (which ends technological progress) and continued development (which involves the risk of being pre-empted). Contrasting outcomes with complete and incomplete information, we find that there appeared to be considerable uncertainty about rivals' technological progress.

1 Introduction

Standardization is important whenever strong network effects operate and (potential) user benefits crucially depend on the interoperability of components. With the emergence of modern information and telecommunication technologies and the convergence

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of related industries including the computer and software industries, telecommunication and consumer electronics, compatibility standards have consistently been subject to academic attention (Besen and Saloner, 1989; Shapiro and Varian, 1999; Weitzel, 2004). A large number of theoretical as well as empirical studies have studied standardization processes in detail.[1] Key issues in this research are the identification of circumstances under which standardization is (socially or privately) desirable, and the characterization of (however defined) appropriate ways to achieve a standard. Clearly, there is a lot to learn from the study of past (successful or unsuccessful) standardization processes. In this paper, we focus on the introduction of the compact disc (CD) and explore how coalition formation, prelaunch strategies and technological progress may have affected its success.

The introduction of the CD was a particularly successful standardization process in terms of its smoothness and speed. The process displayed a set of action typically attributed to two fundamentally different (and mutually exclusive) types of standardization processes; de facto standardization through market mechanisms, and formal standardization through explicit agreements in committees and industry consortia (Farrell and Saloner, 1988). While in the former, a standard emerges from competition between different technical solutions in the marketplace, the latter refers to the definition of a standard prior to its commercialization. An increasing number of standardization processes however cannot be placed squarely in either of the two categories. Recent theoretical as well as empirical contributions to the standardization literature have started studying such forms of "hybrid standardization" (see e.g. Farrell and Saloner, 1988; David and Monroe, 1994; Funk and Methe, 2001; Funk, 2002; Keil, 2002) and have identified several stylized facts related to hybrid standardization. In their seminal paper, Farrell and Saloner (1988) show that hybrid standardization processes may be superior to either of the pure mechanisms, market or committee. The main driver of this result is that the firms interested in setting a standard have two opportunities for coordination in each period: the market and the committee. Coordination is therefore achieved more frequently than with the market mechanism alone, and faster than by solely using the committee mechanism.

The Compact Disc standard appears to have been much smoother than some standards battles in similar technologies,[2] but also much quicker than many of the standard-setting committees – for instance, the average time for agreement on an IEEE standard is 7 years (Spring et al., 1995). Other authors have focused on other features of the CD industry, such as the capacity investments by major players in introducing the tech-

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[1] From a conceptual perspective, see e.g. Kindleberger, 1983; Farrell and Saloner, 1985, 1986; Katz and Shapiro, 1985, 1986; David and Greenstein, 1990; Besen and Farrell, 1994; Axelrod et al., 1995; from an empirical perspective, see e.g. Weiss and Sirbu, 1990; Funk and Methe, 2001; Keil, 2002; Dranove and Gandal, 2003.

[2] For example, even though the VHS-Betamax standards did end up with a winner, Sony, owner of the the losing technology, incurred substantial losses in the process (Ohashi, 2003, Park, 2003).

nology in the US market (McGahan, 1993), the existence of indirect network effects (Gandal et al., 2000) and the comparison with similar, but unsuccessful, technologies (Rohlfs, 2001). Our paper focuses on the CD standardization process in particular. Building a simple model of standard-setting with technological progress, we find that it may have been precisely the mixture of market elements (in the form of a product prelaunch) and committee elements (in the form of the industry's approval conference) that contributed to the success of the outcome. We are especially interested in studying the various motives for a prelaunch. In particular, it is interesting to see if the prelaunch in this particular case predominantly revealed the prelaunching firms' type or if there are some extraneous benefits to a prelaunch (for instance, through enlarging the action space – making concession possible – and, thereby, creating the possibility of an increase in the total size of the prize to be gained).[3]

In our analysis, we focus on the time period prior to the widespread agreement on the Philips/Sony solution, i.e. the standard's development process which was completed by its approval at the Digital Audio Disc (DAD) conference in Japan in April 1981. We choose this event even though the approval forum at the conference actually approved of two different solutions (the Philips/Sony technology, and also the technology proposed by JVC) and despite the fact this approval represented just the prelude for the actual establishment in the market place (which followed rather quickly). However, evidence from the case as well as an analysis of the agents' incentives suggest that in fact just one viable technology (the Philips/Sony standard which survives to this day) emerged from the conference. Neither of the unapproved technologies nor JVC's approved technology ever got to the market.

The paper is structured as follows. We summarize the main facts of the CD case in Section 2.[4] We then introduce the basic model in Section 3 and relate the results of our model to the CD case in Section 4. We conclude in Section 5.

2 Introducing the Compact Disc

The invention of the phonograph by Thomas Edison in 1877 marked the first audio recording technology. It was only in the 1940's however when the long-playing record (LP) as well as the magnetic tape were created and enabled widespread use of audio technology by final consumers. By the late 1970's, analog technologies had reached their limits: among other problems, analog recordings had a very limited dynamic range[5] and

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[3] In this sense, our paper is related to a recent paper by Hoerner and Sahuguet (2004) which extends a classic war of attrition to allow for a wider action space beyond the binary choice between "wait" and "concede".

[4] For a more detailed account of the case see e.g. Gamharter 2004).

[5] The dynamic ranges indicates the range of frequencies that a sound medium covers. A larger dynamic range implies that hardly (but still) audible signals are reproduced, resulting in better sound

suffered from quality losses associated with the master recording process and wear and tear during use. Increasing recognition of these inherent limitations triggered the dawn of a new audio playback standard for the mass consumer market: the Compact Disc Digital Audio System, or CD.[6]

2.1 A new technology

Enhanced audio technology sparked worldwide developer interest: Nearly all major (and some minor) consumer electronics manufacturers became increasingly committed to research and development in search of a new audio playback technology in the late 1960s and 1970s. Among the main players were Philips N.V. from the Netherlands, Sony Corporation (Japan), The Victor Company of Japan Ltd. (JVC) and its parent firm Matsushita, as well as Telefunken/Decca (German Teledec). RCA (USA) and Thompson (France) were also working on enhanced video systems and were hence at least at the periphery involved in the development of an enhanced audio format. In 1977, several firms (Mitsubishi, Sony and Hitachi) presented early versions of digital audio discs and players at the Tokyo Audio Fair. Different technological trajectories were pursued: Telefunken, for instance, worked on a mechanical system (”Mini Disc”) with information engraved in grooves similar to phonograph records. JVC's system (”Audio High Density”) was based on magnetic scanning. Philips developed an optical disc system based on an early prototype of the VideoDisc[7] using a digital code instead of putting an analog picture onto the disc. Philips then announced its first digital Compact Disc Audio System, a 110mm optical disc, in May 1978. Sony as well was experimenting with an optical system to record digital audio.

Despite all these diverse and initially dispersed efforts, there was a strong belief from the outset that, in view of the large installed base of the LP and magnetic tape technologies, joint efforts would be required in order to assert any new audio playback format. In particular, getting the new technology adopted in the popular segment was a major source of concern (McGahan, 1993) – a belief that may retrospectively appear surprising given the success of the CD and evidence suggesting that CD technology actually possessed several features that made it particularly attractive to final users in the popular segment (e.g. remote control, possibilities of programming sequences of titles, no need to reverse/repeat options, and the possibility of using the same software for home use and en-route). Winning over this segment which was much larger compared

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quality.

[6] In fact, digital audio had first been developed by Thomas Stockman at MIT in the early 1960's. Through his company, Soundstream Inc., he also pioneered the commercialization of digital sound recording. The technology's target in these early days however was clearly professional use, for instance by large broadcasting and production houses.

[7] The VideoDisc, based on digital signals, was introduced by Philips in the 1970s and failed dismally. Only 1000 players were ever sold.

to the other basic group, the classical segment was, however, considered crucial for the establishment of a new industry standard. In addition, the experience from recent standards battles was still fresh for some of the involved firms. In the well-documented video wars, Sony had just lost out with its Betamax technology to JVC's VHS system. Philips, on the other hand, had been successful in setting the de facto industry standard for the compact cassette in 1963 against the German consumer electronics manufacturer Grundig – by means of a strategic alliance with Sony. In view of these experiences, as well as concerns regarding the adoption by software producers and final consumers and in recognition of the complementarity of their particular fields of strength in this development process, two of the main players finally teamed up in 1979: Philips and Sony signed an agreement to jointly develop a technical standard for digital audio playback.

2.2 Introducing a new technology

There are three stages at which standardization decisions can be taken. The development stage of a new technology, the approval, or committee phase, and the commercialization phase. Agreeing on a standard in each (or more) of the stages has its own advantages and disadvantages. Standardization in the first stage is equivalent to foregoing development of competing, incompatible technologies, which carries a technological opportunity cost (since it is not clear that the chosen technology is the efficient one). On the other hand, firms avoid duplicating development cost, and firms might benefit from knowledge sharing (Cabral, 2000). Standardization through committees has been studied in detail by Farrell and Saloner (1988). Their general intuition is that finding a common solution might be time-consuming, but will likely lead to a more efficient solution than market-based standardization. Finally, standard battles (i.e. de facto standardization on the market) may still generate inefficient outcomes and is likely to be very costly for sponsors of a particular standard. The following sections outline the events in these three stages in the particular case of the CD launch. Our emphasis however will be on the first two stages, since we are especially interested in the way standardization took place. A detailed presentation and analysis of the commercialization of the CD is McGahan (1993).

2.2.1 The development phase

Philips and Sony teamed up in the first phase to form a technology development alliance. Philips' initial approach had been based on the (analog) VideoDisc. As the human ear is more sensitive to quality flaws than the human eye however, this approach kept delivering unsatisfactory results. As a result, Philips turned towards digital recording. In 1974, Philips started working towards recording music digitally and reading the data by an optical signal, thereby avoiding wear and tear. Yet, digital code turned out to be much more error-sensitive than analog data, resulting in undesirable playback errors.

Despite its expertise in the optical domain and with the precision mechanics of the system, Philips recognized that it lacked expertise in the coding of digital information and error correction systems. Hence, for technological as well as strategic reasons, a strategic alliance seemed attractive. From these considerations, Sony emerged as the strategic partner in the technological development process. Philips and Sony, although competitors in many areas, shared a long history of cooperation, for instance in the joint establishment of the compact cassette standard in the 1960's. In their initial forays into digital audio, Sony specifically focused on the development of signal error correction technology, that is, an error protection code that allows for detection, correction or concealment of (inevitable) recording errors – precisely the area which Philips was lacking expertise in. Also on both firms' minds was that by teaming up they each eliminated a formidable competitor (McGahan, 1993; Besen and Farrell, 1994).

Meetings in 1978 at which Philips at least partly revealed its audio digital disc technology set the stage for an agreement that was signed in October 1979 at which both firms agreed to jointly develop a digital audio playback technology and attempt to establish it as a standard. In marketing the final products however both firms would compete against each other again. Philips brought its expertise in opto-electronics and some basic patents from its LaserDisc development to the alliance, while Sony contributed its advanced error correction system. In addition, both firms had a presence in the music industry via CBS/Sony, a joint venture between CBS Inc. and Sony Japan Records Inc. dating from the late 1960s, and Polygram, a 50% subsidiary of Philips. Both music companies were basically engaged on all relevant stages of music production from planning to recording, promotion and sales. Winning the music industry's support for the new technology was essential: without sufficient music available in the new format, there would be no chance for widespread adoption by final consumers with sizeable LP and tape libraries. In 1983, 915 in 1000 UK households owned record and/or tape playback equipment (BPI Yearbook 1992). Strong indirect network effects and (sunk) investments in incompatible software libraries implied the presence of significant switching costs.

After the agreement had been signed, research teams of Philips and Sony entered into negotiations over the technological properties of the jointly developed disc. In the development process, they faced a trade-off. On the one hand, extensive development times meant maximizing the quality of the technology and thereby maximizing chances of approval at the upcoming DAD conference and gaining the support of other consumer electronics manufacturers. On the other hand, bringing the technology on the market quickly seemed attractive due to the danger of preemption by other manufacturers developing competing systems. In June 1980, the exact specifications werde determined. They were documented in the System Description Compact Disc Digital Audio, the so-called Redbook, to ensure that all software produced for this technology (the Compact Disc Digital Audio technology) could be played on all pieces of hardware (the corresponding players). The Redbook addressed not only static compatibility, but also ensured (backward) compatibility of future hard- and software manufactured within the standard. The publication of the Redbook a year before the DAD conference effectively prelaunched the technology – its fundamental properties became fixed and common knowledge. To some extent, it even went beyond an ordinary product prelaunch since, although neither of the developers had presented a workable product by that time, they soon started licensing the technology to industry players at relatively low rates. As a result, by late 1981 Philips/Sony had already granted licenses for the development of CD-compatible products to 30 audio equipment manufacturers and 8 record replicators. The licensing strategy adopted was influenced by two main objectives: broadening the support base for the technology (by offering favourable licensing terms), and protecting compatibility (by insisting on compliance with the Redbook). The launch of the Redbook was followed by announcements by both Philips and Sony to present individual prototypes at the 29th Japan Audio Fair in October 1981.[8]

2.2.2 The approval phase

Approval of the new audion standard took place at the DAD Conference in Japan in April 1981. Organized by the Japanese Ministry of International Trade and Industry (MITI) with the explicit aim of defining a digital audio standard, it had been put in place already in 1978 and was attended by 29 consumer electronics manufacturers. The aim was to lay the ground for establishing a new audio standard: based on the approval, first the support of the relevant software producers, mainly the music industry and record manufacturers, had to be gained. Later, with hardware and a certain amount of software available, final consumers would be targeted. The DAD conference eventually approved two technologies: Philips/Sony and JVC. Telefunken's proposal for a mechanical system was not approved. Despite the DAD's approval however, JVC's technology never made it to the market. While the conference had been scheduled in 1978 already and took place in April 1981, it was effectively preempted by the events between June 1980 (submission and publication of the Redbook) and January 1981 when Matsushita, the parent company of JVC, announced its intention to support the Philips/Sony technology. This latter date in particular marked the real turning point since from then onwards, the CD was supported by the three largest consumer electronic firms (Dai, 1996).

The fact that only one technology was commercialized subsequent to the DAD conference certainly smoothened the standard-setting process in hindsight. By no means however was it already clear at that point, that the technology that had managed to throw several other new technologies out of the race would also be a success when racing against the LP and the compact cassette.

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[8] Press release Nr. 8403E, October 1980, by Philips Press Office.

2.2.3 The commercialization phase

The licensing policy adopted by Philips/Sony was probably influenced both by Philips' successful licensing of the compact cassette standard and Sony's negative experience in the VCR standards battle where they, as sponsors of Betamax, lost out against a heavily licensed technology (VHS) with its corresponding advantages in terms of critical mass and lower prices. Although winning the support of other hardware manufacturers seemed relatively simple, initial acceptance by software producers, i.e. the music industry (software content) and record manufacturers (physical elements of software) was sluggish. Partly, this stemmed from the new technology's lack of a built-in copy protection device, partly from the fact that the industry had just recently invested heavily in expanding and improving production facilities for the old technology, and partly from the requirement to pay royalties (however low) to Philips/Sony for both hard- and software production – after all, licenses for the compact cassette standard a few years prior had been granted freely by Philips. Finally, firms in the music and recording industry were skeptical about adoption among final consumers in the mass market because of the high initial price and recent experiences of failed consumer electronics technologies.[9] Therefore, any initial momentum in the software area had to come from software producers that had some link to the standard sponsors.[10] On October 1, 1982, Sony launched the first commercially available CD player, the CDP-101. Philips followed a month later with the CD player "Pinkeltje". The initial product launch in Japan and Europe was followed by the US launch in early 1983. The set of the first 50 CDs included classical as well as popular and rock releases. Both Philips and Sony ran extensive marketing campaigns aimed at increasing awareness among final consumers, getting them to experience the technology and shaping expectations, i.e. establishing the CD as the technology of the future in consumers' minds. Despite being competitors in the market place, there was a strong impetus to promote not only their own products but also the generic technology in order to establish it as the new industry standard. In spite of the initial scarcity in software, adoption by final consumers was fast and widespread. Increased sound quality, but also ease of use and many convenient functional features won over the popular segment in particular much faster than expected by many industry participants and observers (McGahan, 1993). Prior to its introduction in 1982, Philips/Sony had been hoping that somewhat more than 10m CDs would be sold worldwide in 1985. Within a year, they revised their forecasts to 15m CDs. Actual sales of CDs in 1985 were 59m.

Viewed historically, the introduction of the CD seems straightforward. Philips has

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[9] The failure of quadraphonic sound was only a few years back and fresh in producers' minds (Postrel, 1990), as was the VideoDisc unsuccessfully introduced by Philips.

[10] Not surprisingly, 97 out of the 107 CD titles available in 1983 were supplied by CBS/Sony and Polydor K.K. (an affiliate of Polygram GmbH, W. Germany). The scarcity of software was short-lived however: by 1985, approximately 1750 classical titles and 3250 pop titles were available on CD (see BPI Yearbooks 1986 and 1987 for more detailed data).

even been likened to "a virtuoso who makes a very difficult piece seem easy" (Rohlfs, 2001, p. 91). Nevertheless, players faced significant uncertainty about strategies and their likely outcomes. Aware that replacing an ubiquitous industry standard involved high risk, but high potential rewards, all industry participants took actions that may seem rational once the complete picture is known, but had to be taken with a degree of uncertainty both about future payoffs and likely actions by their rivals. For example, why did Philips/Sony publish the Redbook quite some time before the DAD conference, risking premature commitment to a potentially inefficient technology? Similarly, why did JVC/Matsushita announce its intentions to support Sony/Philips' standard months before the DAD conference? After all, by continuing development of their own technology they might have been successful in asserting theirs as a standard.[11]. We will address these and related questions in the following simple model.

3 The Model

We start with a general formulation of our model. Two risk neutral players i, j compete for the highest share of a divisible (common-value) prize. The overall size of the prize depends on three factors: market size X, product quality of the (weakly) superior technology $q = \max(q_i, q_j)$, and cooperation or concession benefits λ. The total size of the prize is $\Pi(\lambda, q, X)$.

Suppose that there are two stages, a development and a bargaining stage:

1. *Development stage.* In the first stage, both technologies improve exogenously over time, i.e., $\frac{\partial q_i}{\partial t} > 0$. We use a continuous time setting. Development ends at $t = T$, so that $q_{i,\max} = q_{i,T}$. A better technology will have a higher chance of being accepted in the marketplace, i.e. post-introduction.[12] This gives players an incentive to wait until T to introduce their technology. On the other hand, committing to one's own technology first (i.e. before the other player does) may confer pre-introduction advantages, which gives players an incentive to preempt each other. When firms cooperate, payoffs increase increase by a factor $\lambda \geq 1$. The longer the players cooperate in the run-up to the bargaining stage, the higher the benefit, i.e. $\frac{\partial \lambda}{\partial t} \leq 0$. We ignore discounting.[13]

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[11] The fact that both Philips/Sony's and JVC's technology were approved suggests that the quality of JVC's technology exceeded a certain absolute quality threshold, which rules out the most convenient answer to JVC's dilemma, namely that their technology was simply a "dead duck" without any potential for commercialization.

[12] We model this as market profits being an increasing function of product quality. This is of course identical to modelling the probability of acceptance as an increasing function of product quality.

[13] This is a sensible assumption since up to T, the players compete for *claims* to the final prize rather than the final prize itself. Claims that are acquired earlier are no more valuable to the players than those acquired closer to the deadline T.

2. *Bargaining stage.* After T both players start bargaining over the distribution of profits. We assume that the bargaining strengths are affected by their respective qualities, i.e. $\frac{\partial \pi_i}{\partial q_i} \geq 0$, $\frac{\partial \pi_i}{\partial q_j} \leq 0$.

The players' strategy space is determined by the previous history of the game: If no action has been taken, a player can choose to stay in (S) and continue developing the own technology or prelaunch (P) her own technology. If a prelaunch has taken place, a player can concede (C) or stay in (S). Each player can move (i.e. play P or C) only once. S is straightforward in its implications: The technology in question improves over time, and there are no changes in payoffs otherwise. The other strategies are described in more detail below.

- *Prelaunch.* Prelaunching one's technology ends technological progress. Essentially, by prelaunching the player commits to implementing a technology conforming to the specifications set out in the prelaunch. Prelaunching is possible at any time between 0 and T. We normalize the time horizon of the development game to 1, i.e. $T = 1$.
- *Concede.* Conceding is only possible after a prelaunch has taken place.[14] C implies that the player stops development on the own technology and starts supporting the rival standard. This implies being awarded the smaller share of the prize $(1-\theta)$, but it gives rise to concession benefits λ. In other words, a player conceding will obtain a smaller share of a larger pie. The assumption that concession benefits decrease over time implies that, if concession takes place at all, it will take place immediately following a prelaunch.[15] If no concession takes place throughout the game, $\lambda = 1$.

3.1 Payoffs

Suppose now that a prelaunch by firm i was successful, i.e. firm j conceded immediately thereafter. Firm i's payoffs are $\pi_i = \pi_i(t_i, q_i, \lambda, \theta, X)$. The remainder, $(1-\theta)$, will be firm j's payoff.

We use specific functional forms for the elements of our payoff function. Where our assumptions are restrictive in a sense that alternative specifications generate different outcomes, we will discuss this in Section 4.

- *Overall market size* (X). For simplicity, we normalize $X = 1$.

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[14] In our model, we assume that technologies improve exogenously and costlessly over time. This implies that C is dominated by S as long as profits in the bargaining stage increase in the technology's quality. Therefore, our assumption that C is only available after a prelaunch is not restrictive.

[15] Note that this may not hold true with stochastic technological progress, in which case it may be optimal to stay in for some more time.

- *Winner's share* (θ). We assume that the winner is whoever has the better technology at T or whose technology has been accepted as the industry standard. The winner's share is assumed to be $\theta > \frac{1}{2}$, the loser's $(1-\theta)$, and independent of the time of standardization or the difference in qualities. If both technologies are of equal quality, both players share the market.
- *Technological quality* ($q_{i,t}$). We assume that there are two different speeds of development ($s$low and $f$ast) and that technologies develop linearly. This means that we can write $q_{i,t} = d_i t_i$, $d_i \in [s, f]$.
- *Concession benefits* ($\lambda(t) = \lambda_t$). Concession benefits are assumed to be decreasing linearly over time, and assumed to exceed the payoffs from not conceding (1) at the end of the development stage. The assumption of decreasing benefits over time seems realistic: prior to the bargaining stage at T, the earlier both firms join forces, the less R&D costs are duplicated, the more time the coalition has to exert influence on third parties in favour of their technology, the more time third parties have to adapt their products to the technology, etc.. The assumption that concession still conveys benefits at T can also be justified on the grounds that prior to bargaining for a standard, a pre-negotiation agreement will still save the time and effort of negotiating. The simplest specification of this scenario of concession benefits is $\lambda_t = M - t$, $M > 2$.
- *Market profits* (Π). Finally, we assume that our market profit function is multiplicative, i.e. $\Pi = q\lambda X$.

3.2 Equilibrium

- *Bargaining stage*

If no agreement on either one of the technological solutions has been achieved until T, the players bargain over the distribution of profits during a single round (the approval conference). The general structure of our bargaining stage is very simple and basically a version of "Splitting the pie" (e.g. Rasmusen, 2001): Two players choose shares ω_i, ω_j of the total prize. We assume that the bargaining strengths are affected by their respective qualities, i.e. $\frac{\partial \pi_i}{\partial q_i} \geq 0$, $\frac{\partial \pi_i}{\partial q_j} \leq 0$. At the start of the bargaining stage (i.e. the approval conference) at the latest, the qualities of the players' technologies are made publicly known, i.e. become common knowledge. We distinguish between two cases:

1. Both players' technologies have the same quality at T ($q_i = q_j$) and, hence, equal bargaining strength. Both players choose simultaneously. If $\omega_i + \omega_j = 1$, each player obtains its chosen share. If $\omega_i + \omega_j > 1$, both players get zero (failure to achieve agreement, which leads, e.g. to a standards battle in the market place).

The game has a continuum of Nash equilibria with any strategy combination (ω_i, ω_j) such that $\omega_i + \omega_j = 1$ representing a Nash equilibrium. However, there is one strategy combination which represents a focal point and unique symmetric pure strategy equilibrium (in a continuous strategy space), $(\frac{1}{2}, \frac{1}{2})$.

2. Players' technologies differ in their quality at T ($q_i \neq q_j$) and, therefore, also in their bargaining strengths. Players move sequentially. Superior technology gives a player (e.g. player i if $q_i > q_j$) with the ability to move first. We assume θ (exogenously given for now) to represent the maximum share a player can ask for.[16] Again, if $\omega_i + \omega_j = 1$, each player obtains its chosen share. If $\omega_i + \omega_j > 1$, both players get zero. The unique Nash equilibrium is $(\theta, 1-\theta)$ where $\omega_i = \theta, \omega_j = 1-\theta$.

- *Development stage*

We solve the game by backward induction. For the second mover, we derive a concession condition (CC) which gives parameter constellations for θ, λ, q_i and t_i for which the follower, after a prelaunch, will want to concede or stay in until the end. The (prospective) first mover then takes this into account in the decision whether and when to prelaunch. That is, we look for the prelaunch condition (PC) for the prospective first mover.

3.2.1 Stackelberg Leadership

We first analyze the case in which firm i is a Stackelberg leader and can initiate a prelaunch. Firm j can only decide whether to concede or stay in if a prelaunch has taken place. If both players are of the same type (i.e. $d_i = d_j$), we obtain the following proposition (which follows from the algebra below):

Proposition 1 *With Stackelberg leadership and symmetric types, the leader will only prelaunch if the follower concedes. If not, both players will stay in until time T. If a prelaunch takes place, it will be at the efficient time.*

The intuition of this result is quite simple. If both the leader and the follower would benefit from agreeing on a standard prior to introduction, they will do so at the most efficient time. In this case, the follower concedes because it is privately optimal to do so, and the leader will maximize its payoffs by maximizing its share of the prize, $\theta\Pi$,

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[16] An alternative way of modeling would be to have bargaining strengths determined by the players' respective qualities. For instance, we could define player i's bargaining strength $b_i = \frac{q_i}{q_i+q_j}$. This would also allow us to characterize the player's shares $\theta, (1-\theta)$ at the development stage as a function of their technologies' qualities, i.e. for $b_i > b_j \Rightarrow \theta = b_i = \frac{q_i}{q_i+q_j}$ and for $b_i < b_j \Rightarrow \theta = b_j = \frac{q_j}{q_i+q_j}$. This would allow for more parsimonious modeling. We therefore plan to extend our analysis to include this modification but do not expect qualitative changes to our current results.

which amounts to maximizing overall payoffs Π. On the other hand, the follower would only refuse to concede if it ends up winning, i.e. if $q_{i,t} < q_{j,T}$, in which case the leader is better off ensuring a share $\frac{1}{2}$ of profits rather than $(1-\theta)$.

The concession condition is determined by the relative strength of concession benefits λ and winner's share θ. If concession benefits are relatively small and the winner's share is large, the follower is less likely to concede.

We derive the concession and prelaunch conditions below. Player j concedes if $\pi_i(C) \geq \pi_i(S)$, i.e.

$$q_{i,t_i}\lambda_{t_i}\left(1-\theta\right) \geq \; q_{j,T}\theta.$$

The concession payoff is simply the smaller share of total payoffs from a technology prelaunched and agreed on at t_i. The payoff from staying in until T is the winner's share of a technology that has been developed until T. The concession condition is therefore

$$\theta \leq \theta_C = \frac{t_i\left(M-t_i\right)}{t_i\left(M-t_i\right)+1}$$

This upper bound for the winner's share is increasing in t_i and M, which is intuitive – if the follower's technology has less time left to leapfrog the leader's, or if the benefits from concession are high, the follower will be content with a lower share of overall profits. Note also that for all $M \geq 2$ the Stackelberg leader chould choose an endogeneous $\theta \geq \frac{1}{2}$ to ensure that the follower concedes. We can express CC also in terms of the earliest time t_i at which a prelaunch would trigger concession ($t_{\min C}$):[17]

$$t_i \geq t_{\min C} = -\frac{M}{2} + \sqrt{\frac{M^2}{4} + \frac{\theta}{(1-\theta)}}$$

Turning to the prelaunch condition, we require $\pi_i(P) \geq \pi_i(S)$, or

$$q_{i,t_i}\lambda_{t_i}\theta \geq \frac{q_{i,T}}{2}$$

for symmetric players ($d_i = d_j$). Note that a prelaunch would never be chosen if $\theta > \theta_C$.[18] In this case, staying in would be the equilibrium strategy for the Stackelberg

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[17] For $M > 2$, the alternative solution $t^A_{\min C} \geq -\frac{M}{2} - \sqrt{\frac{M^2}{4} + \frac{\theta}{(1-\theta)}}$ never yields a time t_i within the permissible range of values. As a result, if there is valid solution at all, it is always given by our expression of CC.

[18] To complete the proof, we need to show that in equilibrium, the Stackelberg leader never chooses an unsuccessful prelaunch P_U, i.e. never chooses prelaunch if it does not trigger concession by the follower. Suppose the Stackelberg leader i would choose P_U in equilibrium. This requires $\pi_i(P_U) \geq \pi_i(S)$, or $q_{j,T}\left(1-\theta\right) \geq \frac{1}{2}\, q_{i,T}$, which implies $\theta \leq \frac{1}{2}$. By definition, this only holds for $\theta = \frac{1}{2}$. In that case, i is indifferent between S and P. Note that, i is indifferent between all prelaunch times t_i because they all

leader. We rewrite the *preliminary prelaunch condition* PC_1 as follows:

$$\theta \geq \theta_P = \frac{1}{2t_i\left(M - t_i\right)}$$

This is decreasing in t_i: The later in the game, the smaller the winner's share can be to support a profitable prelaunch. The intuition is that a prelaunch at later stages implies less foregone tchnological progress, i.e. less foregone increase in the total size of the prize until T. Since this foregone improvement needs to be (over-) compensated by a higher share (θ compared to $\frac{1}{2}$), at later stages smaller θ will make a prelaunch profitable. We can express PC_1 as well in terms of the prelaunch time and find the earliest time t_i that satisfies the PC_1 ($t_{\min P}$) from:[19]

$$t_i \geq t_{\min P} = \frac{M}{2} - \sqrt{\frac{M^2}{4} - \frac{1}{2\theta}}$$

Combining the PC_1 and CC conditions, we obtain the following illustrative graph (for $M = 3$):

Of the two conditions, CC is the binding constraint. That is, for each time that CC holds, PC_1 holds as well, but not vice versa. Hence, the *binding prelaunch condition* PC_2 in this case equals CC. Now given that these two conditions are satisfied, when is the efficient prelaunch time t_i^*? With the specific functional forms we use, t_i^* is at T, since there will still be benefits from prelaunching, but technological progress will have been maximized. If player i is the Stackelberg leader, i maximizes $\max \pi_i(P)$,i.e.

$$\max q_{i,t_i}\lambda_{t_i}\theta = \max d_i t_i (M - t_i)\theta$$

It is easy to see that this yields the optimal prelaunch time $t_i^* = T$ for all development speeds (as long as PC_2 holds at all during the interval $[0, T]$).

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yield the same payoff. What about the follower j? The above reasoning requires j (for $\theta = \frac{1}{2}$) to have $\pi_j(S) \geq \pi_j(C)$ i.e. $\frac{q_{j,T}}{2} \geq \frac{q_{i,t_P}\lambda}{2}$ or, for our specific functional forms, $\frac{1}{t_P} + t_P \geq M$. Since $M > 2$, there exists at least one time $\widehat{t}_i (= 1)$ for which this does not hold, i.e. if player i was to prelaunch at $\widehat{t}_i$, j would concede because C and S get j the same share of the prize (because of $\theta = \frac{1}{2}$), but concession benefits still accrue. This in turn affects player i: i can obtain a higher payoff than $\pi_i(P_U) = \frac{q_j^T}{2}$ by undertaking a prelaunch at $\widehat{t}_i$ instead of earlier times. Hence, player i prefers prelaunching at $\widehat{t}_i$ to an (unsuccessful) earlier prelaunch. Consequently, the Stackelberg will never choose an unsuccessful prelaunch in equilibrium.

[19] For $M > 2$, the alternative solution $t_{\min P}^A \geq \frac{M}{2} + \sqrt{\frac{M^2}{4} - \frac{1}{2\theta}}$ never yields a time t_i within the feasible range of values. As a result, if there is valid solution at all, it is always given by our expression of PC_1.

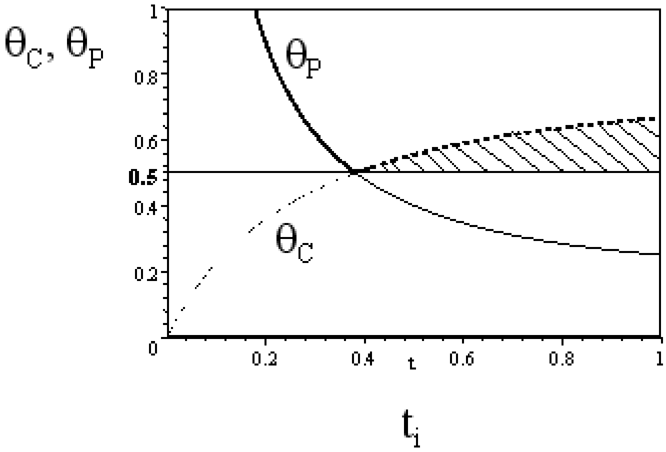

Figure 1: Prelaunch and concession conditions

If the Stackelberg leader prelaunches, the prelaunch will take place at $t_i^* = 1$ and j concedes at the same time.[20] Note that for $M = 3$ and $\theta = \frac{3}{5}$, the earliest time when both PC$_1$ and CC are met is $t_{\min P,C} \approx .63$, but the existence of Stackelberg leadership ensures that the prelaunch takes place at the profit-maximizing time. In other words, the absence of any threat of preemption ensures the efficient outcome if such an outcome can be achieved in the first place.

So far, our assumption was that both players are symmetric in their technological capabilities. We now analyze the impact of technological asymmetry on the outcome of our game with a Stackelberg leader. Suppose first that the leader has the more efficient technology, i.e. $d_i = f$, $d_j = s$. We first consider the prelaunch condition PC$_1$. For $q_i > q_j$, the prelaunch condition is independent of θ: $M > t + \frac{1}{t}$. This is a consequence of the imposed Stackelberg leadership: knowing that it will not be preempted, firm i is certain of the winner's share. Prelaunching in general then is profitable whenever the (induced concession) benefits are sufficiently large to offset the lost technological progress. Consequently, if $M > 2$ (so that there are some prelaunch benefits even at $t \rightarrow 1$), the prelaunch condition will be met at the very end of the game at least. The leader i is certain to undertake a prelaunch at some $t_i \in [0, T]$. Unlike with symmetric types, a prelaunch (followed by concession) is certain to take place. Turning to the concession condition, we can identify prelaunch times (before T) for which the follower

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[20] In our model, since concession benefits λ increase with distance from T, early concession is strictly favoured over later concession, if CC is met at all in the interval leading up to T. Hence, if player i concedes at all, then $t_P = t_C$.

will concede. We then derive the following concession condition CC

$$\text{for } q_{j,T} > q_{i,t_i}\text{: } \theta \leq \theta_C^{'} = \frac{d_i t_i \lambda_{t_i}}{d_i t_i \lambda_{t_i} + d_j}$$

which is less binding than in the symmetric case (for $q_{j,T} < q_{i,t_i}$, player j always concedes).[21] With our specification of $\lambda(t) = M - t$, we obtain a more clear cut result. The optimal prelaunch time t_i^* coincides with the latest possible time for a prelaunch, i.e. $t_i^* = T$. As a result, in equilibrium player i always undertakes a prelaunch at $t_i^* = T$ and player j always concedes, i.e. $q_{j,T} < q_{i,t_i^*}$.

Suppose now that the leader i has the less efficient technology, i.e. $d_i = s$, $d_j = f$. The concession condition CC becomes:

$$\theta \leq \theta_C^{''} = \frac{d_i t_i \left(M - t_i\right)}{d_i t_i \left(M - t_i\right) + d_j},$$

which is more stringent than in the symmetric case since $d_j > d_i$ – it takes a higher share of the payoffs to make the follower sacrifice her own (superior) standard. Turning to the prelaunch condition PC_1, we find that for $d_i = s$, $d_j = f$

$$\theta \geq \theta_P^{''} = \frac{d_j}{d_i t_i \left(M - t_i\right) + d_j}.$$

Depending on the value of $\lambda_{t_i} t_i$, this condition may either be stricter or less strict than with symmetric types Stackelberg leadership. For $\lambda = (M - t)$, we know that $t_i^* = T = 1$. This allows us to derive a well-defined relationship: For $d_i = s$, $d_j = f$, $\theta_P^{''} > \theta_P$, which implies that a higher winner's share is required to make a prelaunch profitable for the less efficient Stackelberg leader. As the rival technology is superior, this makes sense: By (succesfully) prelaunching, the leader increases its share of the pie (from $(1 - \theta)$ to $\theta_P^{'}$). But the size of the prize is affected by two effects working in opposite directions: The prelaunch allows for some increase of the prize through concession benefits, but also leads to some shrinkage in its size due to the choice of the less efficient technology. This latter effect is not present with symmetric types and Stackelberg leadership. So the greater winner's share θ required to induce a prelaunch serves as a kind of "built-in" protection mechanism against the inefficiency associated with pre-assigned roles and a less efficient leading firm.We summarize our results on technological asymmetry with Stackelberg leadership in Proposition 2:

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[21] In case $q_{j,T} = q_{i,t_i}$: we would obtain $\theta \leq \theta_C^{'} = \frac{\frac{1}{2} d_j}{d_i t_i \lambda_{t_i}} + 1$, which is also less strict. However, with continuous types there would be zero probability of this case. Hence, in the following we concentrate on the case of $q_{j,T} > q_{i,t_i}$.

Proposition 2 *If the Stackelberg leader is the efficient firm, a prelaunch will take place for smaller values of the loser's share. Conversely, for the specification of concession benefits we use, a prelaunch is feasible only for a smaller range of values of the winner's share if the leading firm is less efficient, and the outcome is inefficient since either the inferior technology is chosen or concession benefits are not realized. If the leading firm is less efficient, there is a limit to the relative superiority of the follower's technology for prelaunch and concession to take place.*

P roof. See appendix. ■

The presence of pre-assigned roles (Stackelberg leadership) may create an inefficiency by not allowing the technologically stronger party to move first and undertake a prelaunch. This scenario differs from the symmetric case and the case where the more efficient party is the Stackelberg leader where Stackelberg leadership serves as a benchmark because the equilibrium result is more efficient than without pre-assigned roles (as will be shown in the following section). Such a scenario may seem counterintuitive at first – why would a less efficient firm be a Stackelberg leader? Given that firms will develop many products in their existence however, this seems like a genuine possibility. Stackelberg leadership may be determined from a broader context. Consider for example a case where product (pre-)announcements are only credible by one player, but the quality (i.e. development speed) of a particular technology may be high or low, so that a Stackelberg leader may be developing the inferior technology.

3.2.2 Strategic Symmetry

As mentioned, Stackelberg leadership generates the efficient outcome unless the Stackelberg leader has an inferior technology. We will now analyze the incentive by firms to preempt each other by prelaunching their technology in a scenario of strategic symmetry, so that both firms can end up the leader but no roles are pre-assigned a priori. Again, we start with the symmetric case for illustrative purposes and then analyze the changes to the results if players are not (type-)symmetric.

Without pre-assigned roles, the players each have an incentive to preempt each other by undertaking a prelaunch. At the same time, they have an incentive to wait as long as possible before undertaking a prelaunch (see above). The incentive to preempt prevails as long as the payoff of the player that gets to succesfully prelaunch ($\pi(L_{P_S})$) is greater than the payoff of the player that ends up following ($\pi(F)$), i.e. $\pi(L_{P_S}) > \pi(F)$ or $t_i\left(M - t_i\right) \geq \frac{\theta}{1-\theta}$, i.e. the concession condition holds, meaning that a prelaunch would be successful. If the parameter constellation of M, θ is such that the concession condition is fulfilled from some time $t_{\min}$ onwards,[22] both players have an incentive to prelaunch at $t_{\min}$ to avoid being preempted. On the other hand, if $\pi(L_{P_S}) < \pi(F)$ for all t_i, no

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[22] The LHS is increasing in t_i, while the RHS is time-invariant, so that if $\pi\left(L_{P_S}\right) > \pi\left(F\right)$ holds for $t_{\min}$, it holds for all $t_i > t_{\min}$.

player will want to prelaunch. With strategic and type symmetry, we therefore obtain the following proposition.

Proposition 3 *If a prelaunch can be successful at any time during the interval, with strategic and type symmetry there will be a unique mixed-strategy equilibrium in prelaunch times and identities. With probability* $\frac{1}{2}$*, player* i *prelaunches at the earliest profitable prelaunch time* $t_{\min}$ *and player* j *concedes immediately. The roles are reversed with probability* $\frac{1}{2}$*.*

P roof. See appendix. ■

This setting is comparable to Fudenberg and Tirole (1985), and in particular their "Case A". Here, the leader's maximum payoff is strictly greater than the payoff from simultaneous adoption (reinterpreted as the payoff from both staying in). With contiuous time, we rely on the assumption that a "mistake" in the sense of simultaneous prelaunch is impossible and that therefore the question to be resolved is the identity of the leader, but not the prelaunch time.

As a result, prelaunch and concession take place much earlier than in the Stackelberg case (if they take place at all). Strategic symmetry creates incentives to preempt, which results in an inefficiency, since the prelaunch takes place at $t_{\min}$ rather than t^*. To some extent, this result is the "rent equalization" result in Fudenberg and Tirole (1985).

How does this result change if the players are different types? Being a stronger type involves a tradeoff. On one hand, prelaunching is feasible at an earlier time. On the other hand, however, the opportunity cost from prelaunching are higher since the remaining development time would be more profitable. Assuming that a prelaunch is profitable to begin with, however, we can determine the identity of the prelaunching firm:

Proposition 4 *If the less efficient player's CC is ever satisfied, the more efficient player always undertakes a prelaunch. The timining of this prelaunch depends on whether her own CC is ever satisfied during the interval. If that is not the case, that is, the stronger player's CC is never satisfied, the prelaunch will take place at the optimal time* t^**. If the stronger player's CC is satisfied during the interval, she will preluanch just before her own CC is satisfied, that is, just before the weaker player would prelaunch. The prelaunch time is strictly earlier in this case. An inefficiency due to foregone technological progress arises.*

P roof. See appendix. ■

A number of interesting results emerge in comparison to the other cases. First, the identity of the prelaunching party is determined endogenously – a stronger firm prelaunches first. Second, compared to the respective Stackelberg leader case, an inefficiency arises from the danger that the less efficient firm might undertake a prelaunch as well. This however will only restrict the leader's behaviour if the difference in types is not too large. This implies that a case arises where competition between unequal rivals may be more efficient than between equal rivals.

3.2.3 Incomplete Information

Consider now the case where development speeds (i.e. types) are private information and drawn independently from a continuous uniform distribution on the interval $d_{i,j} \in [0,1]$. A prelaunch will reveal a player's type. If no player undertakes a prelaunch until the end of the game (T), both players' types are revealed at T and payoffs are allocated as described above. With incomplete information, players do not know if they are the more or less efficient type. Nevertheless, in effect one player will end up being the follower (player j) and the other one being the leader (player i), unless both players stay in until T.[23]

Suppose that firms have to (privately) commit themselves to a prelaunch time at the start of the game. This seems reasonable given the considerable lead times required for prelaunching a complex product and the milestones-based project planning approach usually adopted for complex, long-term projects. We start by analyzing the follower's (j) considerations. Given that the leader (i) has undertaken a prelaunch and thereby revealed its type, player j decides, based on its private knowledge of its own type, whether to stay in or concede. We derive the concession condition as a function of the (revealed) leader's type d_i below. Player j concedes if $\pi_j(C) \geq \pi_j(S)$,[24] i.e.

$$q_{i,t_{t_i}} \lambda_{t_i} (1-\theta) \geq q_{j,T}\theta = d_j\theta \text{ if } q_{j,T} > q_{i,t_i}$$

We solve for a lower limit $\underline{d}_j$ for j's development speed d_j such that for $d_j > \underline{d}_j$, player j decides to stay in after the prelaunch.[25] We obtain the following concession condition:

$$d_j \leq \underline{d}_j = \frac{d_i t_i \lambda_{t_i}(1-\theta)}{\theta} = \frac{d_i t_i (M-t_i)(1-\theta)}{\theta}$$

Turning to i's prelaunch condition, player i considers for each time $t_i \in [0,T]$ whether to undertake a prelaunch at the respective time or not. This is based on the expected payoff from a prelaunch at t_i, $\widehat{\pi}_i(P)$ where P_S reflects the payoff from a successful prelaunch (i.e. followed by j's concession), P_U the payoff from an unsuccessful prelaunch,

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[23] With a continuous, uniform distribution over types d, there is zero probability of $d_i = d_j$, and, hence, of a simultaneous prelaunch.

[24] S is strictly dominated by C in case j was not able to overtake or at least catch up with i's technology (as revealed in the prelaunch) by T, i.e. $q_{j,T} < q_{i,t_i}$.

[25] The inequality needs to be strict because of assumed weak preference for concession.

and$\widehat{\ }$marks expected values.[26] That is

$$\begin{aligned}
\widehat{\pi}_i(P) &= \underline{d}_j\widehat{\pi}_i(P_S) + (1-\underline{d}_j)\widehat{\pi}_i(P_U) \\
&= \underline{d}_j(d_i\lambda_{t_i}t_i\theta) + (1-\underline{d}_j)\left(\frac{1+\underline{d}_j}{2}T(1-\theta)\right) \\
&= d_i^2t_i^2\lambda_{t_i}^2(1-\theta) + \left(1-d_it_i\lambda_{t_i}\frac{(1-\theta)}{\theta}\right)\left(\frac{1+d_it_i\lambda_{t_i}\frac{(1-\theta)}{\theta}}{2}(1-\theta)\right)
\end{aligned}$$

With a uniform distribution of types and conservative expectation formation (i.e. no additional exogenously given information on types and no Bayesian updating), we have:

$$\widehat{\pi}_i(S) = d_i^2\theta + (1-d_i)[(1-\theta)\widehat{d_j}] = d_i^2\theta + (1-d_i)[(1-\theta)\frac{d_i+1}{2}].$$

We directly derive PC_2 for a set of times from $\widehat{\pi}_i(P) \geq \widehat{\pi}_i(S)$,[27] or

$$\begin{aligned}
& d_i^2t_i^2\lambda_{t_i}^2(1-\theta) + \left(1-d_it_i\lambda_{t_i}\frac{(1-\theta)}{\theta}\right)\left(\frac{1+d_it_i\lambda_{t_i}\frac{(1-\theta)}{\theta}}{2}(1-\theta)\right) \\
\geq \;& d_i^2\theta + (1-d_i)[(1-\theta)\frac{d_i+1}{2}]
\end{aligned}$$

Defining $d_i\,(1-\theta) = z_i$, using our specification of $\lambda(t) = M-t$, and defining $(t_i\lambda_{t_i}) = v_{t_i}$, we obtain

$$d_iz_iv_{t_i}^2 + \left(1-\frac{z_iv_{t_i}}{\theta}\right)\left(\frac{1+\frac{z_iv_{t_i}}{\theta}}{2}(1-\theta)\right) \geq d_i^2\theta + (1-d_i)\left[\frac{d_i+1}{2}\,(1-\theta)\right]$$

We use a numerical example for illustration: We set $\theta = 0.7$, $d_i = 0.8$, and $M = 3$. The lower bound $\underline{d}_j$ as a function of the prelaunch time t_i is then $\underline{d}_j(t_i) = \frac{36}{35}t_i - \frac{12}{35}t_i^2$ (see Figure 2 below). The lower bound is increasing with prelaunch time, which indicates that late prelaunches will be more likely (ceteris paribus) to be successful. The rival's technology simply has less time to catch up, or, to put it differently, the technological progress sacrificed by the prelaunching firm is smaller.

Turning now to the prelaunch condition PC_2, we find that given our parameter values, the first $t_i \in [0,1]$ that satisfies PC_2 is (approx.) $t_{\min P,C} = 0.59$. In the following

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[26] With a continuous, uniform distribution over types d, there is zero probability of $d_i = d_j$, and, hence, of a simultaneous prelaunch.

[27] As long as the other player has not undertaken a prelaunch before, C is not an available action and, hence, not relevant for the comparison. In case, however, the other player has already undertaken a prelaunch, the above reasoning for the follower applies.

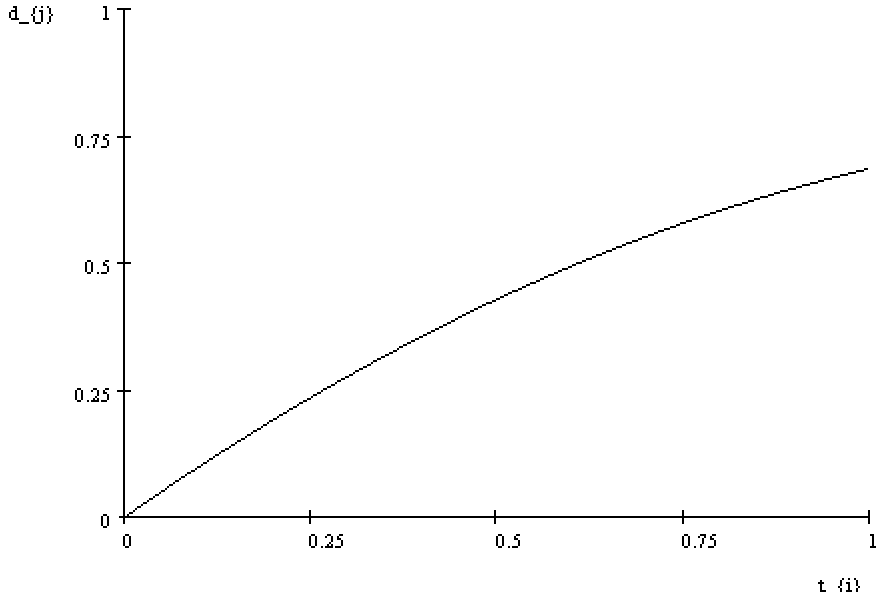

Figure 2: $\underline{d}_j$ as a function of the prelaunch time t_i

panel, we compare this to the symmetric Stackelberg case (where $d_i = d_j = 0.8$), the case with strategic and type symmetry, and the "asymmetric types" case with strategic symmetry but type asymmetry, where $d_i = 0.8$ and $d_j = 0.5$ (equal to the expected value of development speed).[28]

This results in the following proposition:

Proposition 5 *With incomplete information, adoption times are earlier than the efficient outcome. Also, second inefficieny arises because players undertake prelaunches that turn out to be unsuccessful.*

P roof. Preliminary numerical illustration. ■

How does uncertainty affect a player's strategies? Clearly, a player will take into account that prelaunching may not be successful, while in the complete information case this would always be known. As a consequence, prelaunching is a more risky strategy, which will affect its expected profits vis-a-vis the alternative of staying in. Generally, two effects are at work: the incentive to preempt the other player, and the incentive to wait in order to enhance success chances for a prelaunch. We find in our preliminary numerical illustration that the first effect dominates. Uncertainty entraps players to undertake prelaunches earlier and more often that would be efficient.

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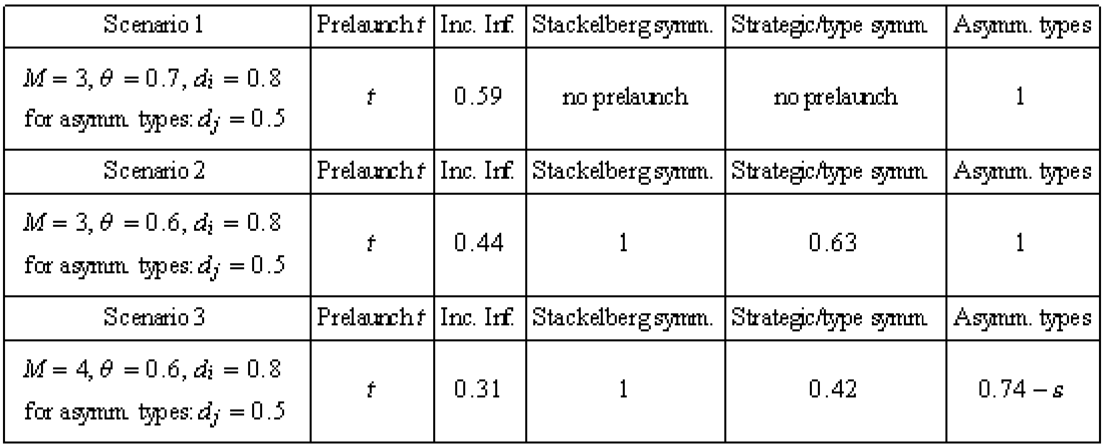
[28] All numbers are rounded.



Scenario 1	Prelaunch f	Inc. Inf.	Stackelberg symm.	Strategic/type symm.	Asymm. types
$M = 3, \theta = 0.7, d_i = 0.8$ for asymm. types: $d_j = 0.5$	f	0.59	no prelaunch	no prelaunch	1
Scenario 2	Prelaunch f	Inc. Inf.	Stackelberg symm.	Strategic/type symm.	Asymm. types
$M = 3, \theta = 0.6, d_i = 0.8$ for asymm. types: $d_j = 0.5$	f	0.44	1	0.63	1
Scenario 3	Prelaunch f	Inc. Inf.	Stackelberg symm.	Strategic/type symm.	Asymm. types
$M = 4, \theta = 0.6, d_i = 0.8$ for asymm. types: $d_j = 0.5$	f	0.31	1	0.42	$0.74 - s$

Figure 3: Scenario comparison

4 Discussion

4.1 The CD launch revisited

The success of the CD can be attributed to any number of factors – including of course the significant quality leap from analog audio systems, the successful targeting of two distinct strata of music lovers, and finally the issues surrounding pre-introduction strategies analyzed in our model. Settling on a standard obviously helped create expectations on the part of consumers, but also on the part of hard- and software producers having to invest significantly in any new audio technology while taking the risk of cannibalizing their existing technology (McGahan, 1993). In our scenarios with complete and incomplete information, the stronger firm consistently prelaunches the technology, and the weaker firm concedes if it is not too strong and/or there are significant benefits from joining the prelaunched standard.

Applying these results to our motivating case suggests that Sony/Philips' design was the more efficient technology and that Matsushita gave up because they would not have been able to catch up in the remaining time leading up to the DAD conference. While it is impossible to analyze counterfactual cases where Matsushita prelaunched first or continued developing their own technology, anecdotal evidence suggests that Matsushita's design had less potential than Sony/Philips' both in terms of technological parameters and the potential linkup with software manufacturers. However, it appears that a fully developed version might have been viable in the marketplace given that it was approved at the DAD conference as well. It is also interesting to try and infer the amount of information and the degree of strategic symmetry from the players' prelaunch behaviour. Given Sony/Philips' prelaunch took place a relatively long time before the DAD conference, it seems that preemption played some role since a significant amount of technological progress was sacrificed in order to establish a standard prior to the conference. Consequently, it seems that strategic symmetry was the more likely scenario. Further, Sony/Philips were active trying to bring other licensees on board and thus make joining their standard more attractive for Matsushita, which would have been unlikely if Sony/Philips had been certain (or sufficiently confident) that Matsushita would have supported their standard anyway. Assuming network effects play a role already in the licensing stage (a technology with more parties signed up is more likely to succeed, which in turn makes it more attractive to join – thus strengthening the bargaining position of the standard sponsors), this sequence of action seems to be inefficient from Sony/Philips' perspective since the bargaining power vis-a-vis potential licensees was lower than with Matsushita on board. If, on the other hand, the support of other industry players was deemed crucial to get Matsushita's support, sacrificing bargaining power in exchange for the higher likelihood of getting Matsushita to join seems plausible. Consequently, it appears that there was a degree of uncertainty about the state of Matsushita's technology and therefore their likely action.

4.2 Applicability of the model

Our model aims to capture some of the crucial features in the introduction of a new technology. A technology develops over time, and although an earlier version of the technology might be functional, improvements are still possible. Further, prelaunching a technology captures a wide variety of actions where a technology's sponsor commits to a certain product specification – for example, exhibiting a prototype at a fair, publishing a set of specifications (as in the case of the Compact Disc), or preannouncing technical features could all be captured with the prelaunch strategy in our model. Likewise, concession by rival technologies could imply the public endorsement of the prelaunched technology, negotiations to ensure compatibility or even redirecting research efforts to conform to the industry standard.

Apart from capturing the main tradeoffs in such a situation, we also assess the effects of strategic asymmetry and incomplete information by analyzing three cases: Complete information and either strategic asymmetry (Stackelberg leadership) or symmetry, and the scenario with incomplete information. Clearly, firms will frequently attempt to maintain secrecy over their research efforts, so that a priori we expect the incomplete information case to be the most likely scenario. On the other hand, if there are significant knowledge spillovers regarding a technology or if players "know each other well" – for example because they have been competing in related industries previously, the complete information case may be more appropriate. This distinction is important in terms of the results they generate – complete information typically yields more efficient results: On the one hand, there will be no unsuccessful prelaunch, and on the other hand, prelaunch times (if there is a perlaunch at all) are typically closer to the efficient time. In other words, the incentive to preempt is more important with incomplete information.

4.3 Firm implications

If standardization confers benefits, but the gains are asymmetrically distributed, firms face a "co-opetitive" situation. On one hand, firms have an interest in securing cooperation with their rivals in order to increase the size of post-commercialization profits. On the other hand, each firm wants their own standard chosen as the industry standard. The fact that the binding constraint for a firm to initiate a prelaunch is the rival's concession condition indicates that a firm would only be willing to "push through" their standard if this is (likely to be) successful, which is confirmed in our analysis. How can a firm influence the likelihood of their prelaunch being successful? In our model, we assume that θ, the winner's share, is exogenously given, but it is conceivable that the sponsor of a standard can choose this, for example by implementing a liberal licensing policy. In fact, from Figure 1 we can see that it is always possible for a Stackelberg leader to choose a share θ and an appropriate prelaunch time t_i to ensure that the follower always joins the standard.

An interesting set of results revolves around the incentives for strategic asymmetry. In particular, in situations where the difference between the winner's and the loser's share is not too big (e.g. for liberally licensed technologies), it may be beneficial for players to settle on an order of moves so that the profit-maximizing prelaunch time t_i^* will be chosen rather than the inefficient earlier time which erodes away some of the profits to be gained from standardization. Agreeing on a Stackelberg leader resembles a Chicken game in some ways. It is better to be the leader than the follower, but being the follower is better than trying to preempt each other. We would therefore expect Stackelberg leadership to emerge endogenously only in a very limited set of circumstances.[29]

5 Conclusion

Our model generates some interesting results on the incentives to prelaunch a developing technology. However, a number of limitations and possible extensions should be noted. Most of our extensions will refer to player's strategies and payoffs in the development stage. This notwithstanding, we are aware that our modeling of the bargaining stage is relatively restrictive. In ongoing work, we therefore intend to analyze an alternative modeling strategy for bargaining outlined in footnote 15. Our main goal however is to ensure the robustness of our results regarding our modeling strategy in the development

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[29] In particular, in our model, pre-agreement on a Stackelberg leader would not be a stable agreement for any $\theta > \frac{1}{2}$.

stage. The following paragraphs outline some of the limitations and the corresponding extensions in the development stage:

1. We currently use specific functional forms that allow us to derive explicit solutions for launch times and the threshold values for the required (winner's and loser's) share. We expect most of our results to remain intact with alternative specifications or more general functional forms, but exploring this possibility is the subject of future research. In particular, we expect that a more general specification of $\lambda(t)$, the prelaunch benefits, will generate prelaunch times other than just prior to the deadline. The assumption that even at $t = T$, there are still some benefits to conceding (and the gradient by which concession benefits decrease in t) drives these results.

2. Technological progress is deterministic (if not necessarily common knowledge) in our model. This simplifies our analysis at the expense of not accounting for one observation in our motivating example – Matsushita did not concede immediately after Sony/Philips had prelaunched their technology. With deterministic technological progress the follower knows immediately after the prelaunch if concession is profitable or not and consequently concedes immediately or stays in until the end. If progress were random, it would be possible for the follower to continue developing its technology for some time until it becomes clear that submitting one's own standard to the DAD conference would not be profitable. This is likely to have been a more realistic scenario regarding Matsushita's behaviour. With the simple specification we use, this is ignored, and incorporating stochastic technological progress is another area of future research.

3. Finally, we also currently assume that in the incomplete information case, players privately precommit to a prelaunch time. This is equivalent to assuming that there is no Bayesian updating with incomplete information. Allowing for agents to constantly update their beliefs about their rival's type would generate some interesting dynamics in terms of players becoming more bullish about their type compared to their rival's. Since stronger players will prelaunch at an earlier time, as time passes the absence of a prelaunch indicates weakness on the part of the players, which in turn feeds back on the incentives of initiating a prelaunch.

These limitations notwithstanding, we feel that our simple and stylized model of prelaunch standardization manages to capture some of the mechanisms at play in such a situation. We believe that the proposed extensions will be fruitful in terms of aligning the model closer to reality, but we are confident that basic intuition of our initial results will remain intact.

6 Appendix

6.1 Proof of Proposition 2

We introduce some additional notation. CC_{AY}, PC_{AY} refer to the asymmetric types Stackelberg game, while CC_{SY}, PC_{AY} refer to the symmetric types Stackelberg game. We analyze both cases in turn:

- The leader is the more efficient firm, i.e. $d_i > d_j$. The concession condition CC_{AY} is less binding than in the symmetric case (CC_{SY})i.e. $\theta_C^{'} > \theta_C$. Less binding means the follower will, all other things being equal, concede for high er winner's shares θ. If $\theta_C^{'} > \theta_C$, we require that

$$\begin{array}{rcl} \dfrac{d_i t_i \left(M - t_i\right)}{d_i t_i \left(M - t_i\right) + d_j} & > & \dfrac{t_i \left(M - t_i\right)}{t_i \left(M - t_i\right) + 1}\ , \\ & \text{or} & \\ \dfrac{t_i \left(M - t_i\right)}{t_i \left(M - t_i\right) + \frac{d_j}{d_i}} & > & \dfrac{t_i \left(M - t_i\right)}{t_i \left(M - t_i\right) + 1} \end{array}$$

  which holds since $\frac{d_j}{d_i} < 1$.

- The leader is less efficient firm, i.e. $d_i < d_j$: The concession condition CC_{AY} is more strict than in the symmetric types case (CC_{SY}), i.e. $\theta_C^{''} < \theta_C$. The follower will, all other things being equal, concede only for smaller winner's shares θ. If $\theta_C^{''} < \theta_C$, we require that

$$\begin{array}{rcl} \dfrac{d_i t_i \left(M - t_i\right)}{d_i t_i \left(M - t_i\right) + d_j} & < & \dfrac{t_i \left(M - t_i\right)}{t_i \left(M - t_i\right) + 1}, \\ & \text{or} & \\ \dfrac{d_i t_i \left(M - t_i\right) + d_i}{d_i t_i \left(M - t_i\right) + d_j} & < & 1, \end{array}$$

  which holds since by definition for the asymmetric case $d_j > d_i$. Turning to the prelaunch condition, we compare the asymmetric and symmetric type cases and obtain the following relationship (defining $(\lambda_{t_i} t_i) = x$):

$$\begin{array}{rcl} \theta_P^{''} & = & \dfrac{d_j}{d_i t_i \lambda_{t_i} + d_j} \lesseqgtr \theta_P = \dfrac{1}{2 t_i \lambda_{t_i}}, \\ & & \text{or, noting the reversal in signs,} \\ 1 & \gtreqless & x\left(2 - \dfrac{d_i}{d_j}\right), \end{array}$$

where $\frac{d_i}{d_j} < 1$ and $(2 - \frac{d_i}{d_j}) > 1$ but x can take any value without further restrictions on either t_i,or λ_{t_i} and M, respectively. However, for $\lambda = M - t$, $t_i^* = T = 1$ which yields

$$1 < (M-1)(2 - \frac{d_i}{d_j}) \Leftrightarrow \theta_P^{''} > \theta_P$$

since $M > 2$.

6.2 Proof of Proposition 3

[TO BE COMPLETED.]

6.3 Proof of Proposition 4

From proposition 1 we know that the CC is the binding constraint as opposed to PC. We concentrate on the relevant concession conditions and derive and compare them below. Players ahve different types, i.e. $d_i \neq d_j$, and no roles are pre-assigned. We assume that $d_j < d_i$ and start by deriving the weaker player's *(j)* concession condition CC$_j$ given that player i has undertaken a prelaunch at time t_i and player j has not undertaken a prelaunch up to or at t_i. We require that $\pi_j(C) \geq \pi_j(S)$, or

$$\Rightarrow (1-\theta)q_{i,t_i}\lambda_{t_i} \geq \pi_j(S) = \begin{cases} (a) & (1-\theta)q_{i,t_i} \quad if \quad q_{j,T} < q_{i,t_i} \Leftrightarrow d_j < d_i t_i \Leftrightarrow \frac{d_i}{d_j} > \frac{1}{t_i} \\ (b) & \theta q_{j,T} \quad if \quad q_{j,T} > q_{i,t_i} \Leftrightarrow d_j > d_i t_i \Leftrightarrow \frac{d_i}{d_j} < \frac{1}{t_i} \\ (c) & \frac{1}{2}q_{j,T} = \frac{1}{2}q_{i,t_i} \quad if \quad q_{j,T} = q_{i,t_i} \Leftrightarrow d_j = d_i t_i \Leftrightarrow \frac{d_i}{d_j} = \frac{1}{t_i} \end{cases}$$

With zero probability for case (c), we concentrate on cases (a) and (b) in the following argumentation. Case (a) is trivial since immediate concession strictly dominates staying in. The (relative) superiority of i's technological development speed is so strong that player j cannot catch up until T with player i's technology (as revealed and fixed at t_i). For case (b) we derive the concession condition CC$_j$ from

$$(1-\theta)q_{i,t_i}\lambda_{t_i} \geq \theta q_{j,T} \Leftrightarrow (1-\theta)d_i t_i \lambda_{t_i} \geq \theta d_j$$

as

$$\Leftrightarrow \quad \theta \leq \theta_{C_j} = \frac{d_i t_i \lambda_{t_i}}{d_i t_i \lambda_{t_i} + d_j} \Rightarrow \theta_{C_j} = \frac{d_i t_i (M - t_i)}{d_i t_i (M - t_i) + d_j}; \text{ and}$$

$$\Leftrightarrow \quad \frac{d_i}{d_j} \geq \frac{\theta}{(1-\theta) t_i \lambda_{t_i}} \Rightarrow \frac{d_i}{d_j} \geq \frac{\theta}{(1-\theta) t_i (M - t_i)}$$

We have $t_{i\min} = \min(V_j)$ as the first time at which the respective CC$_j$ holds when $V_j \subset [0, T]$ is the set of all times during the interval at which CC$_j$ holds. So if the (relative) advantage in player i's technological development speed is small enough as to allow player j to overtake until T provided he stays in, the choice between conceding and staying in depends on the net result from two tradeoffs: (S) earns j a larger share of the prize. (C) earns j a smaller share and implies some foregone increase in technological quality (since the relevant technology for determining the size of the prize in this case is player i's technology at t_i, not player j 's technology at T, and $q_{j,T} > q_{i,t_i}$). However, (C) increases the prize by the concession benefits, λ_{t_i}.

Now we turn to the stronger player's (i) CC$_i$ ($q_{i,T} > q_{j,t_j} \forall t \in [0,T]$). Given player j prelaunches at time t_j and player i has not undertaken a prelaunch up to or at t_j, then we derive CC$_i$ from $\pi_i(C) \geq \pi_i(S)$ as

$$(1-\theta)q_{j,t_j}\lambda_{t_j} \geq \theta q_{i,T} \Leftrightarrow (1-\theta)d_j t_j \lambda_{t_j} \geq \theta d_i$$

$$\begin{aligned}
\Leftrightarrow \quad & \theta \leq \theta_{C_i} = \frac{d_j t_j \lambda_{t_j}}{d_j t_j \lambda_{t_j} + d_i} \Rightarrow \theta_{C_j} = \frac{d_j t_j (M-t_j)}{d_j t_j (M-t_j) + d_i}; \text{ and} \\
\Leftrightarrow \quad & \frac{d_i}{d_j} \leq \frac{(1-\theta) t_j \lambda_{t_j}}{\theta} \Rightarrow \frac{d_i}{d_j} \leq \frac{(1-\theta) t_j (M-t_j)}{\theta}.
\end{aligned}$$

Note that cases (a) and (c) as above are not possible for $d_i > d_j$ and player i undertaking a prelaunch.

By comparing CC$_j$ and CC$_i$ we obtain the following results:

Case (a): If for a given time $t \in [0,T]$ CC$_j$ holds, this implies that $q_{j,T} < q_{i,t_i} \Rightarrow$ CC$_i$ cannot possibly hold.

Case (b): For given $\lambda(t)$, M, respectively,and $d_i > d_j$, the earliest time for which CC$_i$ holds ($t_{j\,\min}$), and hence the first time at which the (weaker) player j would undertake a prelaunch, is greater than the earliest time for which CC$_j$ holds ($t_{i\,\min}$). Since we have:

$$\begin{aligned}
\text{for } CC_i \quad & : \frac{d_i}{d_j} \leq \frac{(1-\theta) t_j (M-t_j)}{\theta} \Leftrightarrow \frac{d_i}{d_j} \frac{\theta}{(1-\theta)} \leq t_j (M-t_j) \\
\text{for } CC_j \quad & : \frac{d_i}{d_j} \geq \frac{\theta}{(1-\theta) t_i (M-t_i)} \Leftrightarrow \frac{d_j}{d_i} \frac{\theta}{(1-\theta)} \leq t_i (M-t_i)
\end{aligned}$$

from which we obtain (because $d_i > d_j$)

$$t_i(M-t_i) < t_j(M-t_j) \Leftrightarrow t_j^2 - t_i^2 < M(t_j - t_i)$$

$$\begin{aligned}
\Rightarrow \quad & \text{for } t_j > t_i\text{:} \quad \frac{t_j^2 - t_i^2}{t_j - t_i} < M \\
\Rightarrow \quad & \text{for } t_j < t_i\text{: } .\frac{t_j^2 - t_i^2}{t_j - t_i} > M
\end{aligned}$$

Since $M > 2$, and $\frac{t_j^2 - t_i^2}{t_j - t_i} \leq 2$ for $t \in [0, 1]$, $t_j < t_i$, the second inequality cannot hold. The first inequality can hold and hence, $t_j > t_i$.

Case (c): CC_j holds at exactly one time t_i with either $t_i = T$, or $t_i < T$. In the latter case, there is at least one later time $t_i' = T$ for which $\frac{d_i}{d_j} > \frac{1}{T} = 1$ holds (see case (a)). As a result, player i would wait until $t_i' > t_i$ before undertaking the prelaunch and getting share θ. Along the lines of case (b), we then have $t_i < t_i' < t_j$ which prevents player j from undertaking a prelaunch first.

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