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# Co-Opetition and Prelaunch in Standard-Setting for Developing Technologies

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**Abstract**
Firms faced with the decision of whether to standardize or not prior to introducing a new network technology face a tradeoff: Compatibility improves the technology's chances of consumer acceptance, but it also means having to share the resulting profits with other sponsors of the standard. In this paper, we show that even prior to market introduction of a new technology, the timing of decisions is important and that firms have to weigh up the cooperative and competitive elements of pre-market choices. We also show that the option to precommit to a technology before it is fully developed (as has been the case with the Compact Disc) can be profitable for network technologies.

JEL Classifications: L63, O32
Keywords: Standardization, compact disc, preemption, war-of- attrition

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# 1 Introduction

Industry standards are set at different stages of a product's development – the technology's development stage, the approval or committee phase, and the commercialization phase. Firms collaborate to jointly develop compatible products (Katz and Shapiro, 1998), firms and standard-setting bodies negotiate standards in committees (Chiao, Lerner and Tirole, 2005), and consumers choose de-facto industry standards in the marketplace (Ohashi, 2003, Park, 2004, Gandal, Greenstein and Salant, 1999). When deciding whether to standardize or not, firms face a tradeoff: In industries with network effects, technological compatibility improves the chances for consumer acceptance, but it also means having to share the resulting profits with other sponsors of the standard. As a result, firms have frequently chosen to introduce competing technologies into the market, sometimes with the outcome that neither of the technologies is adopted by end consumers (Kretschmer, 2005). For example, the failure to converge on a common standard is often put forward as the main reason for the failure of quadraphonic sound (Postrel, 1990).

The Compact Disc (CD) is an example of a particularly successful consumer electronics technology. The Compact Disc was developed in collaboration by Philips and Sony (P/S for the remainder of the paper) in the late 1970s and early 1980s in response to technological developments in related fields and an increasing sense that vinyl records and magnetic tape had reached their limits in terms of audio performance and user-friendliness. There were several competitors to P/S' development, most notably by JVC and its mother company Matsushita. The Japanese Ministry of International Trade and Industry (MITI) scheduled a standard-setting conference in Spring 1981, but the decision taken at the conference (P/S' technology was approved and commercialized, while JVC's technology was approved, but never manufactured for end consumers) was a foregone conclusion because P/S had preannounced the technical features of their technology and JVC/Matsushita subsequently announced their support of the P/S standard. In the consumer electronics market which had seen its fair share of standards battles fought out in the market, this was a remarkable episode; choosing a standard prior to launching the technology in the market avoided a VHS-Betamax-style standards battle, and the process of choosing a standard appeared relatively quick and painless.[1] While other authors have focused on post-launch developments in the CD industry, such as post-introduction capacity investments (McGahan, 1993), the existence of indirect network effects (Gandal, Kende, Rob, 2000) and the comparison with similar, but unsuccessful, technologies (Rohlfs, 2001), we focus on the process by which fierce rivals in the marketplace, Sony, Philips and JVC, were able to agree on a common technological standard before introducing a new audio technology. Viewed historically, the introduction of the CD seems straightforward. In the process itself however, a number of issues were not obvious. For example, why did P/S publish the Redbook before the DAD conference, committing prematurely to a technology? Similarly, why did JVC/Matsushita announce its intentions to support P/S' standard before the DAD conference instead of simply waiting for the outcome of the conference's approval process and continuing development of their technology?

Building a simple, yet comprehensive model of standard-setting with technological progress, we study the tradeoffs emerging prior to launching a technology and identify the tradeoffs between standardization benefits, preemption motives, and technological progress. We show that even in these pre-market stages, the timing of decisions is important and that firms have to weigh up the cooperative and competitive elements of pre-market choices. This captures the intuition of a range of cases (including the Compact Disc

[1] The process from starting intensive development on digital audio technology to setting a CD standard took less than three years. By comparison, the average time for agreement on an IEEE standard is seven years (Spring et al., 1995).

launch) in which competitive and cooperative motives exist simultaneously. We identify a set of parameter values for which standardization on a technological standard is possible, as in the case of the CD, but also identify situations in which standardization is less likely. We are especially interested in studying the incentives for a prelaunch of a technology even before its full technological potential is reached. A prelaunch limits a firm to a certain set of product characteristics and thus curtails further technological development, but at the same time it may persuade rivals to join the proposed standard. Due to its comprehensive formulation, our model allows us to classify emerging technologies into ones where standards battles are likely or where a product standard is likely to emerge prior to the product launch. If agreement on a joint standard prior to commercialization is reached, we are further able to identify conditions under which a prelaunch takes place relatively early, implying foregone technological progress, and conditions for which a later prelaunch is feasible, making full use of the technology's potential. Which result emerges depends on the interaction between the players' relative strengths, the strength of network effects, the degree of substitutability among technologies, and each product's own brand loyalty.

The paper is structured as follows. In the next section, we briefly discuss related literature. We then introduce the basic model in Section 3 and illustrate our central results with an analysis of the CD launch and some numerical simulations in Section 4.[2] We then discuss the results of our model in Section 5. In Section 6 we conclude and point out directions for future research.

[2] For a more detailed account of the case see e.g. Gamharter and Kretschmer, 2004.

## 2 Related literature

Various aspects of pre- and post-market standardization processes have been studied in some detail.[3] For our study, the literature on the emergence of hybrid (pre-market) standardization, which includes both market-based and committee-based elements, is of particular relevance.[4] Farrell and Saloner (1988) show that hybrid standardization processes may be superior to pure (market- or committee-based) mechanisms because firms 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 broader literature on network effects and standardization is vast and will not be reviewed in detail.[5] Related to our study, Sheremata (2004) finds that radical and incompatible innovation can be more profitable than incremental and compatible innovation. High switching costs for consumers favor radical innovation because a greater improvement is needed to compensate for foregone network benefits. We focus explicitly on the role of technological quality in shaping rival firms' decisions to choose (in-)compatibility. Further, we consider a situation where there is no clearly defined incumbent

[3] From a theoretical perspective, see e.g. Kindleberger, 1983; David and Greenstein, 1990; Besen and Farrell, 1994; Axelrod et al., 1995. Empirical studies on the effect of standardization on market success include Weiss and Sirbu, 1990; Funk and Methe, 2001; and Dranove and Gandal, 2003.

[4] See, for example, Farrell and Saloner, 1988; David and Monroe, 1994; Funk and Methe, 2001; and Funk, 2002.

[5] For a management/marketing perspective see e.g. Hill, 1997; Schilling, 2002; Frels, Shervani and Srivastava, 2003; Shankar and Bayus, 2003; for an economics perspective see e.g. Farrell and Saloner, 1985, 1986; Katz and Shapiro, 1985, 1986, 1994; David and Greenstein, 1990; Besen and Farrell, 1994; Koski and Kretschmer, 2004.

competing for the new technological generation.[6]

In addition to the standardization literature our analysis draws on other strands of research in management strategy and industrial organization. First, we relate to research that explores properties of oligopolistic competition dependent on some prior stage of competition, e.g. R&D. Typically, firms make decisions on R&D investments in the first stage and compete in the product market in the second stage (D'Aspremont and Jacquemin, 1988; Amir, Amir and Jin, 2000; Suetens, 2005). The structure of our model is similar, with three major extensions: first, we focus on timing rather than effort or intensity decisions such as R&D expenditure in the first stage. Second, we allow for preannouncement in the first stage. Third, we model an industry with network effects in the market stage. Hence, technology development in our model needs to address issues of (in-)compatibility, standard-setting, and its consequences for the market stage.

Also related to our work are studies of timing such as preemption games (e.g. Fudenberg and Tirole, 1985; Levin and Peck, 2003) or war-of-attrition games (Bulow and Klemperer, 1999, Hoerner and Sahuguet, 2004). Innovation and technology adoption are often modeled as timing games (Hoppe, 2002; Hoppe and Lehmann-Grube, 2005). Two key findings of this literature are that first-mover advantages may speed up adoption through preemption motives,[7] and that late-mover advantages may exist because technologies improve over time (Hoppe, 2002). We model this tradeoff (for an illustration see Hoppe and Lehmann-Grube, 2001) in the context of standard-setting in network effect industries. Further, we extend the action space of the players by allowing for a technological prelaunch.

Our study also relates to the literature on preannouncements. Nagard-

[6] Previous research suggests that new technologies competing against a powerful incumbent may suffer from a lack of standardization in the new technology - as was the case in quadraphonic sound (Postrel, 1990, Kretschmer, 2005).

[7] This may even erode all potential first-mover advantages (Fudenberg and Tirole, 1985).

Assayag and Manceau (2001) analyze the rationale for preannouncements in the context of indirect network effects based on data from French CD audio market in the mid-1980s and early 1990s, and find that consumers' prior-to-launch expectations positively affect the technology's penetration rate. Software producers' expectations have only an indirect influence that largely depends on the level of consumer expectations. Lee and O'Connor (2003) develop a framework for new product launch strategies for network products in which product preannouncements fulfill three primary roles: preemption, alliance seeking and encouragement of complementary goods producers and consumer expectations' management. In a study of the flat panel display industry, Spencer (2003) finds that sharing technological knowledge with competitors may increase firms' innovation performance by enabling it to shape the institutional environment in favor of its own technology. We formalize and extend this literature by (i) simultaneously capturing preemptive and collaborative motivations, and by (ii) analyzing product prelaunch as a particular knowledge sharing strategy in a network effect environment. Dranove and Gandal (2003) study the impact of product preannoucements on standard establishment in the digital video market. They find that preannouncement of the DIVX technology briefly slowed down adoption of the DVD. Unlike their study, we focus on preannouncement effects prior to product introduction. Our work also relates to models of (strategic) information disclosure (Gill, 2004; Gordon, 2004; Jansen, 2005a, 2005b), which emphasize the interaction between the incentives to disclose (usually from sending a "strength"-signal to rivals) and associated disincentives (usually from technological and knowledge spill-overs). Unlike our model, this literature tends to focus on knowledge spillovers of R&D among competitors rather than issues of (in-)compatibility resulting from strategic preannouncements.

Our model combines insights from these streams of research and is to our knowledge the first that explicitly links a timing game (capturing competitive technological development for a new standard) with a subsequent Cournot-type market stage in a network effect industry. In solving the model, we obtain interesting results on our motivating case, the Compact Disc, but also on preannouncement timing and standardization decisions more generally. Hence, we also address previous calls for research on standardization to consider the dynamic aspects of standard adoption and coalition formation (Katz and Shapiro, 1994; Axelrod et al., 1995).

# 3 The Model Setup

Consider a game with two players, 1 and 2, and two stages, a development stage and a subsequent market stage. In the development phase, the qualities of the two competing technologies and their compatibility are determined through the timing decisions of players in the first stage – when to prelaunch or concede (if at all), or staying in. After the qualities of the technologies (and their possible compatibility) have been determined, firms compete in quantities in the (Cournot) market stage.

## 3.1 Development Stage

Both players' technologies develop exogenously over time.[8] Time runs from 0 to $T$. Players are allowed to move (simultaneously) at $N$ discrete times $t$ with $t \in \left\{0, \frac{1}{N}T, ..., \frac{N-1}{N}T, T\right\}$ (cf. Assumption A1 in Hoppe and Lehmann-Grube, 2005; Simon and Stinchcombe, 1989). In our analysis of the timing of strategies in the development stage, we will work with continuous time, which enables us to make use of calculus given we have well-behaved technological progress functions (i.e. continuous and single-peaked) – basically discrete time with infinitely small intervals and continous time are treated

[8] For models using the speed of technological development as strategic variable, see e.g. Harris and Vickers (1985a, 1985b), Fershtman and Markovich (2004) and the literature on patent races in general.

as equivalent. We then discretize our results to recover the results in discrete time. We assume that $T$ is exogenously given.[9] Technological quality for player $i$ is given by the (time-dependent) function $\alpha_i(t)$. Quality is continuously increasing over time and we abstract from R&D costs. Denote $\overline{\alpha}_i \equiv \alpha_i(T)$. In the development stage, at each time, players have the following actions available to them: Prelaunch (provided the other player has not yet undertaken a prelaunch; superscript $^P$), concede (provided the other player has undertaken a prelaunch; $^C$), and stay in ($^S$). *Prelaunching* a technology ends technological progress of the prelaunched technology. By prelaunching the player commits to a technology with the specifications set out in the prelaunch. Prelaunching is possible at any time between 0 and $T-1$, and in keeping with existing literature we rule out the possibility of coordination failures through simultaneous prelaunch by assuming that if both players would want to prelaunch at the same time, each has a 50 per cent chance of getting to prelaunch (Hoppe and Lehmann-Grube, 2005, Dutta, Lach, and Rustichini, 1995, Katz and Shapiro, 1987).[10] *Conceding* also ends technological progress but involves supporting the rival standard. This implies having compatible products in the market stage, but also an increase in the marginal cost of production. In other words, conceding implies a smaller share (because concession implies a cost disadvantage compared to the standard setter) of a larger pie (because larger network effects imply higher equilibrium prices and profits). *Staying in* is straightforward in its implications since technological progress continues until $T$.

[9] An alternative formulation could be a model with decreasing returns to R&D and/or explicit costs of R&D. $T$ would then be the time when the additional cost of continuing R&D outweigh the added quality improvement. An exogenous deadline is however commonly used in the literature on timing games.

[10] However, it would also be feasible to include the possibility of coordination failure in our model. This would yield different prelaunch probabilities in game classes 2 and 4 (see Section 4.2.2), but would not change our general results.

### 3.2 Market Stage

The market stage is a quantity-setting duopoly with network effects. We treat the degree of substitutability as an exogenous parameter. We also allow for homogeneous (*symmetric*) as well as heterogeneous (*asymmetric*) types of players. The types of the players are given by the quality of their technology determined in the first stage, and their costs $m_i$. So asymmetry can arise from differences in the players' technological qualities $\alpha_i$ at the development stage and/or differences in their marginal cost. If firms standardize in the development stage, products are compatible in the product market, which implies that a user derives network effects from both own-technology and other-technology users. We model standardization as an indicator variable $\lambda$ taking value 1 if firms have standardized and 0 otherwise. Firms produce differentiated goods with network effects. Firm 1 faces the following inverse demand function (firm 2's demand function is constructed analogously):

$$p_1 = \alpha_1 + \delta\left(q_1 + \lambda q_2\right) - \beta q_1 - \gamma q_2, \tag{1}$$

where $p_i$ and $q_i$ are prices and quantities, respectively. Quality (determined in the first stage) for the players is denoted by $\alpha_i$, own-brand loyalty by $\beta$, the degree of substitutability $\gamma$, and the strength of network effects is denoted by $\delta$.[11] Suppose now that firm 1 has set the standard and firm 2 concedes. Firm 2 suffers a loss in competitiveness as it has to adjust to a new technology. Normalizing marginal cost without concession (i.e. launching

[11] We assume perfect compatibility so that an additional user of the competing technology is just as valuable as a user of the own technology. In the case of the CD, this seems plausible, but extending our model to allow for imperfect compatibility by setting $\delta_i > \delta_{-i}$ in firm $i$'s demand function is straightforward and would not add much additional insights apart from reducing the benefits of standardization. We are also assuming two-way compatibility. Allowing for one-way compatibility would again reduce the incentives for standardization in the first stage.

one's own technology) to zero, we model this loss in competitiveness from conceding as an increase in the marginal cost of $m_2 > 0$. When convenient, we will write the difference between technological quality and marginal cost as $\widehat{\alpha}_i \equiv \alpha_i - \lambda m_i$. This is a measure of the value a firm adds for their customers (Brandenburger and Stuart, 1996, Adner and Zemsky, 2006). For a firm launching its own technology, $\widehat{\alpha}_i = \alpha_i$, whereas $\widehat{\alpha}_i < \alpha_i$ for a conceding firm.

We briefly discuss the effects of the model parameters. First, note that an increase in network effects $\delta$ is equivalent to increasing own-brand loyalty (decreasing $\beta$). We can write $\widehat{\beta} \equiv \beta - \delta$ as the effective brand loyalty, and $\widehat{\gamma} \equiv \gamma - \lambda\delta$ as the effective degree of substitutability. This illustrates the dual effect of an increase in the competitor's quantity: On the one hand, market prices decrease (through $-\gamma q_2$), but on the other hand, overall network size grows if products are compatible (through $+\delta q_2$). Product quality $\alpha_i$ can differ across firms and depends on time $t$. We model product quality as increasing the willingness to pay for all consumers, i.e. as an outward shift of the demand curve. In the firms' optimization problem, this is equivalent to differing marginal costs. Finally, $\gamma$ measures the degree of substitutability between the technologies. We assume that products are differentiated in terms of brand image, geography, features etc. and that compatibility does not affect product differentiation.[12] An increase in $\gamma$ therefore increases the overlap between the product markets ($\gamma = \beta$ implies perfect substitutes[13]), while higher $\alpha_i$ increases market size for a product, and $\frac{\alpha_1}{\alpha_2}$ represents the

[12] Allowing for negative correlation between product differentiation and compatibility would render standardized markets more competitive and thus less profitable. Standardization would be less attractive in such a setting.

[13] While not explicitly covered by our model, the case $\beta = \gamma$, $\alpha_1 = \alpha_2$ corresponds to the standard homogenous Cournot model. From there, decreasing the value of $\gamma$ separates the previously joint markets into only partially overlapping markets. For $\gamma = 0$ both firms have local monopolies (see Figure 1).

ratio of the market sizes, as illustrated in Figure 1.

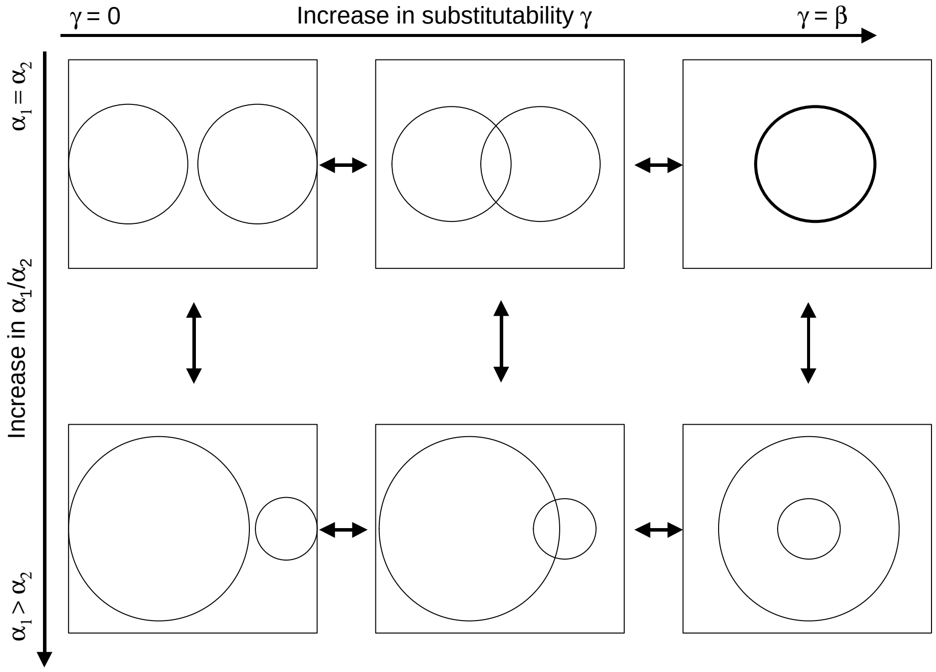


Figure 1: Effect of substitutability and quality ratio on market size and overlap.

We note some parameter restrictions: $(i)$ $\beta \geq \gamma > \delta \geq 0$; $(ii)$ $\alpha_i(T) > m_i,\ i \in \{1,2\}$; $(iii)$ $\frac{\alpha_i}{\alpha_j} \geq \frac{\gamma}{2\beta}',\ i,j \in \{1,2\}, i \neq j$. The first restriction rules out upward-sloping demand curves (because of a dominant network effect) and assumes perfect substitutes as limit case.[14] The second restriction rules out the case where adaptation costs are so high that concession is never an option. The third restriction ensures positive production quantities. We now discuss the analysis of the game and equilibria in the two stages in the

[14]One can also allow for every player to have her own value of $\beta$, and also for asymmetry in the $\gamma$'s: player 1's product may be substitutable for player 2's, but vice versa this may be not the case, at least not to the same degree. The analysis of this more general model is beyond the scope of this present paper.

next section.

# 4 Analysis

We solve the game by backward induction and analyze the Cournot stage in section 4.1 and the development stage in 4.2. We show that our general game can take on very different characteristics depending on parameter values. Specifically, our first stage game can resemble a war-of-attrition, a preemption game or a last-minute agreement, given certain model parameters. Due to the flexibility of our model, we can therefore describe and analyze a broad class of situations with our model. We will first develop a procedure to solve the game in general and then illustrate some applications for particular parameter constellations in Section 5.

## 4.1 Market stage equilibrium

In the market stage, firms maximize profits given the outcome of the development stage. If a prelaunch is followed by a concession, products are compatible ($\lambda = 1$). In all other cases – no prelaunch or an unsuccessful prelaunch – products are incompatible and $\lambda = 0$. Prices, quantities and profits are:

$$q_1^* = \frac{2\widehat{\beta}\widehat{\alpha}_1 - \widehat{\gamma}\widehat{\alpha}_2}{4\widehat{\beta}^2 - \widehat{\gamma}^2}, \quad p_1^* = \frac{2\widehat{\beta}_1^2\widehat{\alpha} - \widehat{\beta}\widehat{\gamma}\widehat{\alpha}_2}{4\widehat{\beta}^2 - \widehat{\gamma}^2}, \quad \pi_1^* = \beta' \left( \frac{2\widehat{\beta}\widehat{\alpha}_1 - \widehat{\gamma}\widehat{\alpha}_2}{4\widehat{\beta}^2 - \widehat{\gamma}^2} \right)^2, \quad (2)$$

and accordingly for firm 2. It is straightforward to see that for equal qualities, the conceding firm makes lower profits and has lower market share than the standard-setting firm since $\widehat{\alpha}_i < \widehat{\alpha}_{-i}$. We now present some insights on how profits change with parameter values. All proofs are in the appendix.

**Lemma 1** *Profits $\pi_i^*$ are increasing in own technological quality $\alpha_i$.*

No matter whether the outcome of the development stage is a common standard (compatibility), or not (incompatibility), both players' profits always benefit from higher quality. As a result, each player generally has an interest to develop her technology as far as possible. From Lemma 1 and the profit function in equation (2) it follows directly that a conceding player's profits $\pi_i^*$ decrease in her adaptation costs $m_i$, while profits for a standard-setting firm $\pi_j^*$ increase in adaptation costs $m_i$. This is intuitive: The higher the cost of adapting to another firms' technology, the lower profits and the less attractive is standardization. Also, player $i$' s profits $\pi_i$ are decreasing in the technological quality of its rival $\alpha_j$ which can be seen by inspection of the profit functions for incompatibility and compatibility. Note that a one-unit increase in the rival's quality lowers $i$'s profits by less than a one-unit increase in $i$'s own quality since $2\beta > \gamma$. Each player therefore generally profits from competing against a weaker rival. Additionally, if both players have equal development speed in the development stage this also implies that $i$'s profits decrease by less per period of the rival's development time than they increase in own development time. Ceteris paribus therefore, this gives players an incentive to have both players continue until the deadline.

**Proposition 1** *Player i' s profits $\pi_i^*$ are decreasing in $\gamma$ if $\frac{\alpha_i}{\alpha_j} < \frac{4\widehat{\beta}^2+\widehat{\gamma}^2}{4\widehat{\beta}\widehat{\gamma}}$ and increasing for sufficiently high $\gamma$ if $\frac{\alpha_i}{\alpha_j} \geq \frac{4\widehat{\beta}^2+\widehat{\gamma}^2}{4\widehat{\beta}\widehat{\gamma}}$.*

This Proposition is illustrated in the following graph (Figure 2), which shows $\pi_1^*$ (assuming incompatibility) for three different ratios $\frac{\alpha_1}{\alpha_2}$ and varying levels of $0 \leq \gamma \leq \beta$.

We first note that player 1's profit function has a minimum at $\gamma_{\min} = \frac{2\left(\alpha_1\widehat{\beta}-\sqrt{\alpha_1^2\widehat{\beta}^2-\alpha_2^2\widehat{\beta}^2}\right)}{\alpha_2}$. An increase in $\frac{\alpha_1}{\alpha_2}$ means that player 1's quality increases relative to player 2's, which implies a lower $\gamma_{\min}$. There is an upper bound for $\gamma$ since $\gamma \leq \beta$. Depending on the value of $\frac{\alpha_1}{\alpha_2}$, $\gamma_{\min}$ can be below or above $\beta$. If $\gamma_{\min} \geq \beta$, $\pi_1^*$ is strictly decreasing in $\gamma$. It is straightforward to show that with compatibility (incompatibility) this is always given for $\frac{\alpha_1}{\alpha_2} < \frac{5}{4}\,(1)$ – increasing substitutability between products reduces profitabil-

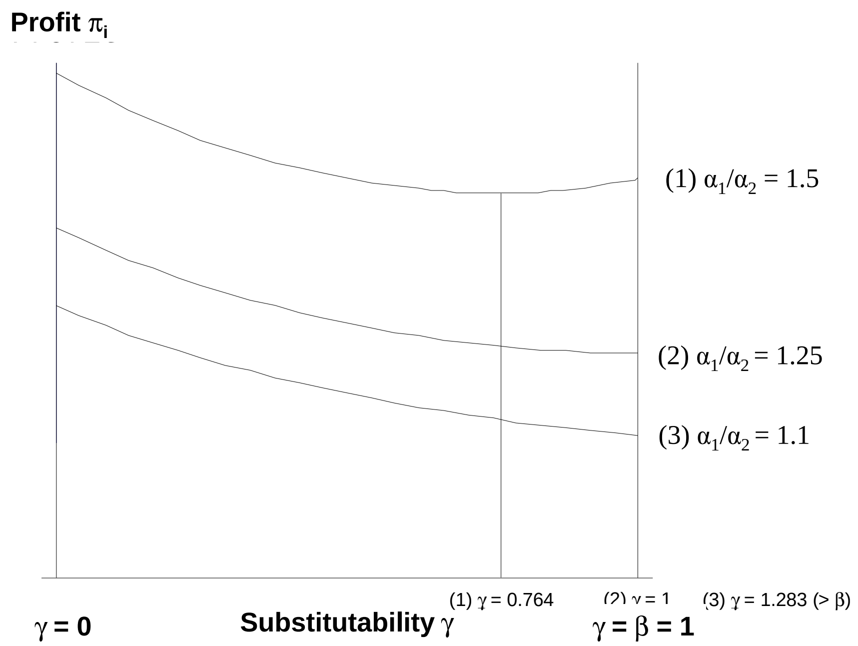


Figure 2: Profit functions for different quality ratios and degrees of substitutability.

ity. Conversely, if the quality ratio exceeds this threshold, profits may be increasing in $\gamma$ for sufficiently high values of $\gamma$ ($\gamma > \frac{2\left(\alpha_1\widehat{\beta}-\sqrt{\alpha_1^2\widehat{\beta}^2-\alpha_2^2\widehat{\beta}^2}\right)}{\alpha_2}$), which at first appears counterintuitive. This can occur if a player has much higher quality than the rival. While increased substitutability still increases competition in the player's home market, it also gives increased access to the weaker rival's market, thereby increasing profits. Conversely, for the weaker player the negative effects of increased substitutability dominate.

**Proposition 2** *(i) With incompatibility and type-asymmetry* ($\alpha_1 \neq \alpha_2$)*, profits of the higher-quality firm increase in the strength of the network effect* $\delta$*, and profits of the lower-quality firm decrease in the strength of the network effect* $\delta$*. (ii) For incompatibility and symmetric types* ($\alpha_1 = \alpha_2$) *profits of* *both players always increase in the strength of the network effect $\delta$. (iii) With compatibility (prelaunch and concession), a player's profits always increase in the network effect strength $\delta$.*

We first explain the type asymmetric case, (a). We have one player with a larger technological quality $\alpha$, and one with a smaller quality. Recall that technological quality $\alpha$ also determines the size of the market for each player. Assumption $(i)$ implies that the substitutability $\gamma > 0$. This means that the markets of both players have at least a small overlap. In this constellation, the customers who are in the overlap of the markets, have, with growing (market-specific!) network effects, a stronger incentive to be part of the bigger market (i.e. network), and hence are lost for the weaker player. So for the weaker player, the network effect is negative, while the stronger player gains from it because it enhances the relative attractiveness of her network. For incompatibility, case (b), the case is simpler: since the markets do not overlap, both players gain from increasing network effects within and specific to their own markets. The final case, (c), is similar: since both player's essentially share the same market, they both gain from increasing network effects. There is only one joint network, so that both players always profit to the same extent from an increase in the strength of the network effect which applies to their joint network.

Having derived profit functions for the two scenarios, we can now go to the first stage of the game and identify conditions for a successful prelaunch in terms of the market parameters in the second stage.

## 4.2 Development stage equilibrium

Abstracting from timing for the moment, three different outcomes of the developing stage seem possible: $(i)$ one of the players undertakes a prelaunch and the rival does not concede, $(ii)$ one of the players prelaunches and the rival concedes at some point prior to the conference, $(iii)$ nothing happens and both players keep developing until $T$. If a prelaunch occurs, we are also interested in who acts as a prelauncher in equilibrium. We now analyze the conditions under which each outcome emerges in equilibrium and identify which player prelaunches and/or concedes – if at all. We first eliminate some dominated strategies: prelaunching before $T$ after the other player has prelaunched is dominated by either staying in until $T$ or conceding. This means that we will only see one prelaunch in the game, and concession will take place, if at all, at the latest possible time. This gives the following two results:

**Lemma 2** *If a player concedes to a prelaunch she always does so at the latest possible concession time.*

Consider a firm that is faced with a prelaunch by its rival some time before the deadline. The firm's decision proceeds in two steps: first, the firm has to determine which concession time would maximize concession profits. This maximum concession payoff is then compared to the payoffs from staying in. Following Lemma 1, concession payoffs are maximized at $T$. So if concession takes place at all, it will be at the latest possible time – even if it occurs in response to a much earlier prelaunch.

**Lemma 3** *With increasing technological quality, only prelaunches that would trigger concession will be undertaken in equilibrium. Undertaking an unsuccessful prelaunch is dominated by staying in until $T$.*

The intution behind this Lemma is straightforward: prelaunch ends one's technological progress. This can only be worthwhile doing if there is a gain in return: concession on the part of the rival and resulting benefits (from a joint network) for both players in case of a successful prelaunch (i.e. one that triggers concession), and the improved competitive position arising from the rival's adaptation costs. These gains disappear if the prelaunch is unsuccessful. We can thus reduce the number of possible outcomes from three to two, since no unsuccessful prelaunches take place, eliminating possibility $(i)$. Following Lemma 2, we can also characterize outcome $(ii)$ – a prelaunch followed by concession: even if a prelaunch takes places much earlier, concession will be at the latest possible time. With these results, we now proceed to analyze the development stage equilibria.

### 4.2.1 Timing conditions

To analyze players' equilibrium strategies and the outcomes they yield, we calculate three times for each player (labeled "timing conditions"): $(i)$ the first time $\tau_i^{CC}$ when a prelaunch by the rival would trigger concession by a player (player $i$'s *concession condition* $(CC_i)$), $(ii)$ the first time $\tau_i^{PC}$ when a player would rather (successfully) prelaunch than simply stay in (player $i$'s *prelaunch condition* $(PC_i)$), and $(iii)$ the first time $\tau_i^{WPC}$ when a player would prefer to prelaunch rather than concede in response to a rival's prelaunch (player $i$'s *weak prelaunch condition* $(WPC_i)$). Overall, no player $i$ will want to prelaunch before times $\tau_i^{PC}$ and $\tau_i^{WPC}$, and no player will prelaunch before for the opponent $j$'s $\tau_j^{CC}$ is reached. As soon as all conditions are fulfilled, player $i$ would like to prelaunch.

**Concession Condition (CC)** Suppose the rival has just undertaken a prelaunch. Following Lemma 3, player $i$ faces the choice between conceding and staying in. Player $i$'s concession condition is defined by the earliest time $t$, denoted as $\tau_i^{CC}$, at which player $i$ would concede if there was a prelaunch at time $\tau_i^{CC}$. In other words, we compare $\pi_i^C(T)$ – the payoff from conceding at $T$ (see Lemma 2) – and $\pi_i^S(T)$ – the profits from staying in (and not conceding) until $T$. From $\pi_i^C(T) \geq \pi_i^S(T)$ we obtain:

$$\frac{2\widehat{\beta}\left(\overline{\alpha}_i - m_i\right) - \widehat{\gamma}\left(\alpha_j\left(\tau_i^{CC}\right)\right)}{4\widehat{\beta} - \widehat{\gamma}^2} \geq \frac{2\widehat{\beta}\overline{\alpha}_i - \gamma\left(\alpha_j\left(\tau_i^{CC}\right)\right)}{4\widehat{\beta}^2 - \gamma^2}, \text{ or}$$

$$t \geq \tau_i^{CC} = \alpha_j^{-1}\left(\frac{2\widehat{\beta}\left(\overline{\alpha}_i\delta\left(2\gamma-\delta\right)+\left(4\widehat{\beta}^2-\gamma^2\right)m_i\right)}{\delta\left(4\widehat{\beta}^2-\delta\gamma+\gamma^2\right)}\right) \tag{3}$$

**Prelaunch Condition (PC)** Suppose no prelaunch has taken place at time $t$, so that player $i$ can either prelaunch or stay in. Analogous to the CC, player $i$'s prelaunch condition is determined by the earliest time $t$, denoted as $\tau_i^{PC}$, at which player $i$ would prefer prelaunching to staying in until $T$, i.e. $\pi_i^P\left(\tau_i^{PC}\right) \geq \pi_i^S\left(T\right)$.[15] We find:

$$\frac{2\widehat{\beta}\alpha_i\left(\tau_i^{PC}\right)-\widehat{\gamma}\left(\overline{\alpha}_j-m_j\right)}{4\widehat{\beta}^2-\gamma'^2} \geq \frac{2\widehat{\beta}\overline{\alpha}_i-\gamma\left(\overline{\alpha}_j\right)}{4\widehat{\beta}^2-\gamma^2} \text{ or}$$

$$t \geq \tau_i^{PC} = \alpha_i^{-1}\left(\frac{\widehat{\gamma}\left(\overline{\alpha}_j-m_j\right)}{2\widehat{\beta}}+\frac{\left(4\widehat{\beta}^2-\widehat{\gamma}^2\right)}{2\widehat{\beta}}\frac{2\widehat{\beta}\overline{\alpha}_i-\gamma\overline{\alpha}_j}{4\widehat{\beta}^2-\gamma^2}\right) \tag{4}$$

**Weak Prelaunch Condition (WPC)** The $WPC$ captures a player's preference of prelaunching over conceding. For each time $t$, given that the rival has not yet undertaken a prelaunch, player 1 faces the *hypothetical* choice between prelaunching and conceding to a prelaunch which *could* happen at this time $t$. We define player $i$'s weak prelaunch condition by identifying the earliest time $t$, denoted as $\tau_i^{WPC}$, at which player $i$ would prefer prelaunching over conceding (at the latest possible time $T$) in response to a rival's prelaunch at this time $t$. Comparing $\pi_i^P\left(\tau_i^{WPC}\right)$ and $\pi_i^C\left(T\right)$, we obtain (a derivation can be found in the Appendix):

$$\frac{2\widehat{\beta}\alpha_i\left(\tau_i^{WPC}\right)-\widehat{\gamma}\left(\overline{\alpha}_j-m_j\right)}{4\widehat{\beta}^2-\widehat{\gamma}^2} \geq \frac{2\widehat{\beta}\left(\overline{\alpha}_i-m_i\right)-\widehat{\gamma}\left(\alpha_j\left(\tau_i^{WPC}\right)\right)}{4\widehat{\beta}^2-\widehat{\gamma}^2} \text{ or}$$

[15] Since the other player has not yet undertaken a prelaunch, concession is not an option. From Lemma 3 we know that only prelaunches that trigger concession will take place, so we need only care about the profit function for such prelaunches. Consequently, in deriving an equilibrium we look simultaneously at the players' prelaunch and concession conditions, since it may be that $\tau_i^{PC} < \tau_j^{CC}$, since both the prelaunch condition for $i$ and the concession condition for $j$ have to be fulfilled for $i$ to prelaunch successfully.

$$
\begin{aligned}
t &\geq \tau_i^{WPC} = f(t)^{-1}\left(\frac{2\beta'}{\gamma'}(\overline{\alpha}_i - m_i) + (\overline{\alpha}_j - m_j)\right), \quad (5)\\
\text{where } f(t) &= \alpha_j\left(\tau_i^{WPC}\right) + \frac{2\widehat{\beta}}{\widehat{\gamma}}\alpha_i\left(\tau_i^{WPC}\right)
\end{aligned}
$$

Depending on which of these conditions are met, we can identify a number of different equilibrium constellations ("game classes").

#### 4.2.2 Game-class dependent equilibria

Having ruled out unsuccessful prelaunches, we classify our equilibria by their outcomes.[16] Either no prelaunch takes place, there is a coordination failure, or there is a (smooth and successful) prelaunch. To see if all sensible time orderings $\left(\tau_i^{CC}, \tau_i^{PC}, \tau_i^{WPC}, \tau_j^{CC}, \tau_j^{PC}, \tau_j^{WPC}\right)$ can be mapped into one of these outcomes, we first rule out impossible orderings[17] and then consider all permutations of orderings. We find that all permutations can be mapped into "no action" games and prelaunch games with a prelaunch either considerably before the deadline or last-minute. We characterize the prelaunch games in more detail – not all games carry a preemption motive as one might expect, and we thus highlight the underlying tradeoffs in a situation with technological progress, network effect and adaptation costs.

**Class 1: "No action" games** For none of the players, the conditions necessary for a successful prelaunch (i.e. $t \geq \max\left[\tau_i^{PC}, \tau_j^{CC}\right]$) are ever fulfilled prior to the deadline. For "no action" games, the equilibrium strategies are never to prelaunch and to concede iff $\tau_i^{CC} \leq t \leq T$. "No action" equilibria

[16] Prior to analyzing our game classes, we convert our times $\tau_i^{CC}$ etc. to discrete time. Note that therefore two times may coincide in discrete time even if they would in continuous time. In fact, coincidence of times depends on the number of rounds $N$ and by increasing $N$ we can always recover the continuous-time case.

[17] For example, $\tau_i^{CC}, \tau_i^{WPC} < T$ and $\tau_i^{PC} > T$ is not possible since $t > \tau_i^{CC}$ implies $\pi_i^C(T) > \pi_i^S(T)$ and $t > \tau_i^{WPC}$ implies $\pi_i^P\left(\tau_i^{WPC}\right) > \pi_i^C(T)$, from which it follows that $\pi_i^P\left(\tau_i^{WPC}\right) > \pi_i^S(T)$ so that $\tau_i^{PC} < T$.

will emerge if the benefits from standardization are relatively low compared to the cost of conceding, i.e. for low values of $\delta$ and high values of $m_i$. We summarize this case in the following proposition.

**Proposition 3** *If no player could successfully prelaunch, both players will enter a standards battle in the market stage.*

**Class 2: Preemption games** If all three conditions for a successful prelaunch hold for both players (i.e. $\max\left\{\tau_i^{PC}, \tau_i^{WPC}, \tau_j^{CC}\right\}, \max\left\{\tau_j^{PC}, \tau_j^{WPC}, \tau_i^{CC}\right\} \leq t \leq T$), players will try and preempt each other: Both players prefer prelaunching to conceding (since $t \geq \tau_i^{PC}$), but they would concede if the other player did prelaunch before (since $t \geq \tau_i^{CC}$).

There are two scenarios we have to consider: ($i$) if the conditions are met for one player before they are met for the other, the identity of the prelauncher is well-defined. Suppose that $\max\left\{\tau_i^{PC}, \tau_i^{WPC}, \tau_j^{CC}\right\} < t < \max\left\{\tau_j^{PC}, \tau_j^{WPC}, \tau_i^{CC}\right\}$. The equilibrium strategy for the player $i$ is to prelaunch before $\max\left\{\tau_j^{PC}, \tau_j^{WPC}, \tau_i^{CC}\right\}$, but as late as possible following Lemma 1. If $j$ prelaunches at any $t$ with $t > \tau_i^{CC}$, concede at $T$. Otherwise, stay in until $T$. Player $j$'s equilibrium strategy is to prelaunch at $\max\left\{\tau_j^{PC}, \tau_j^{WPC}, \tau_i^{CC}\right\}$ if $i$ has not prelaunched. If $i$ has prelaunched at any $t$ with $t > \tau_j^{CC}$, concede at $T$. Otherwise, stay in until $T$. In equilibrium therefore, player $i$ will prelaunch just before all conditions are met for player $j$. ($ii$) if $\max\left\{\tau_i^{PC}, \tau_i^{WPC}, \tau_j^{CC}\right\} = \max\left\{\tau_j^{PC}, \tau_j^{WPC}, \tau_i^{CC}\right\}$, both players will want to prelaunch at the same time. We find a mixed-strategy equilibrium in which each player prelaunches with probability $p_i^t$ in each round $t$. Note that while $\pi_i^{P,N-1}$ refers to player $i$' s payoff from prelaunching in round $N-1$, $\pi_i^{C,N-1}$ refers to player $i$' s payoff from conceding in round $N$ in response to a prelaunch by the other player in round $N-1$. In the last round in which players could concede, i.e. in $N$, if one player has undertaken a prelaunch in a previous round, the other player will concede with probability 1. If no player has prelaunched prior to this round, both players stay in. In the last round in which players could prelaunch, i.e. in round $N-1$, player $i$ prelaunches with probability $p_i^{N-1} = \frac{\pi_j^{P,N-1} - \pi_j^S}{\frac{1}{2}\pi_j^{P,N-1} + \frac{1}{2}\pi_j^{C,N-1} - \pi_j^S}$ and stays in until the next and final round with probability $1 - p_i^{N-1}$ (where she either concedes if the other player has prelaunched in round $N-1$, or stays in otherwise). Player $j$'s probabilities are formed accordingly. In all previous rounds $t$ with $1 \leq t \leq N-2$, player $i$ prelaunches with probability $p_i^t = \frac{\pi_j^{P,t} - E(\pi_j^{t+1})}{\frac{1}{2}\pi_j^{P,t} + \frac{1}{2}\pi_j^{C,t} - E(\pi_j^{t+1})}$, where $E(\pi_j^{t+1}) = (1-p_i^{t+1})p_j^{t+1}\pi_j^{P,t+1} + p_i^{t+1}(1-p_j^{t+1})\pi_j^{C,t+1} + p_i^{t+1}p_j^{t+1}\left(\frac{\pi_j^{P,t} + \pi_j^{C,t}}{2}\right) + E(\pi_j^{t+2})$ is the expected payoff of player $j$ in round $t+1$ given that no player has undertaken a prelaunch before that. In addition to this mixed strategy equilibrium, there are also two subgame perfect pure strategy Nash equilibria, in which player $i$ always prelaunches at the first possible time given no prior prelaunch ($\tau_j^{CC}$), and concedes at the latest possible time otherwise. The other player concedes at the latest possible time in response to a prelaunch at $\tau_j^{CC}$, and prelaunches at the next possible time ($\tau_j^{CC} + 1$) if no prelaunch takes place at $\tau_j^{CC}$.

**Proposition 4** *If both players prefer conceding over a standards battle, but both prefer prelaunching over conceding, a preemption game follows. If one player can prelaunch before the other, this player will prelaunch just before the later prelauncher would.*

**Class 3: Late prelaunch games** If only one player's conditions for a successful prelaunch are met, this player can choose the optimal time to prelaunch without any threat of being preempted. The conditions for this scenario to obtain are $\max\left\{\tau_i^{PC}, \tau_i^{WPC}, \tau_j^{CC}\right\} \leq T \leq \max\left\{\tau_j^{PC}, \tau_j^{WPC}, \tau_i^{CC}\right\}$. The pure strategy equilibrium is that player $i$ will prelaunch at the latest possible prelaunch time, and player $j$ will concede at the latest possible concession time $T$. This class can also emerge if $\left[\tau_i^{PC}, \tau_j^{CC}\right] \leq T$, but no other conditions are met before $T$. In this case, player $i$ would prelaunch and player $j$ would follow, although player $i$ would prefer to concede herself (since $T < \tau_i^{WPC}$ implies that profits from concession to a prelaunch at $T-1$ are higher than profits from prelaunching at $T-1$). Nevertheless, since $PC_i$ states that prelaunching successfully yields higher profits than a standards battle in the market stage, a prelaunch will take place at the latest possible time, round $N-1$, where $N$ is the last round of the game.

**Proposition 5** *If only one player can successfully prelaunch, a prelaunch (by this player) will take place at the latest possible time before the deadline.*

**Class 4: War of attrition games** If both players prefer a successful prelaunch to a standards battle in the market at some point in the game (i.e. $\left[\tau_i^{PC}, \tau_i^{CC}, \tau_j^{PC}, \tau_j^{CC}\right] \leq T$), but both players would prefer conceding to prelaunching themselves (i.e. $\left[\tau_i^{WPC}, \tau_j^{WPC}\right] > T$), the game becomes a war of attrition. Similar to the preemption game (Class 2), both players will prelaunch with a certain probability (derived in the same way as the prelaunch probabilities in the preemption game, see the Appendix) starting from the time when a prelaunch would be successful and preferred over a standards battle. The main difference to the preemption game is that both players would rather develop until the end and let the other player prelaunch. This is likely to occur if the opportunity cost of prelaunching is relatively high – for example if the speed of technological development is high and the distance between rounds is large – and the cost of conceding is comparably low – because the loss in competitiveness ($m_i$) is small. Note that if only one player would prelaunch ($\left[\tau_i^{PC}, \tau_j^{CC}\right] \leq T < \tau_j^{PC}$), the prelaunching player would do so at the latest possible time, but the conceding player would still make higher profits. In addition to the mixed-strategy Nash equilibrium described above, we can also find two pure-strategy equilibria, in which player $i$ (or $j$) always prelaunches at the latest possible time (round

$N-1$) and the other player concedes immediately thereafter (round $N$). We summarize this class in the following proposition.

**Proposition 6** *If players prefer conceding and developing their technology as far as possible to prelaunching, a war of attrition will emerge, with a prelaunch taking place with increasing likelihood as the deadline approaches.*

To summarize, our model can generate a range of different behaviour and outcomes given the times the respective conditions for prelaunch and concessions are fulfilled. In particular, depending on the opportunity cost of prelaunching in terms of technological progress and the cost of conceding, we obtain either a preemption game where inefficiencies arise because technologies are prelaunched at a time when there is still significant technological progress to be made, or a war of attrition where both players attempt to delay their prelaunch, hoping that their rival will prelaunch in the meantime.[18] If players are significantly different in their respective payoffs, only one firm may be able to prelaunch successfully, in which case prelaunch and concession take place at the latest possible time (last-minute standardization). Finally, if none of the players would concede following a prelaunch, a standards battle in the market is inevitable. This typology can be used to classify specific cases into these regimes and make some inferences about the respective payoffs from prelaunching, conceding and waging a standards battle.

#### 4.2.3 The Development of the Compact Disc

**An introduction to the case.**[19] By the late 1970's, analog audio playback technologies had reached their technological limits. Recognizing analog's inherent limitations, nearly all major (and some minor) consumer electronics manufacturers were committed to **research and development** in

[18] This is similar to the penguin effect described by Besen and Farrell (1994).

[19] For a detailed overview see Gamharter and Kretschmer (2004), or Dai (1996).

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 involved in the development of an enhanced audio format. The players pursued different technological trajectories: Telefunken worked on a mechanical system ("Mini Disc"). JVC's system ("Audio High Density") was based on magnetic scanning. Philips developed an optical disc system based on an early prototype of the (digital) VideoDisc. Philips announced its first digital Compact Disc Audio System, a 110mm optical disc, in May 1978. Sony was also experimenting with a digital optical system. There was a strong belief in the industry from the outset that, given the large installed base of the two incumbent formats, vinyl and cassette tapes, joint efforts would be required in order to assert any new audio playback format. In 1983, 915 in 1000 UK households owned record and/or tape playback equipment (BPI Yearbook 1992). In particular therefore, getting the new technology adopted in the crucial popular music segment was a major source of concern (McGahan, 1993). In addition, the experience from recent standards battles on consumer electronics was still fresh. Sony, for instance, had just lost out with its Betamax technology to JVC's VHS system. Against this background, and in recognition of the complementarity of their particular (technological and market-based) strengths, Philips and Sony (P/S) finally teamed up in 1979 to jointly develop a technical standard for digital audio playback. They were to remain competitors in the product market, however. The two firms already had a history of cooperation, and by teaming up each eliminated a formidable competitor (McGahan, 1993; Besen and Farrell, 1994). Moreover, both had a presence in the music industry, whose support for the new technology was essential: without sufficient music available on CD, end consumers would never switch to CD. In June 1980, the exact specifications were published in the System Description Compact Disc Digital Audio, the so-called Redbook, to ensure that all software could be played on all pieces of hardware. The publication of the Redbook a year before the DAD conference effectively prelaunched the technology – its fundamental properties became fixed and common knowledge, and Philips and Sony started licensing the technology to other electronics manufacturers, which ensured a broad support base and compatibility for the technology. By late 1981 P/S had already granted licenses to 30 audio equipment manufacturers and 8 record replicators. 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.[20]

**Approval** of the new audio standard took place at the DAD Conference in April 1981. Announced in 1978 and organized by the Japanese Ministry of International Trade and Industry (MITI) with the explicit aim of defining a digital audio standard, the conference was attended by 29 consumer electronics manufacturers. At the conference, the technologies by P/S and JVC were approved, but only P/S ever commercialized their standard. The conference 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 P/S technology. Matushita's decision marked the real turning point since now the CD was supported by the three largest consumer electronic firms (Dai, 1996). When it came to **commercialization**, there was a strong impetus among competing CD manufacturers to promote not only their own brand but the CD in general to establish it as the new industry standard. Despite initial scarcity in software, adoption by final consumers was fast and widespread. Increased sound quality and user-friendliness won over the pop-

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

ular segment in particular much faster than expected (McGahan, 1993).[21] In the following section, we will relate the outcomes of the case to a set of parameter values in our model that are consistent with it.

**Connecting model and empirical data** Our model gives some insight into the motives of the players in the CD game. First, we note that the outcome of the CD development stage was that P/S prelaunched their technology well ahead of the DAD conference and JVC/Masushita conceded briefly prior to the conference. We further know only two of the solutions presented at the DAD conference (P/S and JVC/Matsushita) were actually approved, which suggests that only these two technologies passed a certain minimum quality threshold set by conference participants. As regards the relationship of their qualities, we argue that JVC/Matsushita's solution was not vastly superior (and probably inferior) to the Redbook standard. If JVC/Matsushita's solution had indeed been superior, the difference in qualities can not have been large enough to offset the advantage from a common standard and the competitive disadvantage through adaptation costs (including licensing fees paid to P/S). From the outcome we infer that the CD launch was either a preemption game or a war of attrition. Both players, the P/S alliance and JVC/Masushita, started their *focused* development effort towards the new audio playback technology roughly at the same time, at some point during the mid- to late-1970's. To be more precise, we consider 1978, when the conference was scheduled for 1981, as the starting point of these efforts and, hence, of our development stage. Given that at this time, none of the technological trajectories pursued was clearly superior, it seems plausible that they started out at similar initial levels. Based on these two propositions, we infer that the speed of technological progress probably

[21] 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.

differed between the two players and that P/S was the "stronger" player experiencing faster technological progress. In that case, it seems rather unlikely that the CD case falls into either the symmetric preemption game class or the symmetric war-of-attrition. As a result, we suggest that the CD case is best described by our "asymmetric" preemption game class and the corresponding equilibrium: While it is clear that there will be a successful prelaunch, and it will be the stronger player who undertakes it, the threat of the weaker player undertaking a successful prelaunch forces the stronger player to launch her technology prior to the preferred prelaunch time, just before the conference. Instead, the prelaunch will take place just before the first time the weaker player could successfully undertake a prelaunch.

**An example with linear technological progress** We now use a specific technological progress function and fix parameter values to illustrate some of our outcomes. Using the expressions we derived for $\tau_i^{PC}$, $\tau_i^{WPC}$ and $\tau_i^{CC}$, we analyze players' timing decisions. While we are relatively confident that standard-setting in the context of the CD was an asymmetric preemption game by knowing the final outcome and the identity of the prelauncher, we cannot ultimately identify whether the (prelaunching) P/S alliance or (the conceding) JVC/Matsushita was the stronger player with respect to the quality of their technology as we will show with a numerical example.

We choose both player's technological progress functions $\alpha_i(t)$ to be linear in time and to have the same initial value: $\alpha_i(t) = a_i t + x$. Denote JVC/Matsushita as firm 1 and P/S as firm 2. Further, we use the values $\gamma = 1$ for substitutability, $\beta = \frac{3}{2}$ for own brand loyalty, $\delta = \frac{1}{2}$ for the strength of network effects and $m_1 = m_2 = \frac{1}{4}$ for adaptation costs. These values satisfy our assumptions $(i) - (iii)$. We can then calculate the times $\tau_i^{PC}, \tau_i^{WPC}, \tau_i^{CC}$ and subsequently convert them to discrete times to derive equilibrium behaviour. We find the following expressions in terms of $a_i, a_j$

and $x$ (common to both players):

| | | |
|---|---|---|
| $\tau_i^{CC} = \frac{2+2a_i-x}{3a_j}$ | $\tau_i^{PC} = \frac{5a_i-\frac{3}{2}a_j-\frac{1}{2}x-\frac{1}{4}}{4a_i}$ | $\tau_i^{WPC} = 1 - \frac{5}{16a_i+4a_j}$ |

We now specify values for the initial technological quality $x = 2$ and their rate of increase, $a_1 = \frac{3}{2}$, $a_2 = 2$ This means that both players initially had the same level of know-how, but P/S was developing faster. We model the process using 1000 rounds (corresponding to $t = 0$ to $t = 1$ in continuous time) and obtain the values in panel 2a).

| | Panel 2a) | | Panel 2b) | | Panel 2c) | | Panel 2d) | |
|---|---|---|---|---|---|---|---|---|
| Player | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| $\tau_i^{CC}$ | 500 | 889 | 600 | 741 | 400 | 1111 | 667 | 1111 |
| $\tau_i^{PC}$ | 542 | 812 | 625 | 725 | 417 | 900 | 625 | 875 |
| $\tau_i^{WPC}$ | 844 | 868 | 837 | 847 | 853 | 891 | 844 | 868 |
| $x$ | 2 | | 2 | | 2 | | 1 | |
| $a_1$ | $\frac{3}{2}$ | | $\frac{3}{2}$ | | $\frac{3}{2}$ | | $\frac{3}{2}$ | |
| $a_2$ | $\frac{4}{2}$ | | $\frac{5}{3}$ | | $\frac{5}{2}$ | | $\frac{4}{2}$ | |

We give an interpretation of Panel 2a). For player 2, prelaunch is an option as soon as $t \geq \max\left\{\tau_2^{PC}, \tau_2^{WPC}, \tau_1^{CC}\right\}$. This is the case from round 868. Conversely for player 1, this is given from round 889 onwards. Player 2 would then prelaunch starting from round 868, but, following Lemma 1, will wait until round 888 to maximize technological progress under the constraint of having to preempt player 1's prelaunch in round 889. Interestingly, player 2 is limited by its own willingness to concede in round 889 – the later player 2's CC is met, the more technological progress can be achieved. In Panel 2b), we bring the technological strength of the two players closer together. This changes the outcome of the game since now player 1 will prelaunch in round 846, just before player 2 would prelaunch. Interestingly, the binding constraint here is whether a player prefers prelaunching over conceding. The stronger player (2) has more to gain from delaying adoption and further improving its technology so that conceding (and getting the full network effects) is preferred over curtailing technological development. In Panel 2c), we assume a greater technological difference between the players. In this case, player 2 would never concede in the relevant time horizon (since $\tau_2^{CC} > T$), so that the only possible prelauncher is player 2, who will prelaunch at the latest possible time, round 999. A similar situation arises if the overall level of technological quality decreases ($x = 2 \longrightarrow 1$) in Panel 2d). In this case, player 2 would never concede, and would prelaunch in round 999.

These numerical examples illustrate a number of interesting points: first, the stronger player does not always prelaunch, as we can see from Panel 2b). Although profits from prelaunching are higher for the stronger player, the benefits from conceding later on may be higher still. Secondly, if technological quality is sufficiently low at the end of the game $T$ (Panel 2d)) or the difference between the two technologies sufficiently high (Panel 2c)), the stronger player may never be willing to concede, which ensures that the stronger player gets to prelaunch without the threat of preemption. Conversely, if the stronger player would concede to a prelaunch relatively early, this limits the degree to which he can delay prelaunching – the preemption threat by the other player gets stronger the smaller the difference in qualities, and in the limit we obtain the rent equalization result from Fudenberg and Tirole (1985), where preemption motives between two symmetric players trigger a prelaunch at the earliest feasible time.

## 5 Discussion

Our results and the information on the case suggest that the development of the CD was an **asymmetric preemption game** where the stronger player got to prelaunch successfully. The threat of preemption by a sufficiently strong rival would have created an inefficiency in terms of foregone technological progress. Applying our model to the motivating case suggests that

P/S' design was indeed the more efficient technology and that JVC conceded because it was not worth introducing an incompatible design into the market, but that there was some concern that P/S might be preempted by a JVC/Matsushita-led alliance.

Two further details are noteworthy: Since higher adaptation costs make it less attractive to concede and thereby reduce the likelihood of agreeing on a common standard, we interpret the fact that the P/S alliance not only launched a prototype but added extensive documentation in the Redbook as having had the positive (side) effect of **reducing adaptation costs for potential conceders**, chiefly JVC/Matsushita. Top management in the P/S alliance explicitly encouraged their R&D divisions to keep the technology as simple as possible given a minimum quality threshold (Gamharter and Kretschmer, 2004). A second interesting issue concerns the time horizon $T$. An increase (decrease) in the relevant time horizon $T$ implies that both player's conditions ($CC$, $SPC$, $WPC$) are satisfied later (earlier). This implies that getting the timing of the deadline (in the CD case, the DAD conference) "right" might contribute a good deal to the success of the standardization process. Too early a time might sacrifice quality for speed and thereby endanger the new standards' acceptance by the end consumer. Too late a time might delay the agreement on a joint solution and prolong the phase of uncertainty, encouraging leapfrogging behavior by final consumers (Shy, 1996).

It is interesting to link the results of our study to a **network relations perspective** (Brass, Galaskiewicz, Greve and Tsai, 2004). Our model illustrates the competitive dynamics of alliances by highlighting the importance of immediate competitive effects as well as more indirect effects in adjacent markets such as complementary goods producers, e.g. record manufacturers. Their initial resistance towards the new audio playback technology made it even more attractive to set a standard early on, as a standards battle with the consequent splintering of software providers would have lowered the attractiveness of any new digital audio technology. Also, the two basic options (pre-market standardization and standards battle) analyzed in our model are comparable to the alternatives discussed in a co-opetition perspective on alliance network evolution (Gimeno, 2004), namely (1) connecting to a rival's network of alliances, and (2) developing countervailing alliances. In the case of the CD, the actors chose the first option, whereas the current battle between Blu-ray and HD-DVD is an example of the second (BusinessWeek, 2005/10/6). Two competing networks (one featuring Toshiba, NEC, Intel and IBM, the other including Sony, Philips, Panasonic and Pioneer) emerged, each containing firms at various stages of the value chain. The networks then engaged in a standards battle in the final consumer market. This situation, apart from generating incompatibility losses, creates scope for third parties outside the two alliance blocks, such as Samsung, to step into the standardization gap by offering hardware compatible with both networks (Smith, 2005).

## 6 Conclusion

To summarize, we believe that our simple model illustrates a number of interesting phenomena, especially the tradeoff between preemption motives and technological development and the likely outcomes in terms of preemptive standardization, last-minute agreements, and all-out standards battles in the marketplace. The strategies specified in our model capture a wide range of activities in the development stage of a new technology. Prelaunching a technology covers 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 CD), or preannouncing technical features are all versions of the prelaunch strategy in our model. Likewise, concession by rival technologies could be the public endorsement of the prelaunched technology, negotiations to ensure compatibility or even redirecting research efforts to conform to the industry standard. Overall, from the interplay of the player' relative strengths, the strength of network effects, the degree of substitutability and each product's own brand loyalty, a wide range of outcomes emerges, depending on the particular parameter values. We group the outcomes into four distinct and fundamentally different classes, for instance preemption games and war-of-attrition games. In addition, we show how slight variations in parameter values can shift a game into a different class, for instance from one where the stronger player prelaunches without threat of preemption, to one where she gets hurried along into a "prematurely" early prelaunch.

We note several limitations to our model. First, we restrict our analysis to two direct rivals. It would be interesting to consider the influence of additional players, either direct rivals or complementors such as software suppliers or hardware manufacturers without own R&D. In fact, recent research on interfirm networks emphasizes the importance of triadic structures and highlights possible differences between triadic and dyadic structures in terms of formation patterns (Madhavan, Gnyawali and He, 2004). Second, our choice to ignore development costs and to set an exogeneous end point of the game was made for analytical convenience, although this enabled us to focus on explaining the outcome of our motivating case. A formulation including development costs and no exogenous deadline could help uncover some interesting dynamics, although the general tradeoff of precommitment versus further technological development would remain the same. Third, technological progress is deterministic in our model. A specification with stochastic technological improvement might generate interesting results on speculative and/or unsuccessful prelaunches. Finally, assuming that players know each other's type restricts the applicability of our model. An analysis of this setup but with incomplete information would be interesting, and is the subject of ongoing work.

# 7 Appendix

**Proof of Lemma 1:** We express player 1' s profit function for compatibility as well as incompatibility in the most general form ($\pi_1(\widehat{\alpha}_1)$) and find that it is increasing in $\widehat{\alpha}_1$. For $\pi_1^*(\widehat{\alpha}_1) = \widehat{\beta}\left(\frac{2\widehat{\beta}\widehat{\alpha}_1 - \widehat{\gamma}\widehat{\alpha}_2}{4\widehat{\beta}^2 - \widehat{\gamma}^2}\right)^2$, we have the first derivative with respect to $\widehat{\alpha}_1$ as $\frac{\partial \pi_1(\widehat{\alpha}_1)}{\partial \widehat{\alpha}_1} = \frac{4\widehat{\beta}^2}{(4\widehat{\beta}^2 - \widehat{\gamma}^2)^2}\left(2\widehat{\beta}\widehat{\alpha}_1 - \widehat{\gamma}\widehat{\alpha}_2\right) \geq 0$ since $2\widehat{\beta}\widehat{\alpha}_1 - \widehat{\gamma}\widehat{\alpha}_2 \geq 0$ by assumption $(iii)$ and $\frac{4\widehat{\beta}^2}{(4\widehat{\beta}^2 - \widehat{\gamma}^2)^2} > 0$.

**Proof of Proposition 1:** Based on the equilibrium profit functions for the market stage we take the first derivative of player 1' s profit function $\pi_1$ with respect to $\gamma$ and $\widehat{\gamma}$, respectively. That is,

$$\frac{\partial \pi_1(\widehat{\gamma})}{\partial \widehat{\gamma}} = \frac{2\widehat{\beta}(2\widehat{\beta}\widehat{\alpha}_1 - \widehat{\gamma}\widehat{\alpha}_2)\left(4\widehat{\beta}^2 - \widehat{\gamma}^2\right)\left(2\widehat{\gamma}\left(2\widehat{\beta}\widehat{\alpha}_1 - \widehat{\gamma}\widehat{\alpha}_2\right) - \widehat{\alpha}_2\left(4\widehat{\beta}^2 - \widehat{\gamma}^2\right)\right)}{\left(4\widehat{\beta}^2 - \widehat{\gamma}^2\right)^4}$$

This is negative for $\frac{\widehat{\alpha}_1}{\widehat{\alpha}_2} < \frac{4\widehat{\beta}^2 + \widehat{\gamma}^2}{4\widehat{\beta}\widehat{\gamma}}$, positive $\frac{\widehat{\alpha}_1}{\widehat{\alpha}_2} > \frac{4\widehat{\beta}^2 + \widehat{\gamma}^2}{4\widehat{\beta}\widehat{\gamma}}$, and constant with respect to $\widehat{\gamma}$ for $\frac{\widehat{\alpha}_1}{\widehat{\alpha}_2} = \frac{4\widehat{\beta}^2 + \widehat{\gamma}^2}{4\widehat{\beta}\widehat{\gamma}}$. By the chain rule, the same holds if we take the derivative with respect to $\gamma$.

**Proof of Proposition 2:** Based on the equilibrium profit functions for the market stage we distinguish between the cases of incompatibility and compatibility. The first derivative of player 1' s profit function $\pi_1$ with respect to the network effect $\delta$ is given by:

(a) for incompatibility and type-asymmetry:

$$\frac{\partial \pi_1^{Incomp}(\delta)}{\partial \delta} = \frac{-8\alpha_1\alpha_2\widehat{\beta}\gamma\left(4\widehat{\beta}^2 - \gamma^2\right) + \alpha_2^2\gamma^2(12\widehat{\beta}^2 + \gamma^2) + 4\alpha_1^2\widehat{\beta}^2(4\widehat{\beta}^2 + 3\gamma^2)}{\left(4\widehat{\beta}^2 - \gamma^2\right)^3}$$

This is positive if the following conditions hold (i) $\gamma < 2\widehat{\beta}$, and (ii) $\frac{\gamma^3 + 12\gamma\widehat{\beta}^2}{6\gamma^2\widehat{\beta} + 8\widehat{\beta}^3} < \frac{\alpha_i}{\alpha_j}$ (where $\frac{\alpha_i}{\alpha_j} < \frac{2\widehat{\beta}}{\gamma}$ and also $\frac{\alpha_j}{\alpha_i} < \frac{2\widehat{\beta}}{\gamma}$, according to model assumption $(iii)$). We now look for the maximum of $\frac{\gamma^3 + 12\gamma\widehat{\beta}^2}{6\gamma^2\widehat{\beta} + 8\widehat{\beta}^3}$. Its identification allows for finding an absolute threshold for the ratio $\frac{\alpha_1}{\alpha_2}$ beyond which the condition always holds, irrespective of the values of any other parameters than the players' qualities (within the boundaries of our model assumptions). From (i), we have $\frac{1}{2} < \frac{\widehat{\beta}}{\gamma}$. From (ii), we have $\frac{\alpha_1}{\alpha_2} > \frac{1+12(\frac{\widehat{\beta}}{\gamma})^2}{6\frac{\widehat{\beta}}{\gamma}+8(\frac{\widehat{\beta}}{\gamma})^3}$ which is strictly decreasing in $(\frac{\widehat{\beta}}{\gamma})$. If a function is strictly decreasing, then it has its maximum at the smallest (allowed) parameter value. Therefore, we know that the inequality will hold for any values of $\widehat{\beta}$ and $\gamma$ if it holds for the smallest allowed ratio of $\frac{\widehat{\beta}}{\gamma}$ (because this is where the maximum of the function $\frac{\widehat{\beta}}{\gamma}$ lies), which is $\frac{1}{2}$. Plugging $\frac{\widehat{\beta}}{\gamma} = \frac{1}{2}$ into the inequality resulting from (ii) yields 1 as threshold. That means if $\frac{\alpha_1}{\alpha_2} > 1$, then (the stronger) player 1' s profits $\pi_1$ are always increasing in $\delta$, while (the weaker) player 2' s profits $\pi_2$ are decreasing in $\delta$ because the reciprocal value does not satisfy the condition $\frac{\alpha_2}{\alpha_1} > 1$.

(b) for incompatibility and type-symmetry, the first derivative of each player' s profit function $\pi_i$ with respect to the network effect $\delta$ is positive.

(c) for compatibility where the conceding player is player 1 with $\widehat{\alpha}_1 = \alpha_1 - m_1$:

$$\frac{\partial \pi_1^{Comp}(\delta)}{\partial \delta} =$$

$$= \frac{(2\widehat{\alpha}_1(\beta-\delta) - \alpha_2(\gamma-\delta))(2\widehat{\alpha}_1(\beta-\delta)(4\beta^2+3\delta^2-2\delta\gamma+3\gamma^2-4\beta(\delta+\gamma))}{(4(\beta-\delta)^2-(\gamma-\delta)^2)^3} + \\ + \frac{\alpha_2(8\beta^3+3\delta^3-11\delta^2\gamma+\delta\gamma^2-\gamma^3-12\beta^2(\delta+\gamma)+2\beta(\delta^2+10\delta\gamma+\gamma^2)))}{(4(\beta-\delta)^2-(\gamma-\delta)^2)^3}$$

This is positive given the above general assumptions of the model are satisfied and additionally $\alpha_j > 0$. And analoguously, for compatibility where the prelaunching player 1 has $m_1 = 0$ and the conceding player 2 has $\widehat{\alpha}_2 = \alpha_2 - m_2$ we have the same reasoning only that $m_2 > m_1$.

**Proof of Lemma 2:** Player $i$'s concession profits $\pi_i^C$ are given by $\pi_i^{C*}(t) = \widehat{\beta}\left(\frac{2\widehat{\beta}\widehat{\alpha}_i(t)-\widehat{\gamma}\alpha_j(\tau)}{4\widehat{\beta}^2-\widehat{\gamma}^2}\right)^2$, where $\tau$ is the time at which the other player's prelaunch took place. The derivative with respect to time $t$ is given by $\frac{d}{dt}\pi_i^*(t) = 4\widehat{\beta}^2\left(\frac{2\widehat{\beta}\alpha_i'(t)-\gamma'\alpha_j(\tau)}{4\widehat{\beta}^2-\gamma'^2}\right)\frac{d}{dt}\widehat{\alpha}_i(t)$,which is positive, since we have $\frac{d}{dt}\widehat{\alpha}_i(t) > 0$

(see assumption ($i$) above) and $t > \tau$ and the production quantity constraint $\frac{\widehat{\alpha}_i}{\widehat{\alpha}_j} \geq \frac{\gamma}{2\widehat{\beta}}$.At any given time $t$ it is therefore beneficial for the conceder to wait a bit longer.

**Proof of Lemma 3:** If firm 1 undertakes a prelaunch at $t$ before the deadline $T$ which does not trigger concession by the other player 2 then we derive for a payoff comparison with the minimum payoff that player 1 can guarantee herself by staying in until $T$: $\alpha_{1,t} \leq \alpha_{1,T} \Rightarrow 2\widehat{\beta}\alpha_{1,t} - \gamma\alpha_{2,T} \leq 2\widehat{\beta}\alpha_{1,T} - \gamma\alpha_{2,T} \Rightarrow \pi_{1,P^{un}t} = \widehat{\beta}\left(\frac{\left(2\widehat{\beta}\alpha_{1,t}-\gamma\alpha_{2,T}\right)^2}{\left(2\widehat{\beta}-\gamma\right)^2\left(2\widehat{\beta}+\gamma\right)^2}\right) \leq \widehat{\beta}\left(\frac{\left(2\widehat{\beta}\alpha_{1,T}-\gamma\alpha_{2,T}\right)^2}{\left(2\widehat{\beta}-\gamma\right)^2\left(2\widehat{\beta}+\gamma\right)^2}\right) =$

$\pi_{1,S}$

**Derivation of Weak Prelaunch Condition (WPC)** Argued from player 1's perspective: This is the case iff $2\widehat{\beta}\alpha_1(t) - \widehat{\gamma}\widehat{\alpha}_2(T) > 2\widehat{\beta}\widehat{\alpha}_1(T) - \widehat{\gamma}\alpha_2(t)$ and this is the case iff $\alpha_1(T) - \alpha_1(t) < \frac{\widehat{\gamma}}{2\widehat{\beta}}(\alpha_2(t) - \alpha_2(T) + m) + m$. The left hand side of this inequality is greater than zero but tends to zero as $t \to T$. The right hand side of the equation is not necessarily greater than zero, but increases in $t$ and approaches $m(1 + \frac{\widehat{\gamma}}{2\widehat{\beta}})$. For nonzero $m$, this is greater than zero and hence the left hand side must at some $t$ (smaller than $T$) be smaller which proves the claim. We can also determine the time at which this is the case, by solving for $t$-dependent quantities: $\frac{2\widehat{\beta}}{\widehat{\gamma}}(\alpha_1(T) - m) - m + \alpha_2(T) < \alpha_2(t) + \frac{2\widehat{\beta}}{\widehat{\gamma}}\alpha_1(t)$ so that the condition is fulfilled from $\underline{t}_{P>C,1} = t_{\min} = f^{-1}(\frac{2\widehat{\beta}}{\widehat{\gamma}}(\alpha_1(T) - m) - m + \alpha_2(T))$ onwards, where $f^{-1}$ is the inverse function of $f(t) = \alpha_2(t) + \frac{2\widehat{\beta}}{\widehat{\gamma}}\alpha_1(t)$ . (Note: this does not necessarily imply that the player' s concession condition and/or prelaunch condition hold.)

**Proof of Proposition 3:** By definition, prelaunch payoffs are always dominated by stay in for both players, and so both players would fare worse if they would deviate from the "always stay in" strategy. Hence the players' strategies are equilibrium strategies.

**Proof of Proposition 4:** Similarly to class one, the strategy is, by construction, an equilibrium strategy. For the symmetric case, we have to show that the probabilities stated in the text actually lead to an equilibrium. The probability for player $i$ to prelaunch is $p_i$. The expected payoff $E_1$ for player one in round $N-1$ is. $E_1^{N-1} = p_1 p_2 \left( \frac{\pi_{c,1}^{N-1} + \pi_{P,1}^{N-1}}{2} \right) + (1-p_1)p_2\pi_{c,1}^{N-1} + (1-p_2)p_1\pi_{p,1}^{N-1} + (1-p_1)(1-p_2)\pi_{s,1}$. We find an equilibrium if no player can improve his expected payoff by changing his prelaunch probability $p$.This is the case if $\frac{dE_1}{dp_1} = p_2 \left( \frac{\pi_{c,1}^{N-1} + \pi_{P,1}^{N-1}}{2} \right) - p_2\pi_c^1 + (1-p_2)\pi_p^1 - (1-p_2)\pi_s^1 = 0$. Solving for $p_2$ produces the formula for round round $N-1$ as given in the text.For any preceding round there is a slight difference: for the case that none of the players prelaunch we cannot assume that the payoff will be $\pi_s$. Instead, we have to insert the expected payoff for the remaining rounds. Hence the players' strategies are equilibrium strategies.

**Proof of Proposition 5:** By construction, prelaunching is always dominated by player $j$, by both concession and stay in. Hence player $j$ would fare worse if he deviated from the strategy. For player $i$, prelaunch before all three conditions are satisfied, is by definition dominated by not prelaunching. Prelaunching before the last possible moment is always dominated by prelaunching in the last possible moment (Lemma 1). Hence the players' strategies are equilibrium strategies.

**Proof of Proposition 6:** See class 2 analoguously. For the mixed-strategy equilibrium, while the derivation of probabilities is analogous to class 2, the different outcomes result from the differences in payoffs from conceding or prelaunching.

**Proof of Proposition 7:** By construction, player $j$ would fare worse if s/he was to prelaunch at any time. Player $i$ would fare better if s/he could concede, but since player $j$ would fare worse if s/he was to prelaunch, player $i$ does not expect this to happen. Stay in, however, is dominated by prelaunch, so player $i$ will prelaunch. According to Lemma 1, this will happen at the latest possible time. Hence the players' strategies are equilibrium strategies.

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