To Hunt or to Scavenge: Competitive Advantage and Competitive Strategy in Platform Industries*

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ABSTRACT

As in any industry, firms in platform industries choose competitive strategies to achieve competitive advantage. However, in platform industries the standards definition of competitive advantage that dichotomizes firms into those with or without competitive advantage is insufficient. We use a dynamic model to characterize types of competitive (dis-) advantage in platform industries and demonstrate that in such industries, market structures can be mapped into these types of competitive advantage. We simulate the model to find the optimal competitive strategy for each type of competitive advantage. Mapping these results back into market structure, we derive guidelines for determining a firm's optimal competitive strategy conditional on the firm's competitive position within the market, namely its competitive position within its platform and the position of its platform within the industry.

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1. INTRODUCTION

Platform industries such as computer systems, DVDs, smart-phones and videogames have become ubiquitous in recent decades. In platform industries, the value of a component, such as software, depends crucially on the market share of the compatible hardware platform. This has been extensively discussed in the literature for the classic example of computer hardware and software (e.g., Church and Gandal, 1992). Identifying competitive advantage in platform industries is far from obvious – for example, does a leading firm on a lagging platform have competitive advantage? Choosing competitive strategy in these markets also remains difficult. Specifically, what is a firm's optimal investment strategy to achieve or foster competitive advantage? As it turns out, in platform industries, the simple "invest more!" strategy is more often false than true.

Bresnahan and Greenstein (1999) define a platform as a "[…] bundle of standardized components around which buyers and sellers coordinate their efforts."[1] Platform markets are often referred to as hardware-software markets and typically exhibit indirect network effects: the more attractive a software, the more attractive its compatible hardware. This, in turn, draws more firms to develop software for this hardware.[2] For example, the large selection of apps for the iPhone is frequently cited as an important driver of the iPhone's success. Indirect network effects thus create synergies between competitors on the same platform: additional competitors on the same platform increase the size of the platform and thus grow the pie (Brandenburger and Nalebuff, 1997), which then can be split between all competitors. The strategic role of investment in determining how this pie will be split and its effect on the firm's competitive advantage in the market, however, has not been analyzed.

[1] Bresnahan's and Greenstein's definition reveals that the division between hardware and software from an analytical perspective is not the defining feature of platforms - it is the interoperability relationship between standardized components. We will use the words "platform" and "hardware" interchangeably in this paper.

[2] This is in contrast to direct network effects, where the number of the products already sold or used in the market, the so-called installed base, directly influences consumers' choice (see e.g., Katz and Shapiro, 1985; Farrell and Saloner, 1985).

In order to study this question one must first define competitive advantage in platform industries. There are two types of leadership in platform industries – across-platform and within-platform. Specifically, a firm may be the leader on the leading platform, a follower on the leading platform, or the leader on the lagging platform. Clearly, the leading firm on the leading platform has a competitive advantage. This is less clear for the leading firm on the lagging platform and a lagging firm on the leading platform. That is, competitive advantage and disadvantage as well as leadership in platform industries are no longer binary. In analogy to the international trade literature, we suggest differentiating between overall competitive advantage and relative competitive advantage.[3] Specifically, we say that the leader on the leading platform has *overall advantage*; the leading firm on the lagging platform has *relative advantage* in comparison to the lagging firm on its platform, while the lagging firm on the leading platform may have relative advantage to the firms on the lagging platform.[4] Mapping this terminology back into market-structure, we distinguish between *competitive position* — a firm's position within its platform—and *platform position*, i.e., whether the firm's platform is leading or lagging relative to the competing platform. We call the combination of competitive and platform position a firm's *market position*.

Lippman and Rumelt (1982) and Adner and Zemsky (2006) are two examples in the literature for studies that develop stylized models to link firms' competitive advantage and competitive strategy. We follow their approach to identify factors that shape software[5] firms' competitive strategy in platform markets. In our model, firms can affect their competitive position within a platform and simultaneously their platform's position within the industry through investment in quality upgrades. Thus, firms' investment strategies constitute their competitive strategies. In this model software firms invest based on

[3] The international trade literature uses the terms absolute and comparative advantage for concepts tied to productivity at the country-industry level. Competitive advantage in platform industries is tied to the firm-platform level. We chose different terms than in the international trade literature to avoid confusion.

[4] Whether the lagging firm on the leading platform has or does not have relative advantage can be viewed both conceptually through the leadership lens as well as from a measurement perspective. While from the former it has relative advantage, from a measurement perspective, e.g. based on profits, it may not have.

[5] We will use the term "software" throughout this paper to denote the shorter lived components within a platform, but the term can represent any type of component within a platform.

expected future profits, taking competitive responses from other firms into account. These responses come from competitors offering software for the same or for a competing platform. Furthermore, firms' investment strategies are affected by consumers' software and platform choices, which in turn are guided by expectations about firms' investment strategies. These responses create highly complex interactions that make it impossible to solve for the model's equilibrium investment strategies analytically. Following Ericson and Pakes (1995), we use numerical analysis to derive conditions for optimal investment behavior in our model. While the model structure identifies categories of market leadership that relate to competitive advantage, the numerical analysis reveals main drivers of optimal investment behavior and delivers four distinct optimal strategies conditional on firms' market position. The two joint together proffer easy-to-follow guidance for the choice of competitive strategy in platform industries and deliver three empirically testable hypotheses.[6]

We examine the relationship between the *type* of competitive advantage a firm enjoys—relative or overall—and competitive strategy. In particular, given a firm's market position, should the firm respond aggressively or complacently to a successful quality upgrade by a competitor? We show that a firm's position in the market—its type and degree of competitive advantage—determines its optimal strategic response to *changes* in its market position. . Combining types of optimal strategic responses delivers four distinct competitive strategies. It is the connection between a firm's market position and these four competitive strategies that provide guidance in platform industries.

Firms' choice of strategy depends on the interplay between its competitive and platform position. Within a platform, a firm can lead, lag, or its leadership may be contested, and analogously for platforms. Contested platform leadership triggers the most aggressive strategies. In contrast, contested leadership within platform sparks less aggressive strategies, with contested leadership on the leading platform prompting the least aggressive strategies. Finally, by how much a firm leads within its platform – the degree of its relative advantage influences its prospect of success: Strong competitors on its platform

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[6] In this paper, we derive the drivers of competitive strategy and formulate the hypotheses based on our numerical analysis. We leave empirical tests for future work.

help ensure or improve the platform's position, while weak competitors on its platform make it hard to obtain or defend platform leadership.

This paper contributes to four lines of literature. First, by defining the types of competitive advantage in platform industries and identifying its drivers, we add to the literature on the analysis of competitive advantage as pioneered by Porter (1980, 1985) and revisited by Adner and Zemsky (2006). We replicate in our model how competitive strategy leads to competitive advantage in platform industries, but also identify how achieved competitive advantage shapes competitive strategy. Second, we contribute to the platform literature in economics. Church and Gandal (1992) suggest exit as the only viable strategy for companies on a lagging platform. We show that this does not need to be the case. In particular, we provide guidance with respect to conditions under which winding down investment in preparation for an ordered exit is optimal, and when aggressive investment to improve competitive advantage is best. Third, the platform leadership literature in business (e.g., Gawer and Cusumano, 2002) only identifies "winning" strategies for leaders, but not for followers. We close this gap. Fourth, we also document the dynamics of innovation in the context of platforms and thus contribute to the literature on innovation. Our within platform results resemble those of the existing innovation literature (e.g., Grossman and Shapiro 1987) only as long as a platform lags behind. Our within platform results when a platform leads and our across platform results exhibit previously undocumented dynamics.

The paper is organized as follows: we first present our model, discuss market structure and document competitive advantage in its context. We derive competitive strategies for different market structures and map those strategies into competitive advantage space to determine four types of competitive strategy. Finally, we discuss the implications of our results and conclude.

2. THE MODEL

We present our model in two steps. First we state the key concepts and corresponding assumptions that motivated the model specification. Then, we present a formal version of the model, which can be skipped without loss of comprehension for readers not interested in the technical details.

2.1 Key Concepts and Model Assumptions

Hardware and software are the two main components sold in platform markets. Software requires compatible hardware and consumers upgrade software more frequently than hardware. When consumers decide which hardware to buy, they take expected future quality of hardware and software into account. Software firms are the more likely to upgrade their product the larger the potential market they can sell to. In other words, their incentives to invest in quality upgrades depend on the current as well as expected future number of consumers who own the compatible hardware.

We reflect this dependence on future opportunities with an infinite horizon discrete choice model where consumers live forever and derive utility from the consumption of software. Consumers' willingness-to-pay increases in the quality of the currently available software and decreases in its price. Hardware technology is needed for the operation of software, but provides no stand-alone benefits. Consumers choose the hardware for which software promises the best expected quality-price relationship. They can only choose from two incompatible hardware platforms; on each platform there are also no more than two software firms. Consumers need to renew or replace their software licenses every period. They need to replace their hardware, on average, every two periods, either with the same type of hardware or switch to the competing hardware. They will do so if the software on the competing hardware offers them higher net benefits, defined as a consumer's willingness to pay net of the price.

Investment in the model is stochastic where the probability of a successful innovation increases with the amount a firm invests. A successful investment increases the firm's quality by one unit; an unsuccessful investment becomes obsolete. Firms decide on the amount to invest on their relative positions in their platform market, as well as on their platform's position relative to the competing platform.

An industry will grow faster than substitute industries if it increases its value to consumers faster than those substitute industries. For example, TV broadcasts, DVDs and on-demand streaming may lose attractiveness for certain age groups if new developments in the video games industry progress further. Consumers will then be more likely to consume video games and the video game industry will consequently grow faster than substitute industries. We therefore measure software quality relative to the average quality of the next best alternatives offered by substitute industries: if the average quality level of next best alternatives increases, the quality level of all available software (on both platforms) decreases proportionally. Developing software for more than one platform can be prohibitively costly as firms need to acquire platform specific knowledge. We therefore restrict firms to only develop a single software product for one platform.

The timing is as follows: in the first stage, consumers and firms observe current qualities of available software on both platforms as well as platforms' market shares. Consumers choose which hardware to buy and software firms simultaneously choose how much to invest in quality. In the second stage, firms compete in prices, and consumers buy one unit of software or their next best alternative from a substitute industry. In the third stage, nature determines which firms' investments were successful, and whether there was an increase in the quality of the next best alternative.

2.2 Formal Analysis

We employ the same basic set-up as in Markovich (2008). We assume that all firms develop the same type of software (e.g., spreadsheets, word-processors, or office suites) and allow for no more than two platforms, *A* and *B*, as well as no more than two software firms on each platform. Since the analysis for platform *B* mirrors that of *A*, we present here the analysis only for platform *A*.

Let W={0,1,2,…,K} be a finite set of possible quality levels of software, and let $a_j \in W$ represent the quality of software firm *j* producing for platform A. $a \equiv (a_1, a_2)$ is the vector of quality levels of both firms producing for hardware *A*, and σ is the market share of platform *A*.[7] $S \equiv (\sigma, a, b)$ denotes the state of the industry, where *b* is the vector of quality levels of all firms producing for platform *B*.

2.2.1 Willingness to Pay

Consumers solely derive benefits from software, which needs compatible hardware to operate. In each period, half of the consumers who own a particular hardware are randomly selected to replace their units. These consumers can either buy the type of hardware they already have or switch to the alternative. Firms license software to consumers

7 σ is the formal equivalent of the so called "installed base," as defined in Farrell and Saloner, 1986.

for one period. After that, consumers can either renew the license at the then-available quality level and price or they can switch to another software firm. Consumers who are not randomly selected for hardware replacement have to select software for the hardware they already possess. For any given period, the willingness-to-pay of consumer *l* who owns hardware *A* and holds a license from software firm 1 for software with quality level a_1 is $WP_{1l}^A(a) = a_1 + \varepsilon_{1l}$, where ε_{1l} denotes differences in taste among consumers (e.g., within the spreadsheet market, some consumers like Lotus while others prefer Excel).

Software Choice. Consumers select software from the set of qualities and prices available for the hardware they own. They acquire a license for one unit of software, unless the best consumption alternative, ε_0, provides them with higher benefits. We assume that consumers' preferences, ε, are independently and identically distributed according to a standard double exponential distribution. As McFadden (1973) shows, denoting the price of software *k* by p_k, consumer *l* acquires a license from firm 1 with probability:

$$D_1(a_1, a_2; p_1, p_2) = \frac{\exp\left(a_1 - p_1\right)}{1 + \exp\left(a_1 - p_1\right) + \exp\left(a_2 - p_2\right)} \tag{1}$$

Hardware Choice. Consumers choose the hardware whose current and expected future software qualities offer the highest net benefit. This expected benefit is the sum of the benefits from software they purchase during the two periods they expect to own the hardware.[8] Consumer *l*'s expected net benefit from purchasing hardware A is then:

$$U_l^A(\sigma, a, b) = E\{[WP_{lj}^A(a) - p_j] \mid \sigma, a, b\} + \beta E(E\{[WP_{lk}^A(a') - p'_k] \mid \sigma, a, b\})) + \xi_l^A \tag{2}$$

$E(WP_{lj}^A(a))$ and $E(E[WP_{lk}^A(a')])$ are the consumer's expected willingness to pay for software *j* in the current period and for software *k* in the next period, respectively. ξ_l^A represents consumer *l*'s preferences over platforms (e.g., viewing operating systems as hardware, some consumers prefer the Windows platform while others favor Linux). a' are next period's qualities and p'_j the corresponding prices. In order to assess equation (2),

8 Consumers replace hardware on average every two periods. Consequently, while some of the consumers replace hardware after one period, some hold their hardware for many periods. Since consumers expect to hold the hardware for two periods, they make decisions based on this expectation.

consumers form expectations about future qualities and prices of software based on the current state, (σ,a,b).

Consumers will choose hardware *A* over hardware *B* if and only if hardware *A* offers a higher net benefit than hardware *B*. That is, setting hardware *A*’s and *B*’s prices at P^A and P^B, respectively, consumer l buys hardware *A* if and only if $U_l^A(\sigma,a,b)-P^A > U_l^B(\sigma,a,b)-P^B$. Once more, we assume that consumers' preferences, ξ_l^k, are distributed independently and identically and follow a standard double exponential distribution. Then, again, employing McFadden (1973), consumer l purchases platform A with probability:

$$\Psi(A,a,b;P^A,P^B)=\frac{\exp(U^A-P^A)}{\exp(U^A-P^A)+\exp(U^B-P^B)} \tag{3}$$

Given our assumptions and eq. (3), platform *A*'s market share in the next period is

$$\sigma'(\sigma,a,b;P^A,P^B)=\sigma/2+\Psi(\sigma,a,b;P^A,P^B)/2 \tag{4}$$

2.2.2 The Market for Software[9]

Each software firm only develops one type of software compatible with only one of the platforms.[10] Software firms compete oligopolistically on quality and prices. Software firms need to invest in order to improve the quality of their product. We assume that the outcome of this investment is stochastic and depends on the level of each firm’s investment. Whether the investment is successful is revealed in the following period.

We assume that quality levels follow a Markov process where future qualities depend on current qualities, regardless of how the firm reached this level. Each firm's quality level in the next period is determined by three factors: its current quality level, its level of investment, and the change in quality in substitute industries. Advances in substitute industries erode quality advantages of software firms. Any innovation in substitute indus-

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9 In this paper, we study only investment strategies of software firms. Software firms can also decide to enter or exit the industry, which we ignore here as it has already been analyzed in Markovich (2008). Innovation in hardware can be viewed as a "platform quality shifter", and can thus be represented by simultaneous innovation in the software market. While interesting in itself, we focus on the more complex interactions in the software market.

10 Typical set up costs and additional development costs required in order to port software from one hardware to another are high and the porting is usually done by a different unit within the organization. One can therefore think of the developing and porting units as two different companies.

tries reduces the quality advantage of all software on both platforms by one unit. Consequently, if a_j is firm *j*'s current quality level, $\tau_j \in \{0,1\}$ is the realization of firm *j*'s investment, and $v \in \{0,1\}$ represents the success of substitute industries in upgrading their quality, then next period's quality level, a'_j, is described by the following Markov process: $a'_j = a_j + \tau_j - v$. We let δ denote the probability of an improvement in the quality of the substitute industry – the so-called outside good – in each period: $p(v=1)=\delta$. We assume that there are no research spillovers: each firm's probability of a successful investment depends only on its own investment. In particular, if firm *j*'s investment level is x_j, then its transition probability is:

$$P(a'_j \mid a_j, x_j) = \begin{cases} (1-\delta)\dfrac{x_j}{1+x_j} & \text{if} \quad a'_j = a_j + 1 \\ (1-\delta)\dfrac{1}{1+x_j} + \delta\dfrac{x_j}{1+x_j} & \text{if} \quad a'_j = a_j \\ \delta\dfrac{1}{1+x_j} & \text{if} \quad a'_j = a_j - 1 \end{cases} \tag{5}$$

Firms' Profits. . Software firms on both platforms take demand as given from equation (1) and set prices to maximize per-period profits. For firm 1 on platform *A*, these per-period profits are the solution to the maximization problem:

$$\max_{p_1 \ge 0} \sigma * M * D_1(a_1, a_2; p_1, p_2) * p_1 \tag{6}$$

where *M*>0 is the total size of the market. Software is costly to develop. For simplicity, we assume that there are no additional marginal or fixed costs of production. σ is the percentage of consumers who own hardware *A*. The first-order condition, the derivative of (6) with respect to p_1, is

$$0 = 1 - \frac{1+\exp(a_2 - p_2)}{1+\exp(a_1 - p_1)+\exp(a_2 - p_2)} p_1$$

There exists a unique Nash equilibrium $(p_1^*(a_1,a_2), p_2^*(a_1,a_2))$ for the pricing game (Caplin and Nalebuff, 1991), which can be computed by numerically solving the system of first-order conditions. The per-period profit of firm 1 in the Nash equilibrium of the pricing game is then given by $\sigma M \pi_1(a_1,a_2)$, where

$$\pi_1(a_1,a_2) \equiv D_1(p_1^*(a_1,a_2), p_2^*(a_1,a_2); a_1, a_2) * p_1^*(a_1,a_2) \tag{7}$$

is firm 1's profit per consumer. Equation (7) relates the measure of competitive advantage of Adner and Zemsky (2006) to those of other contributors to the literature, such as Porter (1985): profits depend on willingness to pay which can be increased through additional value creation, namely investment in quality upgrades. However, due to competition, each firm can only appropriate part of this value created. Firms with superior value creation – quality – also have above average profits, at least on their platform.

Taking the state of the industry $S=(\sigma,a,b)$ as given, incumbent software firms select optimal investment strategies by solving an intertemporal maximization problem. Firm 1 on platform A maximizes its expected future payoff, $V_1^A(S)$, by solving the following Bellman equation:

$$V_1^A(S)=\sup_{x_1\geq 0}\left[\begin{array}{l}\sigma M\pi_1(a,p)-x_1+\\ \beta\left(\sum_{a',b'}V_1^A(S')P(a_1'\mid a_1,x_1^A,\nu=0)P(a_2'\mid a_2,x_2^A(S),\nu=0)P(b_1'\mid b_1,x_1^B(S),\nu=0)P(b_2'\mid b_2,x_2^B(S),\nu=0)\right)(1-\delta)\\ +\beta\left(\sum_{a',b'}V_1^A(S')P(a_1'\mid a_1,x_1^A,\nu=1)P(a_2'\mid a_2,x_2^A(S),\nu=1)P(b_1'\mid b_1,x_1^B(S),\nu=1)P(b_2'\mid b_2,x_2^B(S),\nu=1)\right)\delta\end{array}\right]E(\sigma') \tag{8}$$

where x_1^A is firm 1's investment on platform A. x_2^A, x_1^B and x_2^B are defined similarly. $P(\cdot)$ is given by equation (5), and $E(\sigma'|S)$ is given by equation (4). The right-hand side of equation (8) consists of two parts: the profits from the pricing game in this period, $\sigma M\pi_1(a,p)$, and the expected discounted value of all future profits. The expected value of future profits depends on the state of the industry, $S=(\sigma,a,b)$, as well as on all active firms' investment levels.

Note that firms have to solve for optimal investments for all possible future states. This turns single one-period investment decisions into dynamic investment strategies over the infinite horizon. The expected value of future profits is the market value of the firm. As can be seen from the dependence of (8) on current and expected quality levels of all firms, a firm can only have sustained higher profits as compared to its competitors if it has superior value creation – in our model quality upgrades through investment – over time. This implies that relative market value of firms can be used to capture the idea of sustained competitive advantage as discussed by Besanko, et. al. (1997). So in our model strategy directly determines competitive advantage. Market value, however, only reflects the value creation that firms are able to capture. We get back to this point in the next section.

Equilibrium. Following the literature, we consider the Markov Perfect Equilibrium (MPE) of the game (see Maskin and Tirole, 2001). Each period, firms simultaneously decide on their investment given the current state, *S*, and their future expectations. Investment strategies are defined for every state of the industry, regardless of how this state has been reached.

A *Markov Perfect Equilibrium* for the game described above is defined by

- Investment strategies $x_j^k(\sigma, a, b)$ for j=1,2; k=A,B and every possible state (σ,a,b).
- Value functions $V_j^k(\sigma, a, b)$ for i=1,2; k=A,B, and every possible state (σ,a,b).

Such that:

(i) The strategies $x_j^k(\sigma, a, b)$ are optimal given the value functions $V_j^k(\sigma, a, b)$.

(ii) For every state $S=(\sigma,a,b)$, the value functions describe the present value of profits realized when both firms play the equilibrium strategies $x_j^k(\sigma, a, b)$.

A full formal equilibrium definition and the computational algorithm can be found in Markovich (2008).

2.2.3 Parameterization.

We use the following parameter values for the equilibrium computation. We assume a total of ten consumers in the market, i.e., M=10. Since our focus is on software, we normalize hardware prices $P^A = P^B$ to be equal to zero. Market shares of platforms run from 0% to 100%, and are calculated in increments of 5%. We think of each period as one year and set the discount factor $\beta = 0.92$. Given these parameter values, software firms find it unprofitable to invest in quality upgrades, regardless of market structure, if they reach a quality level of K=6. Once a software firm has reached this quality level, it chooses not to invest at all. We therefore fix K at 6.

We will present all of the results with graphs. Since it is impossible to display our results for all possible value combinations of the model, we select intermediate starting values for the graphs: each platform starts with a market share of 50%, and the level of outside competition, δ, is also set to 0.5. Departing from these values only changes the relative magnitude of the effects, while the principle mechanisms stay the same.[11]

3. COMPETITIVE ADVANTAGE IN PLATFORM INDUSTRIES

Various definitions of competitive advantage have been proposed in the literature (See Rumelt, 2003). In platform industries, identifying and categorizing firms with competitive advantage is even harder than in markets without platforms. We follow Besanko et al. (2000) and focus on value creation. In our model, firms create value through quality upgrades. Value creation relative to competitors has two dimensions: Quality leadership within- and across-platforms. We refer to the first as the firm's *competitive position* and denote the second as *platform position*.

Firms can be leaders or followers within their own platform, and can be operating on the leading platform or on the lagging platform. Clearly, the leading firm on the leading platform has a competitive advantage. The competitive position of the leading firm on the lagging platform or the lagging firm on the leading platform is not as clear. Consequently, we follow the international trade literature and distinguish between *overall competitive advantage* and *relative competitive advantage*.[12] Specifically, we define *overall competitive advantage* to be the case where the firm enjoys a leading competitive position as well as a leading platform position. A *relative competitive advantage* is then defined as the case where the firm enjoys only one type of leaderships—either within- or across- platform.

4. COMPETITIVE STRATEGY

Given the dynamics in our model, leadership may be contested and firms' competitive and platform position may change. One might expect a firm whose leadership is contested to exercise a different strategy than that of a far ahead leader. More generally, one would expect a firms' competitive strategy to depend on the firm's type of competitive

[11] Figures with other parameter values are available upon request from the authors.

[12] The corresponding term in the international trade literature are absolute and comparative advantage. However, we avoid these terms to avoid confusion.

advantage—overall or relative. In our model, competitive advantage is achieved through investment; thus, investment strategies are the firm's competitive strategies. We are interested in the dynamics of firms' optimal investment behavior given their position in the market. Therefore, we study firms' investment responses to their own successful quality upgrades, as well as their responses to a competitor's quality upgrade. From now on we always refer to the competitor on the same platform unless explicitly stated otherwise. We define a firm's *own-investment-response* to be the percentage change in the firm's investment given a one percent change in its own quality level.[13] A firm's *cross-investment-response* is the percentage change in a firm's investment given a one percent change in its competitor's quality level.

The previous literature focused on whether a follower invests more or less than the leader in the market (e.g., Grossman and Shapiro, 1987). In contrast, our analysis focuses on the effect of a firm's position on the firm's investment *response*. A firm can increase or decrease its investment in response to an own- or a cross- quality-upgrade. We call an increase in the firm's investment an *aggressive* response, and call a decrease in investment a *complacent* response. Next, we study how firms' responses depend on their competitive and platform position.

To study how competitive advantage and competitive strategy interact, we study possible quality combinations of firms on platform A, and fix the quality levels on platform B. In the context of our model, we measure platform position as the sum of qualities of the software compatible with a platform relative to this sum on the competing platform. We denote the difference between the two sums by Δ-inter. We measure competitive position to be the firm's quality relative to the competitor on the same platform, and denote the difference between the two by Δ-intra. We select all cases from our model that allow us to avoid corner solutions (where one or more of the firms has no incentive to invest) as much as possible. The quality combinations for all Δ-intra and Δ-inter that fulfill this criteria are displayed in figure A1 in appendix A. We set the quality level of both firms on platform B to 3, so the total quality level on platform B is equal to 6. Platform leadership

[13] Formally, responses in our calculations are elasticities. Since our model can only handle discrete changes in qualities, the percentage changes for the responses have been calculated based on unit changes. For example, an increase from quality 4 to quality level 5 represents a 25% change.

is reflected in the areas where Δ-inter is positive. If the firms on platform A, for example, assume quality levels 5 and 3, the sum of their qualities is 8, which leads platform B by two quality units and Δ-inter = 2. If both firms on platform A assume a quality level of 1, platform A is behind and Δ-inter = –4. Within platform leadership on platform A is reflected by a positive Δ-intra. Using the same examples from above, Δ-intra = 2 in the first example and Δ-intra = 0 in the second. In appendix A, we provide a complete list of quality combinations for all Δ-intra and Δ-inter used in the graphs.

4.1 The Effect of Own Success on Investment Responses

Intuition suggests that if a firm lags behind, a successful upgrade should have a positive effect on firms' investment response, as a successful upgrade increases the probability of catching up and gaining competitive advantage. This should increase the firm's incentives to invest in quality upgrades prompting an aggressive response. In converse, one would expect the opposite effect in the case of a leading firm. A leader cannot win additional market share on its own platform – only from the other platform – and thus has low incentives to invest. Therefore, one would expect a leader to respond complacently and decrease its investment in response to its own quality increase. As the following figure reveals, our model delivers broad, but not universal, support for the intuition above.

Figure 1 plots firm 1's on platform A own- investment-responses as a function of its relative position in the market. In all figures below, the quality level of both firms on platform B is set to 3.

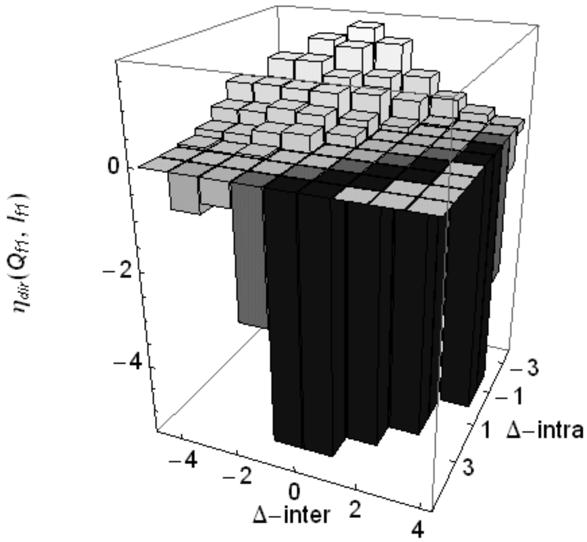

Figure 1: Own-investment-responses.

As figure 1 shows, the more firm 1 lags behind firm 2 (Δ-intra < 0), the more aggressive its investment response to its own quality upgrade. A leader (Δ-intra > 0), however, responds complacently only once its lead is large and secure. A leader with a small lead responds aggressively to an own upgrade—securing its advantage in the market. Thus, the numerical simulation of our model delivers our first empirically testable hypothesis:[14]

HYPOTHESIS 1: *The more a firm lags behind, the more aggressive (in terms of investment) it responds to a successful quality upgrade of its product.*

Firms that lag behind tend to respond aggressively in order to grab market share on their own platform, taking their platform position as given. Intuition suggests that firms may also choose to respond aggressively to an own quality upgrade in response to incentives coming from their platform position—on the leading platform in the hope to secure their platform's leadership, and on a lagging platform in the hope to catch up. Once their platform leads, firms may respond complacently as the marginal benefits from investment at this point is small. Following the same logic, firms may choose to respond complacently once they are on a lagging platform accepting their inferior position.

[14] In this paper, we focus on generating hypotheses that can be tested. Given the rich set of hypotheses the model generates, thorough empirical tests of our hypotheses are outside of the scope of this paper.

Our results show that leadership makes you complacent: firms increase their investment as a response to an increase in their own quality only as long as they are facing a competitive threat. On the lagging platform far leaders *within* their platform become complacent. On the leading platform, even firms that lag behind become complacent (figure 1). Aggressive responses to an own increase in quality are strongest around Δ-inter = 0: when platform leadership is contested; They are weakest for Δ-inter >> 0: when a platform has a far lead.

The discussion above suggests that in platform industries it is the *interaction* of competitive position and platform position that determines the optimal competitive strategy for firms. As long as there is no far leader within a platform, investment-responses are the strongest when platform's positions are close and thus firms compete for platform leadership. In this case the market is very competitive and small changes in quality levels have large effects on market shares. Firms increase investment aggressively to gain platform leadership and enhance the attractiveness of their platform. Once their platform is ahead or behind, incentives are lower—the effect of changes in quality on attractiveness to consumers and market share is smaller. Investment-responses get smaller and may even become negative.

4.2 The Effect of a Competitor's Success on Investment Responses

Figure 2 plots the cross- investment-responses of firm 1 on platform A as a function of its relative position in the market, that is, the firm's response to a quality upgrade by the competitor on the same platform.

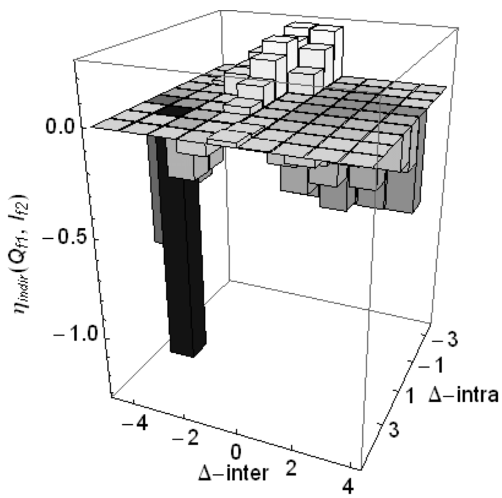

Figure 2: Cross-investment-responses

For the cross-investment responses we find surprising results: The common belief that firms, and in particular leaders, should respond aggressively to an upgrade by their competitors is rarely found to be the optimal competitive strategy. Investment responses to a quality upgrade by the competitor depend more on platform position than on competitive position. In particular, in most cases, responses are complacent: a successful quality upgrade of a competitor discourages investment. Responses are aggressive only when firms see the possibility to contest platform leadership, and the response is the strongest for lagging firms on the *lagging* platform—firms with overall competitive disadvantage.[15] The intuition behind this result is as follows: Consider a lagging firm on a lagging platform. If the leading firm on this platform successfully upgrades its quality, two opposing effects happen simultaneously: (1) the lagging firm loses market-share within the platform, which reduces its incentive to invest; and (2) the platform's position overall gets stronger. If a platform improves its position, it increases its survival probability and future profit opportunities for all firms on the platform; thus, it amplifies all firms' incentives to invest, including those of the lagging firm.[16] When contesting platform leadership gets within reach of the lagging platform, the second effect dominates the first.

[15] Leadership on the reference platform is contested by construction, since we fixed both its firms' qualities at level three.

[16] In accordance with the previous literature in economics, Markovich and Moenius (2009) label the second effect as the *network effect* - the change in a platform's market share driven by an increase in the quality level of one of its firms.

Under these conditions even the lagging firm responds aggressively and increases its investment. Now consider the same situation on the leading platform: The same two effects area at work, however, as we have seen in the discussion of the own effects, the more one firm gets ahead, the less aggressive it becomes. The same is true for platforms: the strengthening of the platform position *reduces* incentives to invest for both firms on the leading platform, so aggressive cross-investment responses are more prevalent on the lagging platform.

Firms on far leading platforms always respond complacently to an increase in their competitor's quality on the same platform. Firms on lagging platforms respond complacently if their relative contribution to gaining platform leadership is less valuable than the contribution of their competitor on the same platform, which is generally the case when they are the within-platform leader. Since platform position is the dominant contributor to long-term profits, competitive behavior within platform is mainly determined by platform considerations. Consequently, firms respond complacently to an upgrade by the competitor on the leading platform as well as on the far lagging platform. However, the closer we get to contesting platform leadership the more important the same two basic forces – loss of within platform market-share, gain in platform market-share – are at work, but at different strengths. As can be seen in figure 2, the more secure the platform leadership, the lower the chance to benefit from additional market-share, the lower the incentive to invest and the more complacent firms get in response to a competitor's quality upgrade. If the platform is leading, both the loss of within platform market share and the gain of platform market share foster complacency, regardless of whether a firm is leading or lagging within the platform. If the platform is lagging, both the loss of within platform market share and the gain of platform market share favor aggression. While complacency still dominates, it is less pronounced on the lagging platform.[17] Thus, market share effects are countering each other for firms on the lagging platform while they are aligned for firms on the leading platform, resulting in a stronger tendency to complacency on the leading platform. The following hypothesis summarizes these results.

[17] The difference of these cross-effects between platform leaders and followers can be seen by the lighter grey shades on the lagging platform, which indicate higher or less negative values for η in figure 2.

HYPOTHESIS 2: *Firms' competitive strategy is determined by the interaction of competitive position and platform position:*

(a) Platform position has an inverted U-shaped effect on firms' response to a competitor's increase in quality—it increases incentives to invest for firms on the lagging platform, but decreases them for firms on the leading platform.

(b) Competitive position determines the potential and size of investment incentives from platform position: followers are more aggressive than leaders, close contestants on a lagging platform attack a competing platform earlier than distant ones; they also get complacent earlier than distant ones after winning platform leadership.

4.3 A Taxonomy of Competitive Strategies

The analysis above isolated the firm's response to an own and a competitor's upgrade. We now investigate the interaction of these two upgrades—i.e., a change in a firm's competitive position. Given firms' own- and cross-investment-responses, the matrix below identifies the optimal competitive strategy for firms in platform industries.

		An increase in your ***competitor's*** quality makes you …	
		Aggressive	Complacent
An increase in your ***own*** quality makes you …	Aggressive	Pack Hunter	Lone Wolf
	Complacent	Puppy Wolf	Scavenger

Table 1: Competitive Strategies

We call a firm that responds aggressively both to its own upgrade and its competitor's upgrade a "Pack Hunter". This is the case when incentives are aligned and both firms seemingly "work together" to improve the relative position of their platform. We call a firm that seeks to get ahead by itself a "Lone Wolf." A "Lone Wolf" firm is encouraged by its own success and discouraged by the success of competitors.[18] A "Puppy Wolf" firm seeks to keep the current distance from its competitors: Thus, it reacts aggressively to a competitor's upgrade and complacently to its own quality upgrade. Finally, we call a firm that finds it optimal to seize current profits and is neither encouraged by its own nor by its competitors' success a "Scavenger." As discussed above, firms' strategic behavior depends on their competitive position and their platform's position. Based on the results of our numerical simulations, Figure 3 plots the different types of competitive strategies for a firm as a function of this firm's competitive and platform position, which jointly constitute the firm's type of competitive advantage.

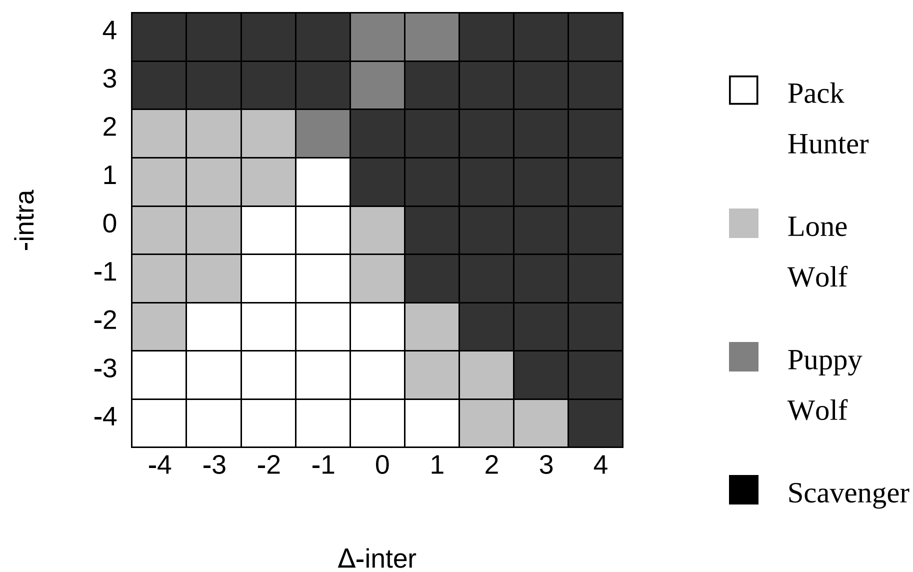

Figure 3: Competitive- and Platform- Position and Optimal Competitive Strategies

Strategies are most aggressive when platforms are of similar strength and either firms are of similar strength, or one firm lags behind. In this case, firms on the same platform behave as "Pack Hunters": They act as if they join forces[19] and invest aggressively in order to strengthen their platform position. A firm behaves as a "Lone Wolf" when it is either hungry or threatened: This is usually the case when it needs to sustain its relative compet-

[18] Note that the Lone Wolf corresponds to the behavior found in the typical R&D literature; e.g., Grossman and Shapiro (1987).

[19] By "join forces" we do not refer to any type of collusive behavior, but rather think about the case where all firms on the platform are motivates by the same aim—increasing the platform's attractivenes.

itive advantage, either as a leader on a lagging platform or as a follower on a leading platform.

“Scavengers” are firms with little incentives to upgrade the quality of their software. For example, a firm with an absolute competitive advantage has no incentive to further increase its investment as long as it is not jeopardized by neither its competitor nor by the other platform; the firm thus prefers to hold onto most of its profits instead of reinvesting them. When the Scavenger is a leading firm on the lagging platform, it cannot win against the competing platform alone. Consequently, it just "feeds" on whatever market share its platform already has. Finally, the "Puppy Wolf" is a far within-platform leader on a contested or a contesting platform. In this case, any catch-up of the lagging firm increases the chance to either win or sustain platform leadership: The “Puppy Wolf” on the lagging platform becomes more aggressive due to the chance of winning platform leadership, while increased safety on the leading platform makes the "Puppy Wolf" more complacent.[20]

HYPOTHESIS 3: *Strong competition across platforms aligns incentives of firms on the same platform to invest aggressively—firms seemingly “work together” to improve their platform position. Once platform position is determined, firms focus more on enjoying or improving their competitive position within the platform.*

4.3 Robustness

How do optimal strategies change when platform market shares or the speed of innovation, for example through faster quality upgrading of the potential substitute products change? We analyze this in the context of nine possible scenarios, where we compare our reference case with slower and faster outside competition as well as a larger or smaller platform market-share. We simulate the model for those scenarios where we set the probability of a one-step quality displacement by the outside good, δ, to 0.1, 0.5, and 0.9. We analyze strategies for initial market shares σ = 25%, 50% and 75%. The results are displayed in figure 4.

[20] The matrix is not perfectly symmetric since the quality levels on the other platform are fixed at (3,3), thus changes in competitive and platform position have asymmetric influence on leaders and followers. This also reminds us that all strategies may be played at different strength. See the discussion in the previous section for details.

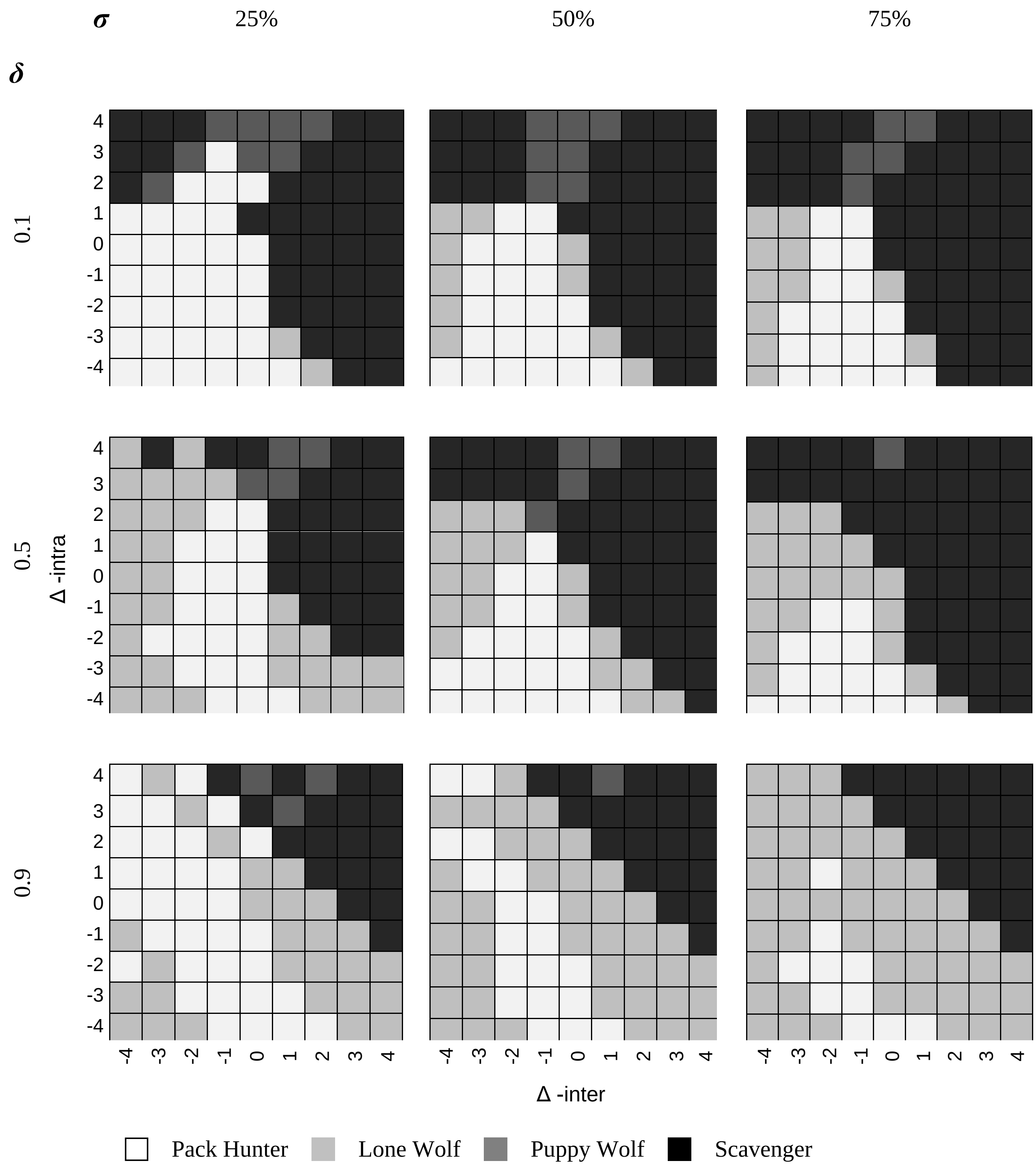

Figure 4: Competitive- and Platform- Position and Optimal Competitive Strategies-Robustness

The comparison across the nine panels in figure 4 shows that innovative pressure from substitute industries and initial market-share determine how frequently our four animals appear in our platform competition. Independent of the pressure from substitute industries, an increase in the platform's market-share σ leads to more complacency: pack-hunters, our most aggressive animals, turn into lone wolves, puppy wolves or even scavengers, our least aggressive animals. Lone wolves and puppy wolves also transition into scavengers. Overall, our model predicts a shift towards complacency with an increase in initial (or already achieved) market share. This is analogous to the tendency of leadership leading to complacency.

Similarly, but not quite as uniform, we observe an increase in aggressiveness as pressure from substitute industries increases, represented by an increase in δ in our model. However, while a decrease in market-share increased both aggressiveness and quasi-cooperative behavior, an increase in outside pressure reduces the amount of apparent cooperation. In terms of our animal strategies, the animal most prevalent when pressure is high is the lone wolf, a rare species when innovative pressure is low. When outside pressure is low, survival is not the issue: variety is the likely ultimate outcome (Markovich 2008). So firms focus on platform dominance to maximize profits. Any contribution to dominance – a firm's own or from its competitor – is thus welcome and makes the pack-hunter thus a frequent appearance. If outside pressure to innovate is high, only one's own successful quality upgrade is sufficient to ensure firm survival. For firms at low quality levels (Δ –intra <0) platform survival is thus of secondary importance and they only respond aggressively in response to their own success. Thus, firms on the path to potential exit adopt a "Lone Wolf" strategy. Firms with high quality levels on lagging platforms, though, see their own survival probability and that of their platform improve through their own and their competitor's quality upgrade, thus they act as pack hunters. Once their platform gained leadership, they fight for the market share on the platform. Only if they are far ahead and leading will they turn to scavengers.

In the literature on patent races, competitors without attachment to platforms mostly resemble the behavior of lone wolves. Introducing platforms not only brings about three more animals, at least in our model it also gives the lone wolf a rather minor role, only prevalent when innovative pressure is high.

5. DISCUSSION

In our model, innovative pressure from substitute industries and the type of competitive advantage a firm enjoys determine the choice of competitive strategy the firm should employ. Furthermore, the firm's type and degree of competitive advantage conveys when the firm should change its strategic response and become more or less aggressive. For example, if innovative pressure is not too high and a firm enjoys an overall competitive advantage, our results suggest that to maximize shareholder value the firm should enjoy profits from its past investments and reinvest moderately. Arguably, while Microsoft still enjoys the "Scavenger" position for some of its products (like its operating system), AMD's aggressive investment, for example, has pushed Intel toward being a "Lone Wolf" in an effort to sustain its leadership.

We also find that firms on the lagging platform will more eagerly "work together" than firms on the dominant platform as long as quality differences across platforms are small; that is, as long as they can contest the leading platform. Moreover, firms on the lagging platform will also more eagerly invite competition in order to beat the dominant platform, while firms on the dominant platform will try to monopolize the market. For example, the large investments by application developers on the Android platform are also motivated by these firms' efforts to challenge the leadership of the iOS platform.

This last result fits well with Brandenburger and Nalebuff (1997) view of co-opetition—firms on the same platform compete for with-in platform market share, yet cooperate in their effort to sustain their platform's lead or challenge the leading platform. Our results provide the conditions under which this strategy is optimal for a firm to achieve or sustain its competitive advantage.

6. CONCLUSION

We study how the existence of competing platforms influences competitive advantage and competitive strategy in the form of investment in quality upgrades. We find that investment behavior is driven by competition across platforms as well as competition between firms on the same platform. At any point in time, past value creating activities determine a firm's current competitive advantage. The nature of the competitive advantage that a firm has achieved, manifested in its own or its platform's leadership position, then determines which one of four competitive strategies the firm should choose: If platform leadership is not contested, the "Lone Wolf" strives to achieve leadership within its platform. Once within-platform leadership was achieved, the "Scavenger" lives off past success and takes profits. If platform leadership is at stake, joining forces as "Pack Hunters" is optimal for roughly equally strong competitors to either win or defend platform leadership. Finally, only a far leader can afford to act as a "Puppy Wolf" that keeps the distance to competitors and simultaneously contributes to winning platform leadership.

Competitive strategy may look different if software firms can produce for both platforms, only facing an adaptation cost. Hardware upgrades may introduce additional uncertainty, again changing optimal strategy choice. Differences in firm specific resources across platforms may further alter the picture. While we believe that we address the most salient issues of competitive strategy in the presence of indirect network effects, we intend to investigate some of these additional issues in our future research.

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APPENDIX A: Quality Combinations and Types of Leadership To characterize the firm's competitive position and the platform position, we divide the space into nine sections based on the two dimensions of leadership: a firm can be a leader (L), leadership may be contested (C), or it may be a follower (F); the same holds for platforms. In figure 1, we label each section with the firm's competitive position (first letter) and the platform position (second letter). For example for firm 1 on platform A, section LF corresponds to the case where firm 1 is a leader within its own platform (L), and platform A is a follower as it lags behind platform B (F).

		Δ-inter								
		-4	-3	-2	-1	0	1	2	3	4
Δ-intra	4	n.a.	(0,4), n.a.	(0,4)	(1,5), (0,4)	(1,5)	(2,6), (1,5)	(2,6)	n.a., (2,6)	n.a.
	3	(0,3), n.a.	(0,3)	(1,4), (0,3)	(1,4)	(2,5), (1,4)	(2,5)	(3,6), (2,5)	(3,6)	n.a., (3,6)
	2	(0,2)	(1,3), (0,2)	(1,3)	(2,4), (1,3)	(2,4)	(3,5), (2,4)	(3,5)	(4,6), (3,5)	(4,6)
	1	(1,2), (0,1)	(1,2)	(2,3), (1,2)	(2,3)	(3,4), (2,3)	(3,4)	(4,5), (3,4)	(4,5)	(5,6), (4,5)
	0	(1,1)	(2,2), (1,1)	(2,2)	(3,3), (2,2)	(3,3)	(4,4), (3,3)	(4,4)	(5,5), (4,4)	(5,5)
	-1	(2,1), (1,0)	(2,1)	(3,2), (2,1)	(3,2)	(4,3), (3,2)	(4,3)	(5,4), (4,3)	(5,4)	(6,5), (4,5)
	-2	(2,0)	(3,1), (2,0)	(3,1)	(4,2), (3,1)	(4,2)	(5,3), (4,2)	(5,3)	(6,4), (5,3)	(6,4)
	-3	(3,0), n.a.	(3,0)	(4,1), (3,0)	(4,1)	(5,2), (4,1)	(5,2)	(6,3), (5,2)	(6,3)	n.a., (6,3)
	-4	n.a.	(4,0), n.a.	(4,0)	(5,1), (4,0)	(5,1)	(6,2), (5,1)	(6,2)	n.a., (6,2)	n.a.

Figure A1: Types of quality leadership in platform industries.

The horizontal dotted lines in the figure separate the within-platform quality leader from the follower, with the middle row corresponding to the case where leadership within a platform is contested; that is, both firms are competing for leadership within their platform. The vertical dotted lines separate the leading platform from its follower, where the middle column corresponds to head-to-head platform-competition.

APPENDIX B: Construction of Figures 3 and 4:

The specifics of our model do not allow to compute all values for direct and indirect effects in figures 3 and 4: quality levels 0 and 6 are frequently associated with zero investment, so division by zero for computing the elasticities prevents between 10 and 25 of the values needed to calculate the 81 cells for each of the individual squares within each figure. To get reasonable approximate values, we employed two methods to compute the missing values. First, we shifted labeling of quality levels by one unit, so that the new base quality is 1 instead of 0, and the new maximum quality level is 7 instead of 6. We also allowed calculating the – in the model never attained – quality level 8 and its corresponding change in investment. Second, in order to overcome the artifact of the model to stop quality upgrading at level 7 (or, before shifting, 6) which is due to the choice of innovative step to be equal to 1 with no fractional improvement allowed, we calculate the implied investment for a fractional upgrade using a first order taylor series expansion at each point where investment equals zero. In some cases, this would have led to negative investment numbers. In these cases we chose the midpoint between the original value and zero as the limiting investment. This automatically implies that we do not get the approximations correct in all cases (as is likely the case when certain strategies become orphans, for example when delta =0.9), but we preferred this approach due to its ability to visualize patterns of strategy choices more clearly.