Competition Dynamics in the Presence of Indirect Network Effects

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ABSTRACT

What determines competitive efforts and market shares of firms when products require compatible and longer lived complementary goods? We analyze this question in a hardware-software framework, where software producers strategically compete in quality upgrades. Software requires compatible hardware, which we assume to be constant in technology and competitively supplied. Using numerical simulation, we examine the effect of various drivers on competitive efforts. We find that indirect network effects generally tie together the competitive efforts of firms on the same platform. Innovations on the same platform are therefore complementary for a broad range of parameters. Consequently, firms may even enjoy a net increase in market-share from an innovation by a competitor on the same platform. Moreover, since with complementary goods adjustment of market shares takes time, history matters.

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1. INTRODUCTION

Why did the DOS operating system outperform CP/M? What drove the success of VHS over Betamax? Why did Consumers so rapidly embrace the Compact Disc technology? While there is a growing body of literature that documents the importance of quality and availability of complementary products (e.g. Breshnahan & Greenstein (1999), Gandal et. al (1999), Gandal et. al (2000), Gandal and Dranove (2003)), a theoretical analysis of how innovation in those complementary products influence competition is missing.

We investigate how quality competition in complementary products affects the overall success of the combination of a longer-lived core product and shorter-lived complementary products. Following the general literature, we call the core product hardware and the complimentary product software. There are different types of hardware, and we call a specific type of hardware a platform.[1] Software producers have to choose which platform to produce for.

Software producers typically face the following delicate trade-off: While the overall success of a platform depends on the quality and variety of complementary software, additional entry on a platform or intense quality competition erodes the profits in the market. How do these contradictory incentives influence competition both within as well as between platforms? Within platforms, indirect network effects tie together the fate of software firms: the business stealing of a successful competitor on the same platform may well be compensated by her contribution to the overall attractiveness of the platform. We find, however, that if firms' strengths within a platform strongly differ, incentives to fortify the platform are misaligned and overall platform performance is weaker than in cases with equally strong competitors. Moreover, since hardware lives longer than software, the sheer existence of platforms introduces frictions to the response of market-shares to software

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[1] For ease of exposition, our definition slightly departs from Breshnahan & Greenstein (1999), who define a platform as a "bundle of standard components around which buyers and sellers coordinate efforts". Thier definition implicitly includes software and peripherals.

innovation. Consequently, history as well as consumers' costs of switching platforms matter. How much history matters depends on how long the hardware lives relative to software: when hardware does not live much longer than software, platforms can lose market share rapidly.

Many network industries are highly dynamic: Software suppliers frequently compete in the market with enhanced quality and improved versions of existing products. Moreover, there is outside competition: regular phones and faxes compete with cell-phones, e-mails and SMSs, and each of the latter again competes against all others. Complex dynamics like these cannot be traced with an analytical model. We therefore use numerical analysis to obtain our results. This allows us to study the following four major drivers of competition: quality levels within platforms, quality levels across platforms, initial market-shares of platforms and the speed of innovation in the outside good market. This allows us to outline how competitive inputs (in our model investment) change when market structure on a platform switches from monopoly to duopoly. We can also show under which conditions within platform competition dominates across platform competition. It permits to illustrate when inertia brakes down. Taking the theoretical and technical framework developed by Ericson and Pakes (1995) and extended by Markovich (2003) as given, our model captures these effects.

We contribute to three lines of literature: First, we add to the literature on dynamic competition within as well as between platforms. For the computer industry, Breshnahan and Greenstein (1999) provide an excellent descriptive taxonomy of platforms, identify main lines of causality and give a detailed description of competition within as well as between platforms. Using a theoretical model, we add to their insights by precisely tracing key trade-offs and details about the short-run mechanisms that drive the different kinds of competition. Moreover, we show that platform shifts can happen under much simpler circumstances than those found in the computer industry.

Second, we extend the analysis of Chou and Shy (1990) and Church and Gandal (1992) who model the software market in order to study inertia and standardization. Note, however, that Chou and Shy (1990) and Church and Gandal (1992) do not allow software firms to choose prices nor quality.[2] .When firms can upgrade quality and choose prices, the degree of inertia depends on the parameters of the model. In our model, overcoming inertia does not require extraordinary technological advances, and whenever this happens, shifts can actually be accelerated by the existence of platforms.

Finally, we show how simple R&D competition[3] is influenced by the existence of platforms. Our within platform results generally resemble those of Grossman and Shapiro (1987), who extend Lee and Wilde (1980). In the context of platforms, however, the stability of their results depends on how strong competitive forces are from the competing platform.

The paper is organized as follows: In the next section, we introduce our model. We then discuss the simple oligopolistic price competition. Section four discusses the various drivers of quality competition and their effects on market shares. The fifth part then discusses the dimensions of competition in network industries, and the sixth part concludes.

2. THE MODEL

Following Markovich (2004), we adapt the framework presented in Ericson and Pakes (1995) and the algorithm for computing it presented in Pakes and McGuire (1994) to allow for dynamics in the demand side. We assume a discrete time infinite horizon model, where consumers care about the set of software-choices offered by a platform, both in terms of quality and variety. Consumers derive utility from the software they purchase, while compatible hardware is needed only to operate the software. We assume that the consumers are forward looking: they evaluate the benefits of currently

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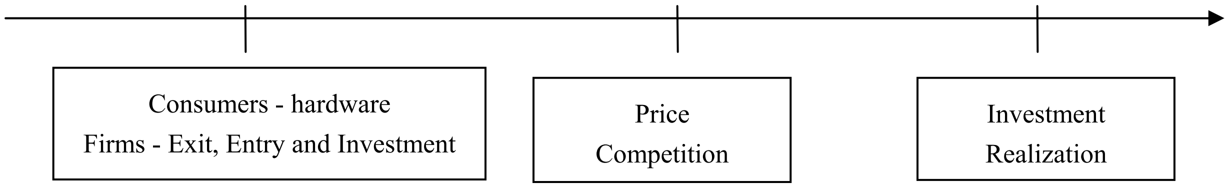
[2] The literature on network effects has traditionally modeled the hardware market and focused on the long-run market structure and its welfare implications (see for example Farrell and Saloner 1985, 1986, 1992 and Katz and Shapiro 1985, 1986, 1992).

[3] See for example, Loury 1979, Lee and Wilde 1980 and Reinganum 1981, 1982, 1983, who study investment in R&D under the assumption that the probability of innovation is governed by an exponential distribution. The aspects of non-stationary R&D races was also studied by Fudenberg et al. (1983), Harris and Vickers (1985) and Judd (1985) among others.

available software on each hardware-platform[4] as well as expected potential quality upgrades and choose hardware and software accordingly. Software-producers develop knowledge that is specific to a platform and therefore cannot switch platforms. Consequently, software firms choose their strategies based on expectations about their own performance, the future performance of their competitors and the future performance of their platform.

We assume that there are at most two incompatible platforms, where each platform can accommodate up to two software-producers. The timing of the game is as follows: First, simultaneously, consumers choose hardware and incumbent software firms decide whether to exit while a potential entrant decides whether to enter. A firm that chooses to stay in the market has to choose how much to invest in quality-upgrades. Incumbents then compete on prices and consumers choose to either buy one unit of software or the outside good. Finally, investment realization determines the outcome of the firms' investment and whether an outside shock has devalued the quality levels of all software producers on both platforms.



We employ the following definitions:

- Let *W={0,1,2…K}* be a finite set of quality levels, and let $a_i (b_i) \in W$ characterize firm *i*'s quality level of software for platform *A* (*B*).[5] The vector $a \equiv (a_1, a_2)$ ($b \equiv (b_1, b_2)$) represents the quality level of all firms on platform *A (B)*.
- *A (B)* is the proportion of consumers who own a unit of hardware technology *A (B)*.[6]

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[4] Here, the number of components that form a platform is only one, the hardware. See Bresnahan and Greenstein (1999).

[5] A quality level of zero indicates that there is no active firm in a certain slot on a platform, and therefore entry is possible.

[6] Some authors refer to these numbers as the "installed base", see for example Greenstein (1993), and Farrell and Saloner (1986).

- State $S \equiv (A, a, b)$ represents the industry structure.

2.1 Consumers' Preferences

Every period half of the consumers on each platform replace their current hardware with a new unit. Hardware only facilitates the consumption of software and provides no stand-alone benefit. The value a consumer gets from the hardware he adopts depends solely on the quality and price of the software he uses, where software provides services for a single period. Let ζ denote the consumers' tastes over the available platforms and software.[7] The one-period utility a consumer with tastes ζ gets from the consumption of hardware *A* and software *j* with quality level a_j is then $U^A(a_j, \zeta) - p_j = a_j - p_j + \zeta_j$, and analogous for hardware *B* and b_j.[8]

Software Choice. Consumers' software choice under both platforms is analogous, we therefore discuss only the software choice of consumers who hold hardware *A*. Each consumer purchases one unit of the software that gives him the highest utility conditional on the vector of available software qualities a_t, his preferences ζ, and the software prices P_t^A. That is, consumer ζ will purchase software *j* if and only if it gives him a higher utility than all other available software. That is, iff:[9]

$$U^A(a_j, \zeta) - p_j \geq U^A(a_k, \zeta) - p_k \qquad \text{for all } k \neq j \tag{1}$$

Let the set $C(a, j; p)$ be the set of ζ's that satisfy equation (1) above and hence represent consumers who consume good *j*. Assuming that ζ has the logit distribution, the market share of firm *j* is then the probability that ζ falls into the set $C(a, j; p)$[10]

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[7] Since each consumer is characterized by his tastes, ζ, we will always refer to consumer ζ, omitting the index of the consumer.

[8] Note that the model can accommodate other utility functions, which may also depend on platform size.

[9] In the limiting case, consumers choose randomly between the software with the highest utility.

[10] See Berry (1994).

$$\sigma(a,j;p)=\int_{\zeta\subseteq C(a,j;p)} dH(\zeta)=\frac{\exp(a_j-p_j)}{1+\sum_k \exp(a_k-p_k)} \tag{2}$$

The proportion of consumers who purchase software j which is compatible with hardware A is then $\sigma(a,j;p)*A$.

Hardware choice. The expected utility consumer ζ gets from purchasing hardware A is:

$$V_A(S,\zeta)=E\{[U^A(a_j,\zeta)-p_j]\,|\,S\}+\beta E(E\{[U^A(a_j^{|},\zeta)-p_j^{|}]\,|\,S\}), \tag{3}$$

where S_t represents the industry structure. $EU^A(a_j,\zeta)$ and $E(E[U^A(a_j^{|},\zeta)])$ are the utilities the consumer expects to get from purchasing software j in the current period and in the next period, respectively. Given the current state S, consumers appraise these expected utilities by forming expectations of future software availability, quality levels and prices.[11]

Consumer ζ will purchase hardware A iff it gives him a higher utility than purchasing hardware technology B. The share of platform A is therefore:

$$\sigma(S;P_A,P_B)=\int_{\zeta\subseteq C(S;P_A,P_B)} dH(\zeta)=\frac{\exp(V_A-P_A)}{\exp(V_A-P_A)+\exp(V_B-P_B)} \tag{4}$$

2.2 The Software Industry

The software market is a differentiated good oligopoly where each firm produces only one type of software compatible with one of the platforms. In each period, the industry structure is represented by states, $S\equiv(A,a,b)$, indicating the distribution of consumers across the platforms and the quality levels of all software firms in the industry. Firms' profits are derived from the price competition, which depend on the firm's own quality level, the quality level of its competitors and the market-share of each platform.

Software firms have three strategies: exit, entry, and investment. In order to decide which strategy to employ, software firms must first form beliefs about the consumers' future behavior as well as about the strategies their competitors will choose. Incumbents then choose their optimal level of investment that maximizes their expected future profits.

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[11] See Markovich (2004) for more details.

Investment. Software firms invest in order to upgrade the quality level of their product. Each firm's quality level in the next period is determined by the following Markov process: $a_i^{|} = a_i + \tau_i - \nu$, where a_i is firm *i*'s quality level today, $\tau_i \in \{0,1\}$ is the realization of firm *i*'s investment and $\nu \in \{0,1\}$ is the realization of a depreciation factor that affects (and is identical for) all firms. We assume that the probability of a quality upgrade increases with the firm's level of investment. In particular, we assume that if firm *i* invests x_i, the probability of success is then $p(\tau_i = 1) = x_i / (1 + x_i)$.

v represents any exogenous events affecting the relative quality evaluations of software firms. We think of *v* as an admittedly crude way to capture the effect of competition from substitute products, and assume that $p(\nu = 1) = \delta$. Adding this factor into the production side is appropriate if some functionality of our software-firms is integrated into those substitute products, eroding an advantage our software-firms held.[12] Consequently, the quality level of software is always measured relative to the quality of the outside good. The realization of *v* is independent of the software firms' level of investment.

Exit and Entry. In each period incumbent firms may exit the industry and get a fixed scrap value *ϕ*. The exiting firm gets *ϕ* in the current period, never reappears and therefore earns neither current nor future profits. In addition, in each period one potential entrant may enter the industry by paying a one time sunk entry fee x^e. The entrant then chooses whether to enter to platform *A*, platform *B* or to stay outside the industry. The entrant's decision takes effect in the following period. In the case of entry on platform *A* (analogously for *B*), the entrant enters at quality level a^e if $\nu = 0$ and at $a^e - 1$ if *v*=1. That is, the entrant is already subject to outside competition in the period of entry. Let $\lambda^A(S) \in \{0,1\}$, $\lambda^B(S) \in \{0,1\}$ and $\lambda^{ne}(S) \in \{0,1\}$ indicate whether firm *i* entered platform *A*, platform *B* or stayed out.

The incumbent's problem. If the industry is in state S, then an incumbent firm solves an intertemporal maximization problem to reach its exit and investment decisions. Let $V_i^A(S,P)$ be the

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[12] Note that *v* causes a positive correlation in the demand and hence the profits of the firms in the industry. Without *v* the model would predict a negative correlation among software firms' profits; which is at odds with the data on the evolution of most industries (see Pakes and McGuire (1994)).

expected future payoff of software-firm *i* on platform *A*. Firm *i* then solves the following Bellman equation:

$$V_i^A(S) = \max\left\{\phi, \sup_{x\geq 0}\left[\Pi_i(S) - x + \beta\sum_v V_i^A(S')\cdot Q^i(A'|S)\cdot q^i(a'_{-i},b')\cdot p(v)\right]\right\} \tag{5}$$

where a_{-i} is defined as the vector of quality levels of firm *i*'s competitors within platform *A*. The max operator compares the exit value of the firm (ϕ) to its continuation value. If ϕ is larger, the firm shuts down. Let $\chi_i(S)\in\{0,1)$ indicate whether firm *i* exits the industry, then in equilibrium firm *i* sets:

$$\chi^i(S)=1 \text{ iff } V_i^A(S)\leq\phi\text{, otherwise } \chi^i(S)=0 \tag{6}$$

$\Pi(S)$ are the single-period profits firms earn in the pricing game. The pricing game is a static game with no future effects or dynamics. Software firms (on each platform) set prices oligopolisticly, and software market shares are then determined according to equation (2).[13]

The expected future returns are computed based on the expectations each firm has about the consumers' distribution across the platforms and the industry structure. Let $Q^i(A'|S)$ denote firm *i*'s beliefs of the consumers' distribution. In order to form expectations of the industry structure firm *i* determines which of the current incumbents will remain active and whether a new entrant will appear. It then uses the quality levels of the continuing firms and the exogenous process determining the quality level of an entrant to form its beliefs. We denote by $q^i(a'_{-i},b'|S)$ the perceived distribution of future qualities conditional on S.

The entrant's problem. An entrant faces a similar optimization problem. The value to a potential entrant from entering with quality level a^e to platform *A* is:

$$V^{e,A}(S) = \beta\sum_v V^A[A',a'+a^e,b']\cdot Q^i(A'|S)\cdot q^i(a'_{-i},b'|S,v)\cdot p(a^e|v) \tag{7}$$

where $a'+a^e$ is the structure of market *A* after entry at quality level a^e took place. As noted before, upon entry an entrant must incur a uniformly distributed random (sunk) setup costs of x^e,

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[13] Note that although the pricing game is static and prices do not directly depend on the structure of the competing platform, profits are also a function of the firm's own platform market share, which in turn depends on the quality level and structure of the competing platform.

$x^e \sim U\left[x_L^e, x_H^e\right]$, and spend a period building its plant. An entrant then would choose to enter platform *A* iff $x^e < V^{e,A}$ and $V^{e,A} > V^{e,B}$. The probability of entry on platform *A* is therefore:

$$\lambda^A(S) = \min\left\{\max\left[\frac{V^{e,A} - x_L^e}{x_H^e - x_L^e}\Pr(V^{e,A} > V^{e,B}),0\right],1\right\} \tag{8}$$

where $\frac{V^{e,A} - x_L^e}{x_H^e - x_L^e}$ is the probability that the entrant's expected value is greater than the entry fee. No entry occurs when $x^e > V^{e,A}$ and $x^e > V^{e,B}$. Therefore, the probability of no entry is $\lambda^{ne}(S) = \left(1 - \lambda^A(S)\right)\left(1 - \lambda^B(S)\right)$.

2.3 Equilibrium in the Industry

A subgame perfect equilibrium for the above game consists of a collection of strategies that constitute a Nash equilibrium for every history of the game. We only consider Markov equilibria so that all strategies depend only on the "payoff relevant" states. This means that the strategies remain optimal for every state, regardless of how that state was reached. Hence the equilibrium is a Markov perfect Nash Equilibrium (MPE) in the sense of Maskin and Tirole (1988). Formally, we define an equilibrium for this industry as the tuple of strategies and beliefs $\left\{x_j(S), \chi_j(S), Q^j(S), q^j(S)\right\}$ for incumbent *j*, and the entry strategies and beliefs $\left\{\lambda^A(S), \lambda^B(S), Q^e(S), q^e(S)\right\}$ for the entrant. The dynamic equilibrium arises from the competitive interaction of incumbents and entering firms on both platforms simultaneously. All firms in the industry know the structure of the whole industry, S, their place in it and the expected impact of their own investment on their future values. The industry is said to be in a dynamic equilibrium when the process generating the change in the industry structure coincides with the perceptions of the firms.

2.4 Computing the Equilibrium.

To compute the MPE, we extend the algorithm described in Pakes and McGuire (1994) to accommodate the dynamics in demand as well as in supply. The computational algorithm is iterative and uses the value function approach. For each state the algorithm calculates the value functions as follows: it first solves for the firms' profits using the market shares in equations (2) and (4). Entry and exit are then solved using equations (9) and (6) respectively. All of these are then used to compute the value functions using (5) and (8). As in Pakes and McGuire (1994), the algorithm is initiated with an arbitrary value function V^0. Iteration k+1 uses iteration k's values ($V^k(\cdot)$, $x^k(\cdot)$) to calculate ($V^{k+1}(\cdot)$, $x^{k+1}(\cdot)$). The algorithm iterates over the value functions and the investment strategies until these values are very close point-wise between iterations.

Parameterization. Since investment realization is a relatively slow process, we take a period to be one year and set the discount rate factor $\beta = 0.92$. K, the highest quality level any software firm can achieve, is endogenously determined in the model: We find that firms with quality level of $K = 6$ find additional investment to achieve a higher quality level not sufficiently rewarding by consumers and therefore choose not to invest at all. This upper bound represents the maximum difference that an incumbent can obtain relative to a potential entrant or to any other player, including those in related industries that produce substitute goods.[14]

All other values are as follows: Sell-off value $\phi = 0.1$; Sunk entry cost $x^e \sim$ U[0.75, 1.25]; Entrant's quality level $a^e = b^e = 2$; Market size $M = 10$.

3. PRICE COMPETITION

Within each platform, price competition takes the form of a simple differentiated good duopoly: higher qualities capture higher prices. The pricing game is static, that is, actors are not forward looking. Prices are determined each period. The following graphs plot absolute as well as relative prices per quality unit as a function of the qualities of the software firms. These graphs are invariant to changes in the vector of qualities on the other platform, initial market share or changes to the level of outside competition.

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[14] In other words, we assume that any other player in the industry including potential entrants can always acquire enough knowledge from publicly available sources so that he will be no further behind than this maximum number of quality steps.

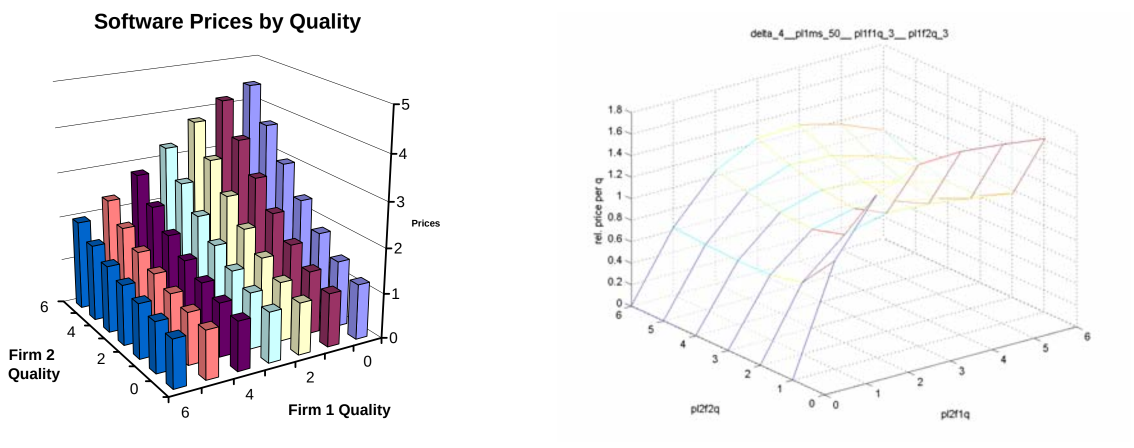

Figure 3: Absolute and per quality-unit relative prices of firm 2 relative to current quality levels of firm 1 and 2 on platform 2,with σ = 50%, δ = 0.4, qualities of firms 1 and 2 on platform 1: 3,3.

A firm can charge higher prices the higher its own absolute level of quality, as well as the higher its quality relative to its competitor on the same platform, and the latter effect dominates. There is a benefit of being different, both in terms of quality as well as in terms of variety: A firm that offers another variety gets a bonus and its price per quality unit is the higher the larger is the quality difference: a firm at quality level one can price its software in per quality unit terms roughly 60% higher than a firm at quality level 6. Of course, the software at quality level 6 is then nearly four times as expensive as the software at quality level 1. However, this variety advantage wears off very quickly: At medium ranges of quality, prices per unit of quality are relatively lower if a company competes against a highest quality firm on the same platform.

Generally, pricing was designed to be fairly simple and straightforward in order to not disturb the analysis of quality competition, which we will turn to next.

4. QUALITY COMPETITION

As stated above, consumers value quality and software firms consequently invest in upgrades of their software periodically. The more a firm invests, the higher its probability of upgrading its product. The investment is void after the attempt, no matter whether the firm reached the next level, remained on the same quality level or even decreased its quality level due to a technology shock from the outside good. This simple set-up allows us to study determinants of investment as well as indicators of outcomes of the competitive process. We consider three different types of influences on the competitive process: the current quality levels of the firms on the same platform as well as the competing platform, initial market-shares of the two competing platforms as well as the speed of innovation in substitute goods industries. We investigate these influences on two aspects of competition: actual investment in innovation and the effects of quality changes on market-shares.

4.1 Investment into Innovative Activities

In this section, we present results for investment in innovation on the firm, the platform and the industry level. We do this conditional on quality levels of firms on both platforms, the speed of innovation of the outside good as well as initial market-shares of platforms. We first discuss the determinants of competition within platforms, then across platforms and finally overall investment in quality-upgrades in the industry.

4.1.1 Determinants of Competition within each Platform

In order to facilitate the discussion, we first present what we call a baseline case, where all determinants assume intermediate values. Then we discuss deviations form this case based on systematic changes in the determinants of competition.

The Baseline Case

In the baseline case, we set the starting market share of each platform to 50%, the exogenous devaluation parameter to 0.4 and the quality levels of all firms on the competing platform to three. In the following figure, we plot the investment in quality upgrades of firm 2 on the second platform relative to both firm's current quality levels.

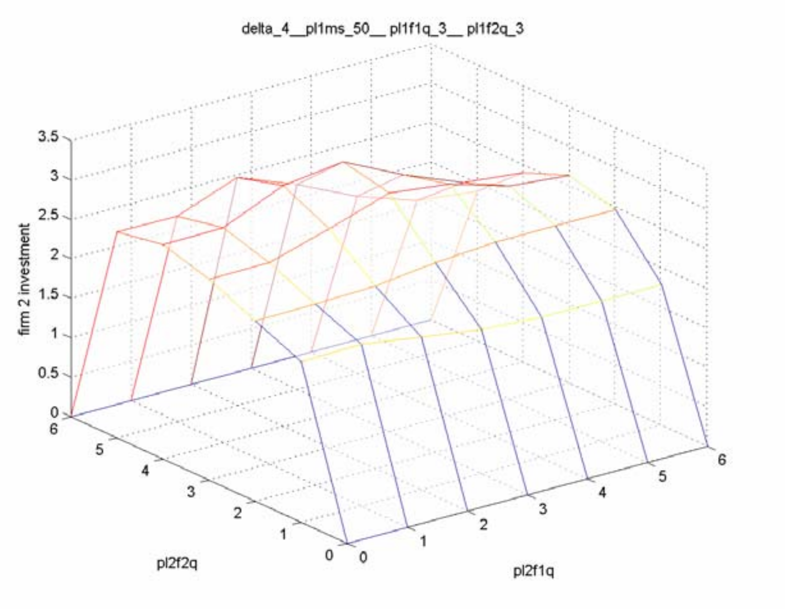

Figure 4.1: Investment in quality by firm 2 relative to current quality levels of firm 1 and 2 on platform 2,with $\sigma = 50\%$, $\delta = 0.4$, qualities of firms 1 and 2 on platform 1: 3,3.

The figure allows us to identify some general features. At quality level 0, firm 2 is not in the market and thus does not invest. Furthermore, it also does not find it profitable to invest once it reaches the highest possible quality level, 6; the extra cost to increase quality beyond this level is not sufficiently honored by consumers to justify this investment. As long as firm 2 is a monopolist, that is firm 1 has quality level 0, firm 2 invests increasingly in quality upgrades the higher its own quality level is. Since in this situation entry on this platform happens with probability one, this reflects the increased profitability of firm 2 for higher quality differences relative to its future competitor.

One might suspect now that the existence of another firm on the same platform might spur investment in general. It turns out that this is only the case for intermediate levels of quality of firm 2, and investment is actually maximized when both firms on the platform are at the same intermediate level of quality. However, at quality level 1 for firm 2, increases in the quality level of firm 1 actually decrease investment, reflecting lower future expected profits due to the fact that a stronger player is in the market. Also for high levels of quality for firm 2, investment first increases and then decreases with higher quality levels of firm 1 on the same platform. The pattern we observe is driven by the higher profitability of higher qualities, but also from the fact that it pays to be different relative to the firm on the same platform: if firm 1 is high quality, it does not pay to invest so much, since there is a benefit of increasing quality, which is honored by consumers generally and it also increases chances of longer survival, but there is also the decreased relative benefit of being not as different from your competitor anymore. The case were firm 2 is ahead in terms of quality can be interpreted analogously. If both firms are at similar quality levels (and about the same as the firms on the other platform), it pays to fiercely invest in order to be the winning platform and get ahead of your own competitor. We are now ready to discuss departures from this baseline case.

Overall Quality of Other Platform

The situation depicted in figure 4.2 is identical to figure 4.1 except that the firms on the competing platform have a lower quality level in the left panel and a higher quality level in the right panel.

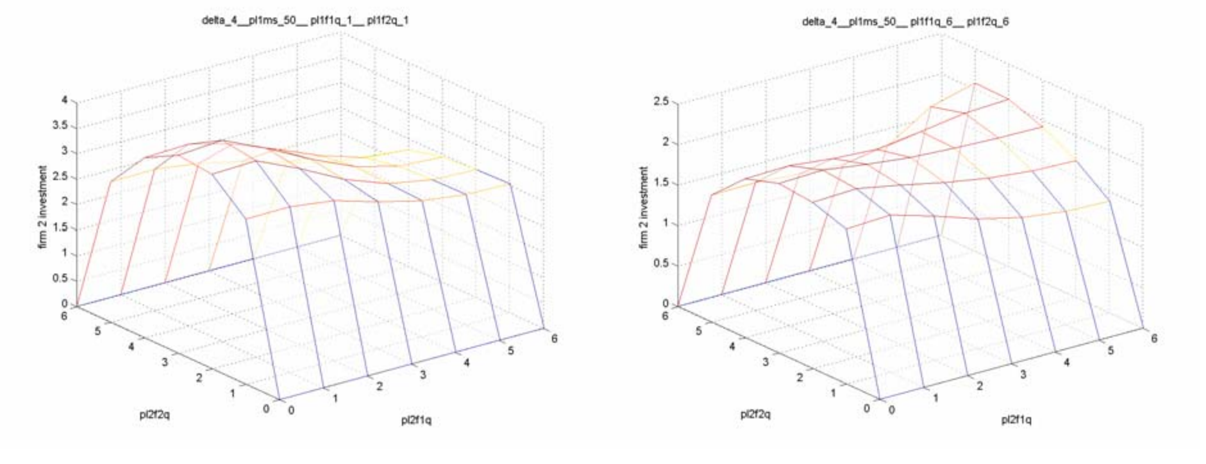

Figure 4.2: Investment in quality by firm 2 relative to current quality levels of firm 1 and 2 on platform 2,with σ = 50%, δ = 0.4, qualities of firms 1 and 2 on platform 1: 1,1 (left side), 6,6 (right side).

There are three remarkable features to be noted: First, investment is the higher, the lower the overall quality level on the competing platform. Second, investment reaches its maximum when the sums of firm's qualities on the two platforms are close to each other. Third, being different on the same platform seems to reduce incentives to invest.

The effects of quality levels on investment are as follows: incentives to invest are the highest when the sums of firms' qualities on the two platforms are close to each other. As we will see later on, this is a consequence of the feature that the shift in market-shares of the platforms is strongest when overall qualities of the available software are roughly the same. In addition, investment levels are influenced by the differences in qualities across platforms: when the quality levels on the other platform are low, this opens the door for large market-share gains (and high profits) as well as the potential for standardization on one's own platform. Here, the stronger your partner is, the more attractive your platform, and thus the lower your own incentives to invest. In summary, we observe three effects: First, higher quality increases profits, independent of current quality levels – otherwise firms would not invest at all. Second, competition is intensified not so much by the configuration of qualities on one's own platform, but by the overall quality on the other platform. In other words, in terms of across platform competition, investment in quality upgrades is complementary – which one should expect from the network externality. Third, within platform there exists a differentiation advantage in quality levels, which runs in the opposite direction of the other two effects. Next we will study the effect of competition from substitute goods on individual firm's investment behavior.

Outside Competition

While differences in quality levels of software firms both within as well as across platforms establish relative advantages or disadvantages, competition from substitute goods always hit the industry as a whole; both platforms in our model suffer equally from such a shock. Our software firms know exactly the probability of such a shock and adjust their investment behavior accordingly.

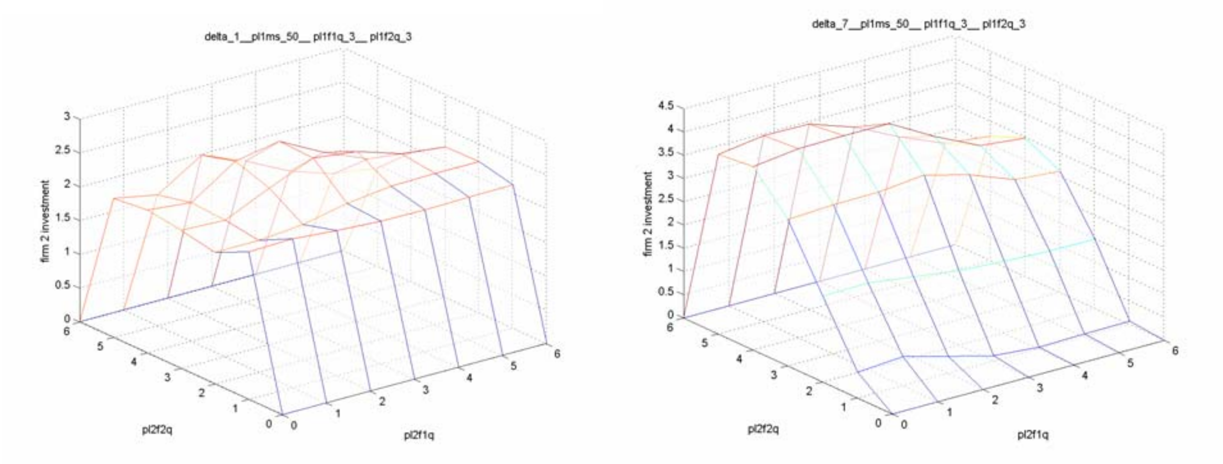

Figure 4.3: Investment in quality by firm 2 relative to current quality levels of firm 1 and 2 on platform 2,with σ = 50%, δ = 0.1 (left side), δ = 0.7 (right side), qualities of firms 1 and 2 on platform 1: 3,3.

Again, we see quite remarkable differences to the baseline case. First, the higher the level of outside competition, the higher the maximum levels of investment. Second, the higher the level of outside competition, the higher the differences between investment at low own quality levels and high own quality levels. Third, the higher the level of outside competition, the more pronounced is the decrease in investment as one's competitor's quality level increases. The first effect is driven by two causes: First, there are benefits of survival. The more I invest, the longer I stay in the market and enjoy profits. Second, it is harder to upgrade my quality relative to outside competition, therefore I will have to spend higher effort to upgrade, leading to higher investment amounts. If one's own quality level is low, however, the probability of exit renders high investment unprofitable (since firms are risk-neutral, and there is no disadvantage from exit), which explains the second observation. Finally, network externalities become more important at high levels of outside competition, since survival of the platform is less likely with stronger outside competition, but a strong partner on one's own platform ensures survival. We are left with the need to analyze the influence of initial market shares on innovative activity.

Initial Market-share

The right panel and left panel in the following figure show investment levels when platform A's initial market share is 10% and 90% respectively:

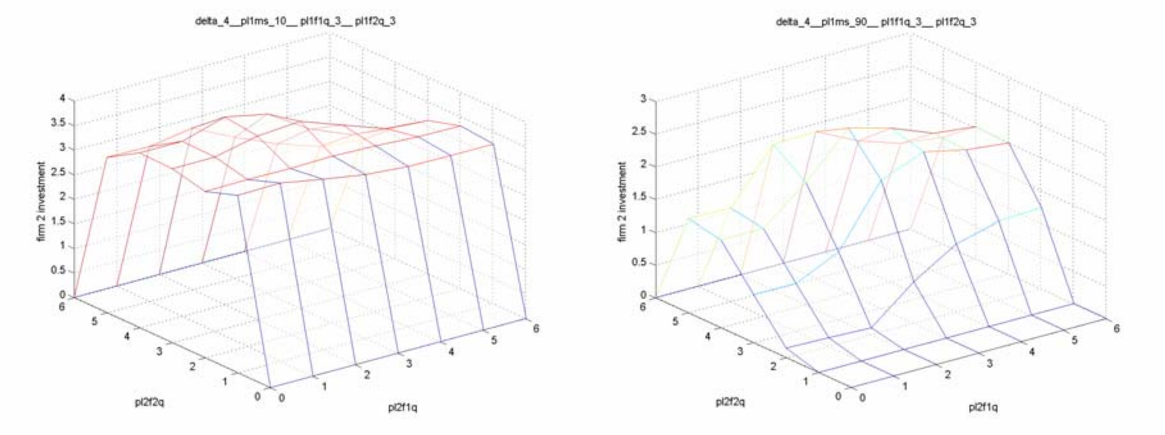

Figure 4.4: Investment in quality by firm 2 relative to current quality levels of firm 1 and 2 on platform 2,with σ = 10% (left side) and σ = 90% (right side), δ = 0.4, qualities of firms 1 and 2 on platform 1: 3,3.

The figure shows that a high market share of one's own platform leads to high investment, higher than in our reference case where the market shares of both platforms are the same. Furthermore, at first sight it looks as if the network effects are reversed when one's own platform market share is low: Firms invest more when facing a strong partner rather than when competing with a weak one. There is, however, an important economic intuition behind the behavior above. When market shares are identical and outside competition is strong as in the previous section, a strong partner on the same platform provides insurance to protect the already won position, allowing for reduced own investment. However, when market-shares are low, a strong partner is valuable for winning market-share, increasing my incentives to invest. A small market share with a monopoly has a smaller benefit (as measured by discounted future net profits) from investment than a strong duopoly. There exists an asymmetry in network effects: while in a weak position, quality levels of firms on the same platform are complements, in a strong position they behave more like substitutes.

4.1.2 Competition across Platforms

The previous section demonstrated that cross-platform competition is a major driver of individual firms' investment decisions. We now turn to study the effect inter-platform competition has on investment decisions. Characterizing these results is somewhat problematic, since there is no clear ex ante ranking for the 49 possible quality combinations on each platform.[15] We therefore introduce the following ranking to improve transparency: Each combination of qualities on a platform is assigned a single number, indicating the sum of qualities, that is, 3-3 and 4-2 would both be assigned the sum 6. Then, for each sum of qualities, initial platform shares and levels of outside competition, we picked the quality combination that delivers the highest expected platform market share in the next period. We only kept those "strong" combinations for the presentations. This reduces the number of states per platform to 13. One can think of the weaker cases to deliver results "in between" the strong cases. For example, the amount of investment for the quality levels of 4-2 lies in between 3-2 and 3-3. We found (with few exceptions) the following pattern: for low levels of δ, monopolies are more attractive than duopolies up until the sum of qualities is 3, after which duopolies promised higher market shares. For higher levels of delta, the cut-off point for monopolies moved to a quality level of 4 instead of 3. This is be visible in the graphs below.

Again, we first discuss our baseline case, setting each platform initial market share to 50% and fixing the level of outside competition to 0.4.

Baseline Case

The following graph displays the sum of investments on platform 2 conditional on the sum of the quality levels of both platforms as described above.

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[15] For example, it is not clear which one of the following quality combinations 3-3, 4-2, 5-1 or 6-0 should be ranked highest.

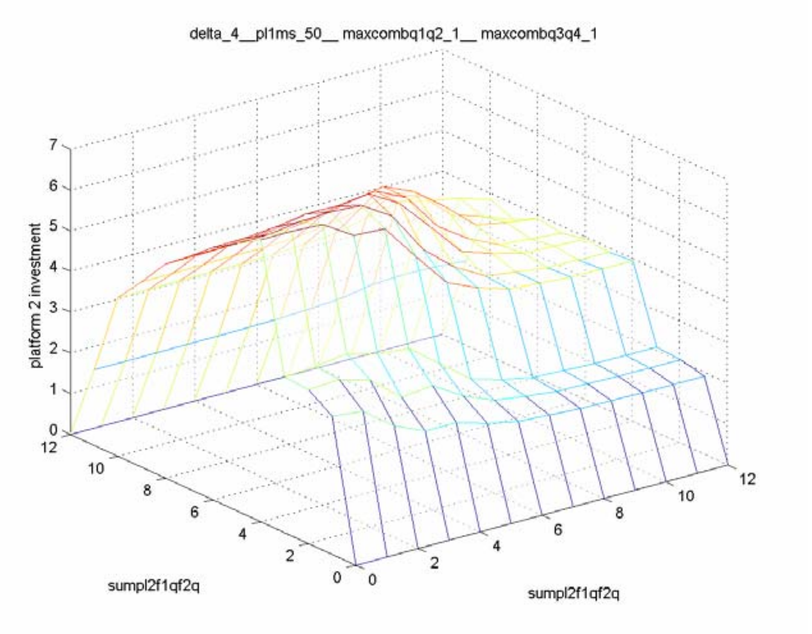

Figure 4.5: The sum of investments in quality by firms 1 and 2 relative to current overall quality levels of platforms 1 and 2,with σ = 50%, δ = 0.4.

A few observations are worth mentioning. Both for monopolies and duopolies, combined investment is higher the more similar quality levels are across platforms. Investment tends to be higher for lower quality levels of the competing platform. Finally, the kink observable at platform-level 3 is the move from monopoly to duopoly. Clearly, combined investment of the duopolies is always higher than the monopolist's investment. The observed patterns can be explained as follows: Shifts in platform-shares are the strongest the closer the overall quality levels on competing platforms are. This promises immediate next period benefits for the successful firms. Increased investment at low quality levels of the competing platform are driven by the prospect of possible standardization on one's own platform, ensuring long-term high profits in the future. The very pronounced step from monopoly to duopoly is partially driven by the effectiveness of investment in our model, since the marginal benefits of investment decrease quite quickly (A8). But it is also driven by the fact that a monopolist takes the probability of entry into account, and therefore investments between duopolists and monopolists don't differ dramatically.

<u>Outside Competition</u>

This section studies the effect of outside competition on the overall investment of firms on the second platform. The following panel depicts the case of low outside competition on the left and fierce outside competition on the right:

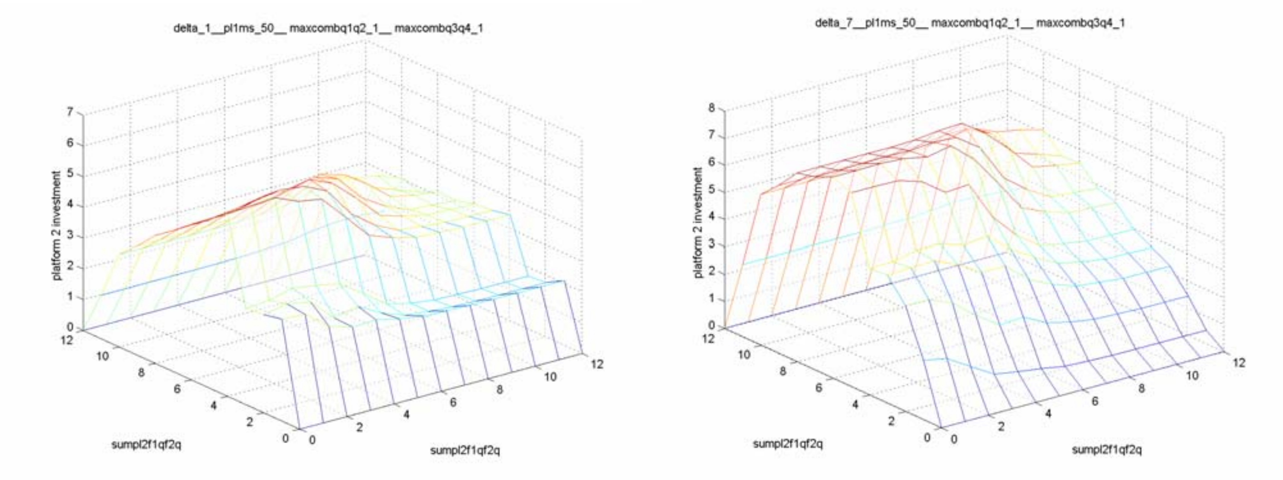

Figure 4.6: The sum of investments in quality by firms 1 and 2 relative to current overall quality levels of platforms 1 and 2,with $\sigma = 50\%$, $\delta = 0.1$ (left side) and $\delta = 0.7$ (right side).

At first glance, the general observed pattern that investment in quality upgrades is the strongest for similar levels of quality across platforms still prevails. The main differences introduced by outside competition are the following: maximum total investment is higher with stronger outside competition. Moreover, the transition from total investment by a monopoly relative to a duopoly is much smoother, especially for high quality levels of the competing platform: entry with fierce outside competition is less lucrative, so the probability of entry therefore is lower, and the monopolist consequently expects to be a monopolist for a longer period of time. This requires a higher level of reinvestment, since she cannot count on a partner to protect the existence and attractiveness of her platform. Consequently, she keeps investing high amounts herself (but also enjoys the higher monopoly profits).

Initial Market-Share

It remains to be analyzed how strongly the initial market share influences total investment amounts on a platform. The results delivered by the model can be found in the next figure.

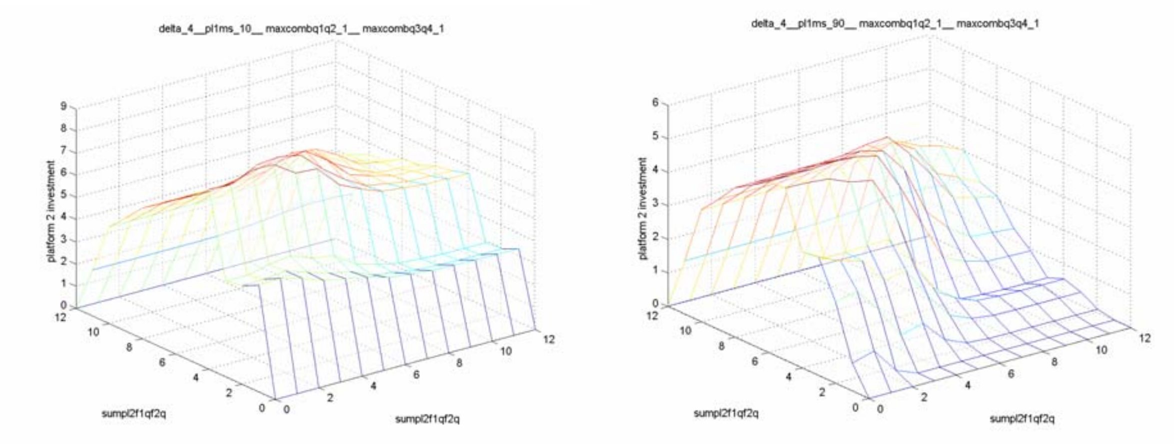

Figure 4.7: The sum of investments in quality by firms 1 and 2 relative to current overall quality levels of platforms 1 and 2,with $\sigma = 10\%$ (left side) and $\sigma = 90\ \%$ (right side), $\delta = 0.4$.

Not surprisingly, higher initial market shares for one's own platform are associated with higher investments: successful quality increases will be met by a larger demand on the platform. Low initial market-share has somewhat similar effects as increased outside competition: while it lowers overall investment, it reduces the probability of entry in the case of a monopoly. Here, however, the monopolist only absorbs comparatively small demand, so it is not as attractive for her to invest large amounts herself. Moreover, the risk of being wiped out through outside competition is not as high as in the case of high outside competition, therefore reducing incentives to invest for the monopolist and leaving the kink clearly visible even for higher levels of quality on the competing platform.

4.1.3 Total Investment in the industry

Finally, we now characterize total investment in the industry. Since the graphs representing changes in initial conditions look quite similar, we just quickly note the effects those changes have on the shape of the graph presented below.

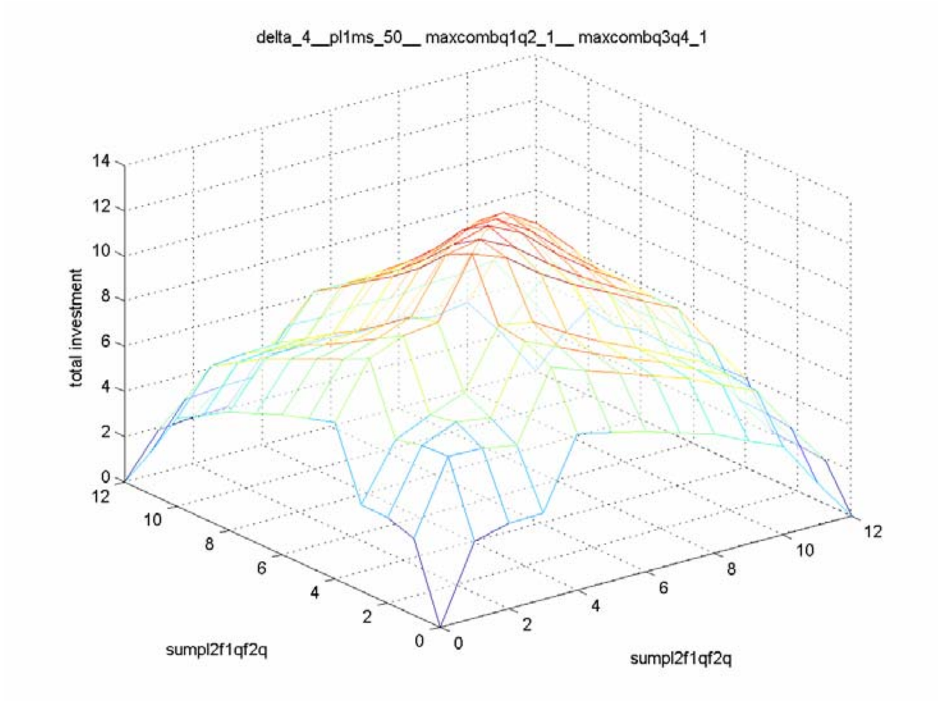

Figure 4.8: The sum of investments in quality by all firms in the industry relative to current overall quality levels of platforms 1 and 2,with $\sigma = 50\%$, $\delta = 0.4$.

The above graph shows again that similar levels of quality across platforms produce the highest levels of overall investment, but market structure plays an important role: the existence of a monopoly on one or both platforms (which occurs whenever one or both overall quality levels are smaller or equal to 3) lowers overall investment. This is true for all asymmetries: generally the further apart the quality levels of the two platforms, the lower overall the amount of investment in the industry. Incentives for investment are reduced for the distant platform-leaders, since they cannot win much additional market-share, and the threat of substantial competition is in the distant future. Incentives are also reduced for the distant followers, since it takes several steps of quality upgrades till they would see substantial profits due to large shifts in the market share in their favor. The benefits are therefore in the distant future, reducing competitive effort today.

In summary, we find the following mechanisms at work: since consumers honor higher qualities favorably, there is an incentive to upgrade quality for software firms. Network externalities provide benefits in the struggle for gaining market-share if one's platform is behind, they also provide insurance if one's platform is ahead. Consequently, substantial differences across platforms lower overall investment, and so do substantial differences within platform, but for a totally different reason: the firm at the lower end benefits from differentiation advantage, lowering her incentives to invest. The probability of entry strongly influences monopolists' behavior: if they expect to be alone in the future, they compete as harshly as two firms combined (!), if they expect entry, they adjust their investment behavior accordingly. To get further insight, we turn now to the question of the effect of quality upgrades on market shares.

4.2 Competitive Outcomes: Market extension Versus Business Stealing

In order to study the effect of successful quality upgrades on market-shares of software-firms and of hardware-platforms in the context of our model, we define as follows (figure 4.9):

***Business stealing effect*:** assuming that everything else stays unchanged, a quality upgrade of firm 1 would draw customers from firm 2. We define this to be the business stealing effect.

Market extension effect: the upgrading firm also draws customers that did not buy software before (bought the outside good). We call this the market extension effect.

Period 1 platform extension effect: assuming that everything else stays unchanged, a quality upgrade of firm 1 on platform 1 would attract more consumers to buy platform 1. Since every period 50% of the consumers purchase new hardware, we define the change in platform 1's market share due to a quality increase of firm1 as the platform extension effect of period 1.

Period 2 platform extension effect: In the second period, again, 50% of the consumers have to decide which hardware to buy. All else equal, there would be another addition of customers buying platform 1 instead of platform 2. We call this the second period platform extension effect.

Since market-shares within platform have already been transferred to the innovator, and the share of the outside good within platform stays unchanged, we do not see market extension or business stealing effects in the second period. However, both firm 2 and (as an artifact of our choice of state-space) the outside good on platform 1 will benefit from the platform effect in period 2 again. In sum, in period 1, all firms and the outside good on platform 1 benefit from the higher attractiveness of their platform due to the quality increase of firm 1. However, firm 1 also attracts market shares within its platform from firm 2 and the outside good. Due to the fact that not all consumers can switch to their preferred platform right away, in period 2, again all firms and the outside good benefit from a second period platform effect. The competitive effects of the model are quite important: a successful competitor on a platform steals market shares from the less successful competitor, but increases the platform overall attractiveness so that the net overall effect for the unsuccessful firm could actually be *positive*. On the other hand, the existence of a platform slows the transfer process of market shares from the firms on the other platform to the innovator, so that in the short run competitors on the second platform are somewhat protected. However, if preferences over software quality dominate variety, this protection may turn into a death sentence: the transfer of market-shares from one platform to the other may exceed the shares that would be transferred in a standard oligopoly market, since consumers are forward looking and do not want to get stuck on an inferior platform. This paves the way for standardization. The argument is summarized in the following diagram, with business stealing indicated with dotted arrows (in red), platform extension with dashed arrows (in blue), as well as the overall effects in solid arrows (green):

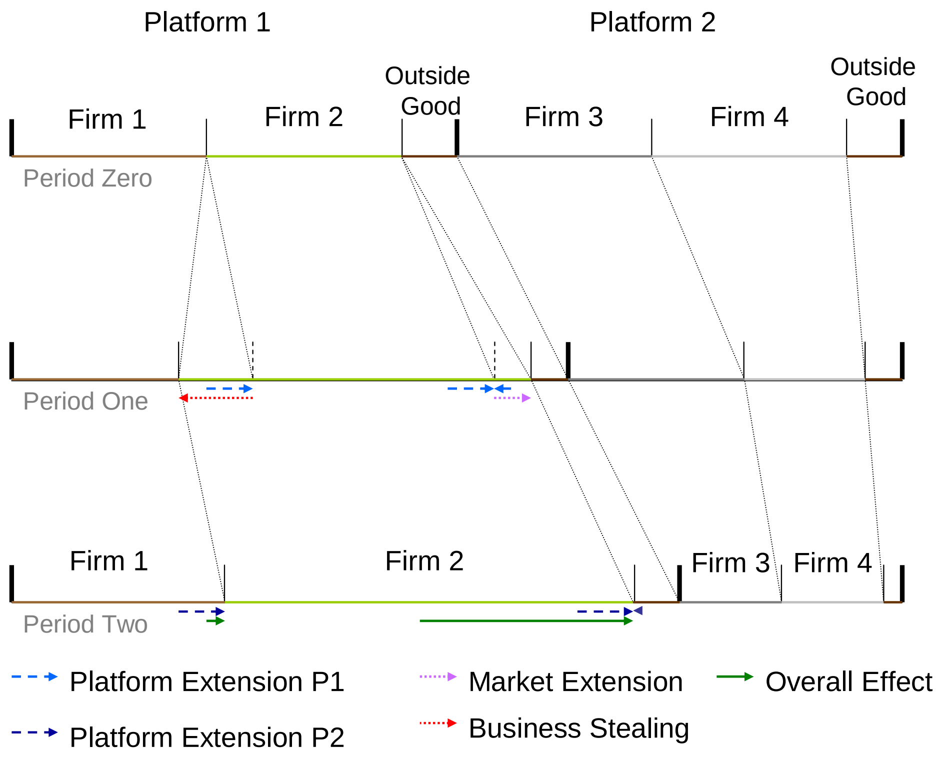

Figure 4.9: Market-share effects over two periods of a successful one time-quality upgrade by firm 2.

We will now characterize the changes in market shares numerically with the help of our model. We decided to illustrate the argument with data from the model for some symmetric cases only, so that the choice of a 50% market-share as a starting value is least distorting. The results are displayed in figure 4.10:

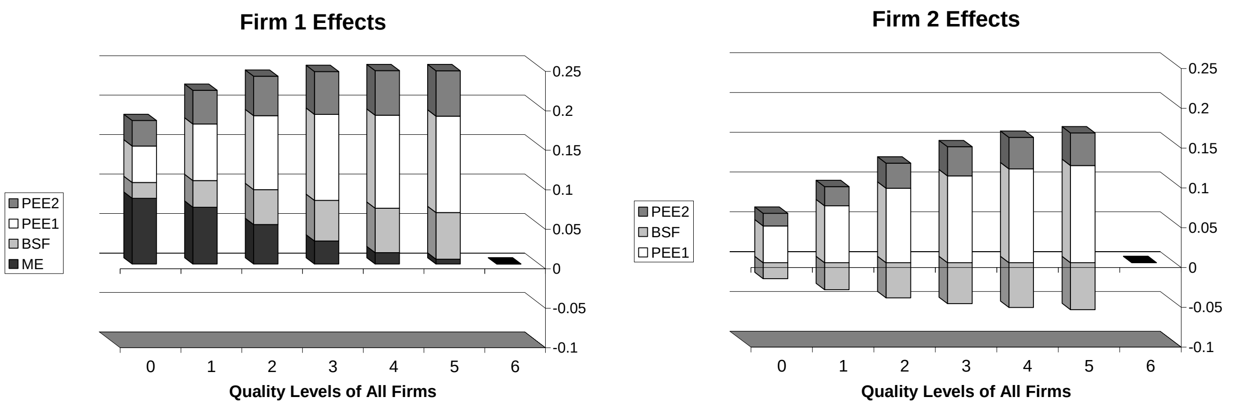

Figure 4.10: Market-share effects in percentage points of a one-step quality upgrade of firm 1 on platform 1 with σ = 50%, δ = 0.4, qualities of all firms on both platforms before the quality upgrade are on the x-axis. ME = Market Extension Effect, BSF = Business Stealing Effect, PEE = Platform Extension Effect.

First, firm 1, the innovator, only benefits from its own quality upgrade, and it does so in the three forms described in figure 4.9: A platform extension effect that stretches out over two periods,[16] a business stealing effect from the competitor on the same platform, and a market extension effect that induces customers who previously bought the outside good to buy software instead. The combined effects seem to be increasing with the initial quality levels of the software firms, which is due to the fact that fewer consumers buy the outside good as we increase quality on the platforms. Any transfers then stem from increased market shares of the platforms overall relative to the outside good. This can also be seen in the shrinking increases of the Market Extension Effect: In the beginning, large numbers of non-buyers switch to buying software, while when quality levels are quite high relative to the outside good, almost all consumers buy software already anyway. While the Market Extension Effect dominates for low levels of software quality, the Platform Extension Effect dominates for high levels. In our model, the platform extension effect outweighs the business stealing effect, meaning that firm 2 on the first platform receives a net benefit from innovation of firm 2. The relative sizes of the effects for firm 2 are depicted in the right side panel, indicating that this net positive effect already occurs in period 1, independent of the quality levels that firms start at.

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[16] The platform extension effect is larger in the first period becauseof the replacement pattern of hardware in the model: each period, 50% of the consumers on a particular platform buy new hardware. Since the size of the second platform is smaller in the second period, the share of the 50% of consumers on this platform that buy new hardware is now smaller relative to all consumers than in the first period.

5. THE DIMENSIONS OF COMPETITION IN NETWORK INDUSTRIES

We identified four different dimensions of competition: competition within platforms, across platforms, with substitute industries and the time-dimension of competition. The interaction of all of these effects determines the total intensity of competition in the market. We therefore need to fully understand how these different effects relate to each other. Careful examination reveals that the main determining variable for this relationship is the lifetime of hardware relative to the lifetime of software. The following thought experiment, based on our results, can clarify this: Assume that the hardware lives much longer relative to software. Then innovation on one platform will result in immediate shifts of market-shares and profits within that platform. But it would have a very slow effect on the other platform. The same is true for competition from outside goods: in a slight stretch of what we learned from the model, we would argue that at same quality levels, substitute goods would have to be cheaper than the software alone in order to eat substantially into the market right away. On the other hand, if hardware is replaced frequently, the across platform shift of market-shares may outweigh the within platform shift. In sum, with slow hardware-replacement, we expect higher within platform volatility of market-shares and profits of software firms relative to across volatilities, and vice versa for fast hardware replacement.

One might ask how important these concepts are. Although hardware and software are important parts of modern industrialized economies we view the basic idea of this analysis far more broadly applicable. In essence, we would like to suggest that hardware and software can be viewed as two different types of complementary specifications, where one of them remains unchanged for a longer period of time, while the other one can change more frequently or can take on more varieties. For example, cars rely on the availability of complementary gas stations. Gas as a fuel for cars has been around now virtually unchanged for decades, while car models come and go, and there has been tremendous innovation in the car industry. Gasoline therefore exists as a long-lived specification, while cars are designed in all kinds of varieties and their specifications change much more quickly than that of gasoline.[17] Therefore, we would think of gas as the hardware[18] and cars as the software. There are other examples with similar basic structure: there is a good with longer innovation cycles, or a longer time to build (a network of gas-stations, hardware) and one with shorter innovation cycles (cars, software) that is complementary to the good that exhibits longer cycles. All of them share the same basic feature: one specification of the complementary pair remains unchanged for a longer period of time relative to the other – that is all what is required for our analysis to hold.

6. CONCLUSIONS

The question we tried to approach was how the existence of competing platforms influences competition, both in terms of competitive inputs, which are investment in quality upgrades in our model, as well as competitive outcomes. We analyzed four drivers of competition: quality levels on the same platform, quality levels across platforms, initial market-shares of platforms and the speed of innovation in the outside good market. With those we were able to identify – and relate to each other – four major dimensions of competition: within platform, across platforms, relative to outside goods and the timing of hardware replacement. Within platforms, we found that indirect network effects tie together the fate of those firms on the same platform. And this tie is the stronger the faster hardware is replaced relative to software. The less frequent hardware is replaced, the weaker is this tie, and the more do firms on different platforms behave as if they were in separate industries. Similar arguments hold for competition from outside goods. In addition, history does matter – adjustment of market shares takes time when complementary goods are involved, and this requires new entrants to have a longer breath in network industries than elsewhere. This is already true even if hardware replacement is fast.

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[17] This simple example shows that hardware does not necessarily be longer lived than software, it only has to stay unmodified as a *specification* for a longer period of time.

[18] The difficulty to establish alternative fuels for cars shows how valid our analysis is for the car industry.

It is instructive to briefly discuss the famous tipping and inertia results in that context: Tipping and tipping reversal is the rule when hardware is relatively short-lived, and consequently there is no excess inertia, but excess sensitivity. Standardization then is a random outcome if tipping reversal has failed to take place repeatedly. If hardware is long-lived, then tipping is much less likely, and the usual excess inertia result seems possible. Again, whether the predictions of the static analysis are correct depends on the speed of hardware replacement.

Since an analytical model would not allow us to address the complexity of these issues or acquire insights comparable to the ones we found, we used numerical methods for our analysis. With this basic analysis, we merely touched on the issues that appear once innovative activities and dynamics are taken into account in network industries. How do incentives to invest change when both hardware and software can experience quality upgrades? What if software firms are not restricted to one platform? What is the role of vertical integration? We intend to address some of these issues in our future research.

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