Winning While Losing:
Competition Dynamics in the Presence of Indirect Network Effects

Sarit Markovich*
Northwestern University

Johannes Moenius**
University of Redlands

January 2006

ABSTRACT

What determines competition dynamics in markets with indirect network effects? We analyze this question in a hardware-software framework, where software producers strategically compete in quality upgrades. We identify market structure as a major determinant of competition dynamics. Using numerical analysis, we examine the effect of initial quality differences on firms' performance, measured by their market values. We find that indirect network effects tie together the performance of firms on the same platform: A successful competitor on the same platform increases the platform's market share, which then increases the incentives of all firms on this platform to invest in quality. This increase in quality further strengthens the platform's position in the market, thereby increasing the market value of all firms associated with that platform. Through this mechanism, a firm may even enjoy a windfall increase in its market value due to an innovation by a competitor on the same platform. Finally, for a wide range of market structures, we find tendencies towards increasing, rather than decreasing, competition between platforms. This is in contrast to the tipping result in the literature.

We would like to thank David Besanko, Ulrich Doraszelski, Shane Greenstein, and Karl Schmedders, as well as seminar participants at Harvard University, Northwestern University and the ZEW conference in Mannheim for very helpful comments. Angela Malakhov, Ami Navon and Veronica Tong provided excellent research assistance. All remaining errors are ours.

* Kellogg School of Management, Northwestern University, Evanston, IL 60208-2013, Tel.: 847-467-3665, s-markovich@kellogg.northwestern.edu.
** School of Business, Redlands, Ca-92373-0999, Tel.: (909) 748-6258, johannes_moenius@redlands.edu

1. INTRODUCTION

It is a commonly observed phenomenon that software firms regularly upgrade their products. For example, Microsoft upgraded its Office 95 suite in 1997, in 2000, and again in 2003. At the same time, we have observed massive increases in R&D spending by software firms, both as a share of sales and in absolute numbers: For example, IBM's R&D expenditure shares on software more than doubled from 1994 to 2003; similar increases took place at Oracle, Microsoft and many other software firms. During 2000, typical R&D spending as a share of revenue for software firms was around 10-20% (Wilson 2001). Moreover, software has grown in economic importance relative to hardware. In 1969, turnover in the US software industry was less than \$ 0.5 billion, or 3.7% of the total computer business (Campbell-Kelly, 1995). In 2002, revenues of the US software industry were close to \$90 billion (US Census Bureau, 2003) – more than double the size of US hardware shipments in the same year (US Census Bureau, 2004).

Software firms in hardware-software industries invest in the quality of their product, not only in order to attract consumers from firms on the same platform, but also to attract consumers from competing platforms. Consumers' choice of platform typically depends on the variety and quality of the complementary software market. The literature defines this as an indirect network effect: demand for the platform technology increases in the availability and quality of complementary products; at the same time, platforms with higher demand attract more variety and higher quality software. Since network effects in the context of software variety are well understood (e.g. Church and Gandal 1992), we focus on indirect network effects derived from quality upgrades, and study competition dynamics in these markets.

R&D expenditure is an investment based on expected future profits. These, in turn, are affected by potential responses from competitors. Since software requires compatible hardware, competitive responses might come from software firms that produce for the same or for competing hardware. This gives rise to interesting questions about the nature of competition in a hardware-software market and how this type of market structure impacts the incentives of software firms to invest in the quality of their products.

In markets with indirect network effects the competitive behavior of software firms is generally driven by two considerations: how strong is the hardware platform for which the firm produces,[1] relative to competing platforms? And how strong is the firm itself within this platform, relative to its competitors? Intuition tells us that if platforms are of similar strength, firms on all platforms will compete fiercely for dominance, since dominance may lead to standardization on one of the platforms. However, it is unclear whether firms on a lagging platform will increase their efforts in the hope to catch up and win the standard race or will simply give up. Also, if software firms on the same platforms are of similar strength, one would expect them to compete fiercely for the consumers on their platform. This, in turn, improves their platform's position relative to competing platforms. Thus, investment strategies in hardware-software markets with indirect network effects are affected by within- as well as across-platform market structure. This suggests that typical results for markets without network effects might not hold for competition in the presence of indirect network effects.

There is a large literature on markets with network effects (e.g., Farrell and Saloner, 1985; Katz and Shapiro, 1985; Church and Gandal, 1992; Breshnahan & Greenstein, 1999; Gandal et al, 1999; Gandal et al., 2000; and Gandal and Dranove, 2003, among many others). While the empirical studies document the importance of network externalities, the theoretical ones focus mainly on the long-run structure of the industry (i.e., standardization vs. variety). This paper takes a different approach and focuses on the short-run dynamics of those markets. We explicitly consider the competitive behavior of firms and its effect on within- as well as between-platform competition. We then study the effect of this competitive behavior on firms' market value.

Adapting the framework developed in Ericson and Pakes (1995), we analyze the effect of market structure (within as well as between platforms) on software firms' incentives to invest in quality upgrades. We assume a market with two incompatible hardware technologies. Hardware provides no stand-alone

[1] It is well established in the literature that whenever a short-lived product requires a compatible longer-lived product, indirect network effects are present. The shorter-lived product is generally referred to as software, and the longer-lived as hardware. We will refer to different types of hardware as hardware platforms or simply platforms.

benefits. Each period, software firms on both platforms invest in quality upgrades and then compete in the product market. Consumers first choose hardware and then software, compatible with their hardware.

Software firms influence the evolution of the market through investment in quality upgrades. The incentives to invest are affected by the distribution of consumers and firms across platforms. Whether a platform dominates the market depends on the market structure to which investments of software firms have led. The outcome of the investment processes is stochastic, and so is the development of the market structure. This model allows for an explicit analysis of the interaction between market structure, software firms' choices, and consumer choices. We solve numerically for the Markov perfect Nash equilibrium (MPE) in order to characterize investment dynamics.

As argued above, market structure is an important determinant of firms' incentives to invest. Each firm's investment determines its next-period quality level, and the combination of all firms' qualities determines the market structure. We therefore present our results in two steps. First, we analyze how market structure influences a firm's market value, which is jointly determined by current market shares and expected future quality levels. Second, we study how current market structures determine whether future market structures are likely to be more or less competitive.

We find that indirect network effects tie together the fate of firms on the same platform and that this tie is stronger the closer competition between the platforms is. When network effects are strong, firms on the same platform increase their competitive efforts. Furthermore, a firm may win additional market value while losing a quality competition: it may receive a windfall increase in market share and market value as a result of its competitor's upgrade, even while keeping its own quality unchanged. Within a given platform, competitive effects are stronger the more similar, in terms of quality levels, the firms on that platform are. That is, as long as platforms are equally strong the network effect and the competitive effect lead to a prolonged, fierce competition. As the previous literature (e.g. Church and Gandal, 1992) suggests, once a platform has taken the lead, the network effect wanes and the competitive effect on the lagging platform weakens, favoring the leading platform. However, our model predicts that if a platform (or a firm) leads in terms of quality, it reduces its level of investment and thus reduces competitive pressure for potential entrants. Therefore, in contrast to the previous theoretical literature, gaining a lead in our model does not necessarily lead to standardization, but is, instead, reversible. Note, however, that the probability of a less competitive market structure is also positive in each period. Once competition is sufficiently weak, less competitive market structures tend to persist and make standardization inevitable.[2] Still, we find neither excess inertia nor "tipping" towards standardization due to a small advantage of one platform over the other.

Our results have important implications: First, we show that market dynamics in the case where indirect network effects are driven by software upgrades differ dramatically from market dynamics in the prevailing literature where network effects are driven by software variety. Second, incentives to innovate depend strongly on how close the race is within as well as across platforms at any point in time. Consequently, the short-run success of innovation matters in determining long-run outcomes. Third, our results suggest that the existence of compatible hardware buys policy-makers time to make decisions should they want to interfere in the market. Note that the implications of these results are not restricted to computer software and hardware products, but rather apply to any market characterized by indirect network effects with quality upgrades in complementary products.

We contribute to three lines of literature: First, we add to the literature on dynamic platform competition. For the computer industry, Bresnahan and Greenstein (1999) provide an excellent descriptive taxonomy of platforms. 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. 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 these authors do not allow software firms to choose prices or quality.[3] Finally, we show how simple R&D competition[4] is influenced by the existence of platforms.

---

[2] Our parameter values are chosen such that the long-run market structure is standardization. Changing the parameters to the case where the long-run market structure is variety does not change our results qualitatively. See Markovich (2004).

[3] 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, and 1992) and Katz and Shapiro (1985, 1986, and 1992).

Our within-platform results generally resemble those of Grossman and Shapiro (1987), who find that the leading firm always invests more than the follower. However, how large these differences are 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, which can be skipped at a first read. We then present the first main result of our paper: network effects can lead to windfall profits in certain cases. We also trace the two main channels of this effect: an immediate change in market share and a change in the incentives to invest. The fourth section studies whether platforms reduce or intensify competition. The fifth section concludes.

2. THE MODEL

Following Markovich (2004), we adapt the framework presented in Ericson and Pakes (1995) and the algorithm for computing it in Pakes and McGuire (1994) to allow for dynamics in the demand side of the model. We assume a discrete-time infinite-horizon model. Consumers care about the set of software choices offered by a platform, both in terms of quality and variety.[5] Consumers derive utility from the software they purchase. Compatible hardware is only needed to operate the software. Consumers are forward-looking: they evaluate the benefits of currently available software on each hardware platform,[6] 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, their competitors', and their platform's performance.

We assume that there are at most two incompatible platforms. Each platform can accommodate up to two software producers. The timing of the game is as follows: first, consumers simultaneously choose hardware and incumbent software firms choose how much to invest in quality upgrades. The outcome of investment takes effect in the following period, and is assumed to be stochastic. Thus, even if a firm

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

5 The effect of variety on consumers' utility is only indirect. More variety increases competition, which then decreases prices. This in turn affects consumers' utility.

6 Bresnahan and Greenstein (1999) define a platform to be a technology around which buyers and sellers coordinate efforts. Their definition of a platform includes hardware, software and peripherals. For ease of exposition, our definition slightly departs from Breshnahan and Greenstein (1999) and only refers to hardware.

invests, it is not guaranteed that its quality increases. Incumbents then compete on prices and consumers choose to buy either one unit of software or the outside good. Finally, nature determines the outcome of the firms' investment and whether an increase in product quality of substitute industries has devalued the quality levels of all software producers on both platforms.

Since the analysis for platform B is analogous, we only discuss platform A. Some definitions before proceeding:

- Let W={0,1,2,…,K} be a finite set of quality values for each firm. Let $a_j \in W$ characterize firm *j*'s quality level when producing software compatible with platform A. The vector $a \equiv (a_1, a_2)$ represents the quality level of both firms on platform A.
- *A* is the percentage of consumers who own a unit of hardware A.[7]
- The state $S \equiv (A, a, b)$ represents the structure of the industry, where the vector *b* represents the quality level of both firms on platform B.[8]

2.1 Consumers' Choice

Consumers get utility from software, but need complementary hardware to operate it, and therefore indirect network effects exist. Consequently, consumers' utility does not depend directly on the size of the installed base of a specific hardware platform. Rather, each consumer cares about the decisions of all other consumers since these decisions influence the incentives to provide complementary products. The more users buy hardware A, the higher the demand for software on this platform. Also, the larger the market-share of platform A, the more valuable is market-share on this platform, leading to increased competition between software firms on this platform. Stronger competition then leads to lower prices or higher quality benefiting consumers on platform A.

Consumers live forever, where every period one-half of the consumers on each platform replace their current hardware with a new unit.[9] Hardware is necessary to consume software, but provides no stand-alone benefit. The utility a consumer gets from hardware depends solely on the quality and price of the software he uses on it. Software provides services for a single period. The one-period utility consumer *i*

[7] Some authors refer to these shares as the "installed base" (e.g., Farrell and Saloner, 1986).

[8] *b* is defined analogously to *a*.

[9] This assumption simplifies the market-share law of motion and avoids the need for additional state variables. The assumption does not affect the results qualitatively, but might slow the standardization process.

gets from the consumption of hardware A and software j with quality level a_j and price p_j^A is $U_{1i}^A(a) - p_1^A = a_1 - p_1^A + \varepsilon_{1i}$, where ε_{1i} represents taste differences among consumers.[10]

Software Choice. Each consumer purchases one unit of software or an outside good that gives a utility of ε_0. Assuming that consumers' preferences, ε, are independently and identically distributed according to a standard double exponential distribution, the probability that consumer i purchases from firm 1 is:

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

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

$$W_i^A(A,a,b) = E\{[U_{ij}^A(a) - p_j] \mid A,a,b\} + \beta E(E\{[U_{ji}^A(a') - p_j^{|}] \mid A,a,b\})) + \xi_i^A \tag{2}$$

where $EU_{ij}^A(a)$ and $E(E[U_{ij}^A(a')])$ are the utilities the consumer expects to get from purchasing software j in the current period and in the next period, respectively. ξ_i^A represents consumer i's additional random utility from platform A.[11] Given the current state, (A,a,b), consumers appraise these expected utilities by forming expectations of future software availability, future quality levels, and future prices.[12] Note that equation (2) reflects the fact that utility is only derived from software, and not from hardware, *per se*. However, once a consumer chooses a platform, he can only buy software compatible with this platform.

Consumer i will purchase hardware A if and only if it gives him a higher expected utility than purchasing hardware B. That is, if and only if $W_i^A(A,a,b) - P^A > W_i^B(A,a,b) - P^B$, where P^A and P^B are hardware A's and B's prices, respectively. Assuming, again, that consumers' preferences, ξ_i^k, are independently and identically distributed according to a standard double exponential distribution, the market share of platform A can be represented by:

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

The law of motion of platform A's market share is then: $A'(A,a,b;P^A,P^B) = A/2 + \Psi(A,a,b;P^A,P^B)/2$.

---

10 Note that the model can accommodate other utility functions, including ones that depend on platform size.

11 The random utility captures consumers' preferences of one platform over the other, regardless of software availability—while some consumers have preferences for the Windows operating system, others prefer Linux.

12 See Markovich (2004) for more details.

2.2 The Software Industry[13]

The software market is a differentiated good oligopoly. Each firm produces only one type of software compatible with one of the platforms. Software firms invest in order to upgrade the quality level of their product. Firms' profits are determined at the price competition stage of the model.

Investment. Each firm's quality level follows a Markov process. Its quality level tomorrow depends on its quality level today, its level of investment today, and the level of competition from substitute industries. Let a_j be firm *j*'s quality level today. The Markov process is then: $a_j^{|} = a_j + \tau_j - v$, where $\tau_j \in \{0,1\}$ is the realization of firm *j*'s investment. We assume that the more a firm invests, the higher is the probability of a quality upgrade. In particular, if firm *j* invests x_j, we take the probability of success to be $p(\tau_j = 1) = x_j / (1 + x_j)$. $v \in \{0,1\}$ represents any technological advance in substitute markets that erodes the advantage held by software firms within the industry of interest.[14] It follows that the quality level of software is always measured relative to the quality of the outside good. Moreover, innovation in substitute markets equally depreciates the quality of all software on both platforms. In each period the probability of an improvement in the quality of the outside good is δ, $p(v = 1) = \delta$, where the realization of *v* is independent of the software firms' investment level. Since in each period the probability that the quality level of all firms decreases by 1 is *δ*, the quality level of firm *j,* which invests x_j, rises by 1 in the next period with probability $(1-\delta)\frac{x_j}{1+x_j}$.[15]

The incumbent's investment problem. Each incumbent firm solves an intertemporal maximization problem to determine its optimal investment. Let the state of the industry be $S = (A, a, b)$, and $V_1^A(S)$ be the expected future payoff of software firm 1 on platform A. Firm *j* then solves the following Bellman equation:

$$V_1^A(S) = \sup_{x_1 \geq 0} \begin{bmatrix} \pi_1(A, a, p) - x_1 + \\ \beta \sum_{a',b'} V_1^A(S') \Pr(a_1' | a_1, x_1^A) \Pr(a_2' | a_2, x_2^A(S)) \Pr(b_1' | b_1, x_1^B(S)) \Pr(b_2' | b_2, x_2^B(S)) \end{bmatrix} \quad (4)$$

---

13 Software firms have three strategies: exit, entry, and investment. Since our analysis throughout the paper does not explicitly examine exit and entry strategies, we do not present the software firms' entry and exit decisions. Interested readers can find the full model in Markovich (2004).

14 More generally, *v* can capture the effect of any exogenous processes affecting the relative quality evaluations of all software firms in the industry of interest.

15 The probabilities that the firm's quality level will stay the same or decrease by one can be calculated analogously.

According to equation (4), software firms earn current profits in the pricing game, $\pi_j(A,a,p)$, plus the expected discounted value of future returns.

The pricing game is a static game with no future effects or dynamics. It resembles the vertical model of competition in Shaked and Sutton (1982). Software firms (on each platform) set prices oligopolisticly. Software demand is determined according to equation (1).[16] Assuming that marginal cost is constant at c, then for any vector of prices, the per-period profit of firm 1 on platform A is:

$$\pi_1(A,a,p) = A * M * D_1(a_1, a_2; p_1, p_2) * (p_1 - c) \quad (5)$$

where M>0 is the total size of the market and A is the percentage of consumers that own platform A.

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 consider only Markov strategies – i.e., the class of strategies that depend only on the "payoff relevant” states. This means that the strategies are defined for every state of the game regardless of how this state has been reached. See Markovich (2004) for the formal equilibrium definition as well as the computational algorithm.

Parameterization. Since investment realization is a relatively slow process, we take a period to be one year and set the discount factor to be β = 0.92. The highest quality level any software firm can achieve, K, is endogenously determined in the model: Firms with a quality level of K = 6 will not find additional investment aimed at achieving a higher quality level to be sufficiently rewarded by consumers and, therefore, these firms will choose not to invest at all. This upper bound represents the maximum difference that an incumbent can obtain relative to any other player, including those in related industries that produce substitute goods. In other words, any player in the industry can always acquire enough knowledge from publicly available sources so that it will be no further behind than this maximum number of quality steps. Market size, M, is set to 10. For simplicity, we set the hardware prices, $P^A = P^B = 0$, and Platform A's market share, A, runs from 0% to 100% in increments of 5%.

In the remainder of the paper, we only present results for intermediate starting values, where each platform starts with a market share of 50%, and the level of outside competition, δ, is also set to 0.5. Changing these parameters changes the shapes of the figures and graphs presented, but not the mechanisms described.[17]

16 Although the pricing game is static and prices do not *directly* depend on software-qualities of the competing platform, it does so indirectly: profits are also a function of the firm's own-platform market share, which in turn depends on the software-qualities of the competing platform.

17 Figures for almost all other parameter-value combinations are available from the authors on request.

3. NETWORK EFFECTS AND THE MARKET VALUE OF FIRMS

The existence of network effects suggests that within-platform competition can affect market values and market structure differently than does competition in the absence of platforms. In order to analyze these effects, we first study the effect of successful quality upgrades on firms' market values. We then study changes in market shares, which are short-run drivers of market values, on the evolution of the market. Finally, we analyze whether network effects intensify or relax competition.

We start with definitions. Fixing the distribution of consumers between platforms, a software firm can only increase profits by winning market share from its competitor on the same platform. We call any effect driven by firms' incentives that are formed holding a platform's market share constant a *competitive effect*. The literature on vertical competition (see, e.g., Shaked and Sutton, 1982) suggests that the competitive effect is strongest when the difference in quality levels between firms on the same platform is zero. Conversely, we call any effect driven by firms' incentives while holding relative quality levels within platforms constant a *network effect*. The literature on indirect network effects (see, e.g., Church and Gandal, 1992) suggests that the strength of the network effect depends on the difference in quality levels across platforms. The distinction between across- and within-platform differences therefore allows us to study the interaction of the network and the competitive effects.

Previous literature has measured the intensity of competition by total investment (e.g.. Grossman & Shapiro, 1987; Doraszelski, 2003). As figure 3.1 shows, in our model total investment in the industry is the highest when quality differences across platforms are zero.[18,19] Total investment on a platform (not shown here) is the highest when quality differences between firms on the same platform are zero. That is,

---

[18] We define total investment in the industry as the sum of investments by all firms on both platforms. Since there are 49 possible quality combinations on each platform, we introduce the following simplification: each combination of qualities on a platform is assigned a number indicating the sum of qualities. For example 3-3 and 4-2 are both assigned the sum 6. Since competitive efforts are the strongest when quality levels on the same platform are similar, we kept only those cases where the quality differences of firms on the same platform were either zero or one. This reduces the number of states per platform to 13. One can think of the weaker cases as delivering 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.

[19] Note that this is true for all cases where the sum of qualities on both platforms is positive. In states where the sum of qualities on one of the platforms is zero or one (no more than one firm develops software compatible with that platform), total investment is the highest when the sum of qualities on the competing platform is 4.

quality differences within and across platforms indicate intensity of competition on and between platforms, respectively. Consequently, in the remainder of the paper we will present all variables of interest as a function of these quality differences.

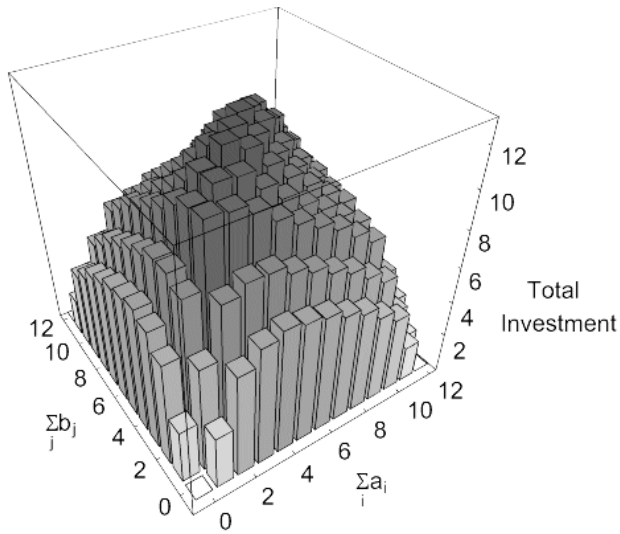

Figure 3.1: The sum of investments by all firms in the industry

3.1 Winning while losing

Can a firm win while losing? In order to analyze this question, we define a firm's own market-value elasticity to be the change in a firm's market value given a one unit change in its own quality level. Cross market-value elasticity is defined as the change in a firm's market value given a one unit change in its competitor's quality level. Figure 3.2 shows a firm's own- and cross-market-value elasticities. We call the analyzed firm *i* and the competing firm on the same platform *-i*. The platform on which firms *i* and *-i* compete is called platform A; the other platform is called platform B. We always measure quality differences relative to firm *i* and to platform A. For example, if firm *i* obtained a quality level of 2 while firm *-i* stays at level 5, our intra-platform difference would be -3.[20] If the firms on platform B exhibit quality levels 2 and 1, respectively, platform A would lead platform B by 4 quality units.

[20] These intra-platform differences are only measured for platform A. For platform B, we always use the strongest combination of qualities as defined above as the point of reference. This implies that there are no quality differences larger than 1 on platform B.

The left panel in figure 3.2 shows the elasticity of firm *i*'s market value with respect to its own successful quality upgrade. The right panel shows the cross-elasticity. We define Δ-intra to indicate the quality differences within platform A. Similarly, Δ-inter denotes the quality differences across platforms A and B. Positive numbers for Δ-intra and Δ-inter indicate that the firm or platform whose elasticities are plotted has a lead over its competitor(s).

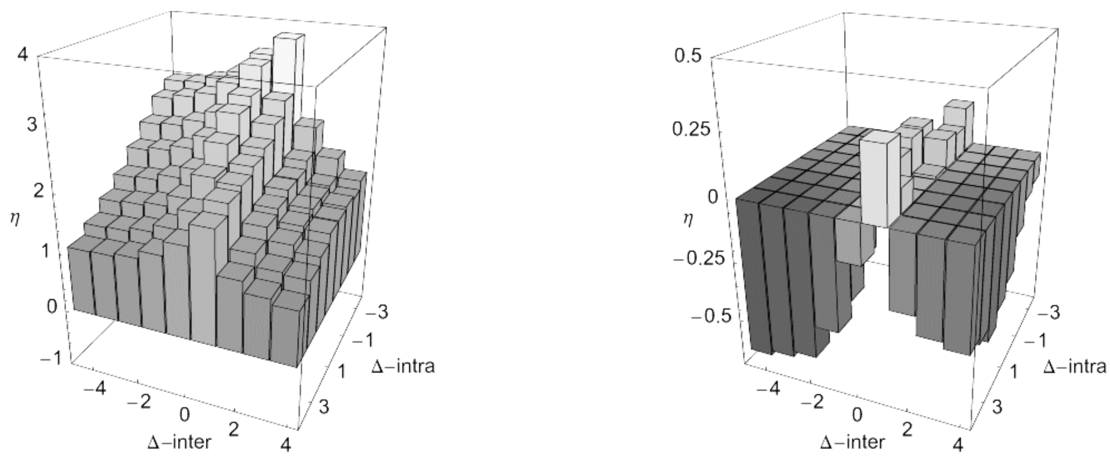

Figure 3.2: Own- and cross-market-value elasticities with respect to quality upgrades.

The left panel of figure 3.2 shows that the more firm *i* lags behind firm *-i* (Δ-intra < 0), the higher is the relative benefit from a quality upgrade. This result is driven by the increase in the competitive effect: Closing in on a competitor on the same platform increases future prospects and with that, market value. The figure also shows that the network effect influences firms' market value the most when overall qualities on both platforms are about the same. This can also be seen in the right panel of figure 3.2, and suggests an interesting feature of competition in the presence of network effects. When platforms are at similar quality levels, a quality upgrade by firm *-i* leads to an increased market value of firm *i*. In other words, if network effects are strong enough, *a firm can win additional market value through its competitors' successful quality upgrade*. This suggests that a firm can receive a windfall increase in market valuation through the innovative success of its competitor on the same platform, as long as quality differences across platforms are small (Δ-inter approximately 0). In order to better understand this effect, the next section illustrates the short-run mechanism of this windfall benefit.

3.2 The Fight for Market Shares

When a firm succeeds in increasing the quality of its product, the following three different effects affect the distribution of market shares: (1) All else equal, a quality upgrade by firm *i* draws customers from firm -*i* on the same platform. We call this a *Business-stealing effect*. (2) The upgrading firm also increases the size of the inside-good market by attracting customers that did not buy software before (i.e., who bought the outside good). This is a *Market-extension effect*. (3) All else equal, a quality upgrade by firm *i* on platform A attracts more consumers to buy hardware A, which we call a *Platform-extension effect*. Since every period only 50% of the consumers on each platform purchase new hardware, there exists a platform-extension effect in two periods, which we call period 1 and period 2 platform-extension effects.[21]

In order to understand how the three effects above interact, we study the effect of a quality upgrade by firm *i* starting from a symmetric situation where all firms have the same quality level and each hardware platform enjoys a market share of 50% (figure 3.3). Since investments are realized at the end of each period, at the beginning of the next period, platform A has a quality advantage over platform B. Since consumers observe software qualities, more buy hardware A; the innovative firm thereby induces a platform extension immediately after the successful upgrade. Therefore, in period 1, both firms on platform A benefit from the higher attractiveness of their platform. At the same time, a larger share of consumers that now own hardware A buy software from the innovator. In other words, firm *i* also wins market share within its platform– from firm -*i*, as well as from the outside good. In the second period, additional consumers buy hardware A. This again benefits both firms. Since market shares within the platform have already been transferred to the innovator, and the share of the outside good within the platform stays

---

[21] More precisely, in our model consumers switch hardware *on average* every two periods. That is, while some switch after 1 period, others might keep their hardware for many periods. Consequently, the platform extension effect spreads over more than two periods. However, since after the first two periods the platform extension effect is marginal, we only focus on the first two periods.

unchanged, we do not see market-extension or business-stealing effects in the second period. Figure 3.3 summarizes the process described above.

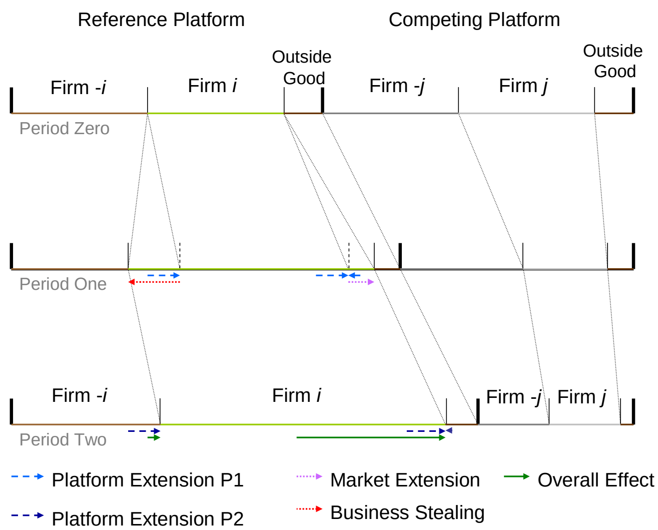

Figure 3.3: Market-share effects over two periods

While a successful competitor on a platform steals market share from the less successful competitor, it also increases the platform's overall attractiveness. The net effect for the unsuccessful firm could therefore be *positive*.[22] Note that the transfer of market shares depends on the durability of hardware. In our case, consumers are locked into the hardware they own, on average, for two periods. In the short run, this protects the firms on the lagging platform, since it slows the transfer of market share from them to the innovator.

Figure 3.4 illustrates these three effects in the context of our model for different quality levels. Qualities of all firms on both platforms before the quality upgrade are on the x-axis and changes in market shares in response to a first-period change in quality[23] of firm *i* are on the y-axis. The different effects are

22 This effect is also present in Church and Gandal (1992). In contrast to their result, in our model this effect is relevant in equilibrium.

23 Strictly speaking, the change in quality is a result of period zero investment that is realized right before period one starts.

denoted as follows: ME = Market-Extension Effect, BSF = Business-Stealing Effect, and PEEj = Platform-Extension Effect, j=1,2

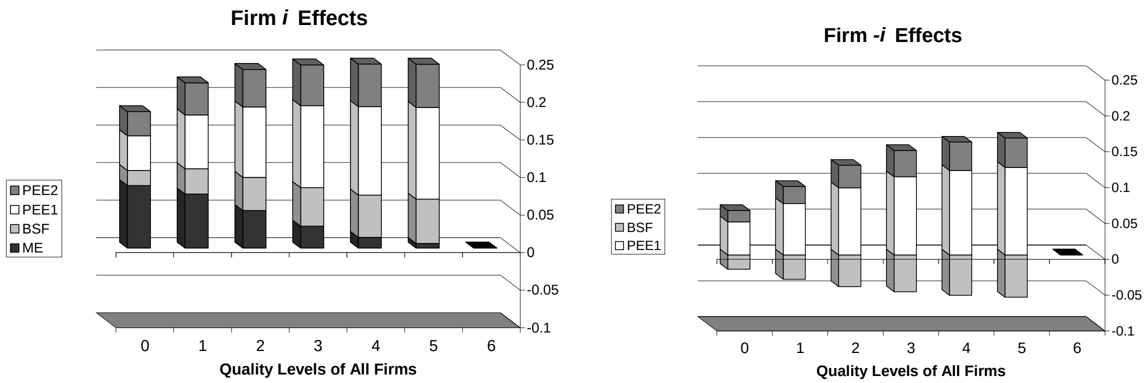

Figure 3.4: Market-share effects of a one-step quality upgrade of firm *i*

Firm *i*, the innovator, benefits from its own quality upgrade in the three ways described in figure 3.3: A platform-extension effect that stretches out over two periods,[24] 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. As the quality of the goods offered increases, the outside-good market shrinks, and the market-extension effect decreases. The platform-extension effect always outweighs the business-stealing effect. Consequently, when all firms start with the same quality level, firm *-i* always enjoys a net increase in overall market share from an innovation of firm *i*. The relative sizes of the effects for firm *-i* are depicted in the right panel, indicating that this net positive effect already occurs in period 1, independent of the quality levels at which firms start. Due to the simplicity of our pricing game, this leads to immediate increases in profits as well as market values as shown in the preceding section. However, this increase in market shares also increases a firm's incentives to invest. In expectation, this further improves its relative position and consequently its market value. We discuss this effect in the next section.

[24] The platform extension effect is larger in the first period because of 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.

3.3 Competitive Efforts: Investment in Quality Upgrades

In this part we characterize how firms’ investment behavior is influenced by market structure. 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, independent of the outcome.

Investment enables firms to influence their position relative to market. As with market-value, overall, a firm's investment depends on three variables: (1) its own quality level, (2) its competitor's, on the same platform, quality level, and (3) the overall quality on the competing platform. An inspection of the results from the model reveals that the effects that drive investment behavior mirrors those that drive market value and will therefore only be reviewed briefly in this section.

In general, Firm *i*'s investment increases in its own quality level. When the quality levels of the two firms on a platform are similar, the competitive effect encourages investment in a fight for future within-platform market share and profits. In converse, the network effect ties together the fate of firms on the same platform. The more similar platforms’ overall strengths are, the stronger is the network effect, pushing firms to join efforts and simultaneously increase investment to gain market share. Once inter-platform differences increase, the competitive effect dominates and firms on the same platform find it more profitable to fight each other rather than to fight their rivals on the competing platform.[25] We get back to this point in the next section.

In other words, substantial differences both across and within platforms lower overall investment, but for different reasons: The network effect weakens when quality differences across platforms increase, while the competitive effect weakens when quality differences within platforms increase. The increase in market value of firm *i* due to its competitor's quality upgrade is therefore driven by two influences. The successful quality upgrade increases the market share of the reference platform, which also benefits firm *i*.

---

[25] Note, obviously firms cannot aim their fight in one direction or the other, nor is this a cooperation game. The discussion merely refers to the incentives behind firms' investment.

This also raises its incentives to invest, increasing its platform's as well as its own market share in expectation. The end result is an increase in its market value.

4. DO NETWORK EFFECTS INTENSIFY OR RELAX COMPETITION?

The preceding analysis shows that competitive efforts are the highest when quality differences within and across platforms are at their lowest. This suggests that the network and competitive effects should favor increased competition. This is in contrast to the existing literature, where the network effect generally leads to standardization, which eliminates competition between platforms. We investigate our hypothesis by studying the effect of current quality differences within and across platforms on future quality differences. Throughout the analysis, we assume that the level of competition is the highest when quality levels are the same. Since hardware market shares take time to adjust, we look at the probabilities that quality differences weakly decrease[26], implying the same or higher levels of competition, over the next two periods[27] as a function of current quality differences within and across platforms.[28]

In order to study the above, we use a vector field diagram. Arrows towards Δ-intra = 0 indicate that increases in intra-platform competition are likely. Arrows towards Δ-inter = 0 indicate that quality differences across platforms will likely be reduced—inter-platform competition is likely to increase. All other types of arrows can be explained analogously. The length of the arrow indicates the probability of (weakly) increased competition.

26 Weakly decrease refers to a situation where quality differences either decrease or stay the same.

27 The graphs that plot probabilities one period ahead look very similar to the ones displayed here.

28 Recall, though, that quality differences within a platform only exist for the reference platform, while quality differences on the competing platform only take on the values of zero (for even quality levels) and one (for odd quality levels) due to the discreet steps of quality upgrades.

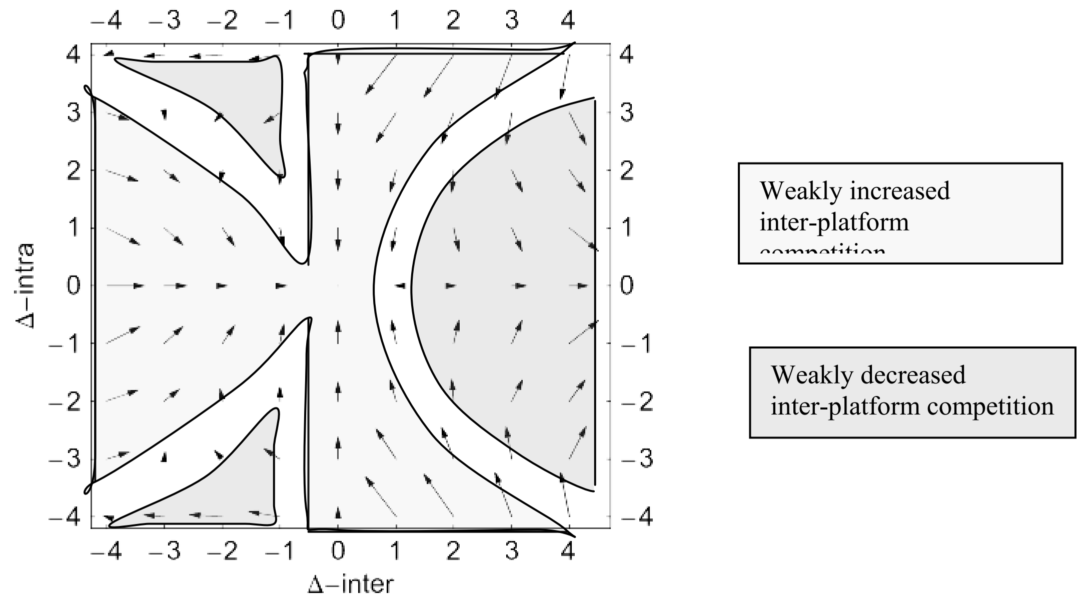

Figure 4.1: Two-period -ahead vector field of weakly increased competition.

The figure shows the following pattern: first, in almost all cases, either inter- or intra-platform competition is likely to *increase*. Second, there are sets of market structures where an increase in competition *between* platforms is likely. Third, the symmetric equilibrium, where Δ-intra and Δ-inter are both equal to zero, has a high probability of persistence. Finally, the path to standardization is paved for the leading platform if its firms are of similar strength. However, "tipping" towards standardization due to a small advantage of one platform over the other does not generally exist in our model. We study the above referencing the platform of interest as platform A, and the competing platform as platform B.[29]

Looking at Δ-intra, we can see that sustained or increased competition within a platform is almost always more likely than lower level of competition. The probability is higher, the more platform A is ahead of platform B: Being ahead implies a larger market share for platform A. This in turn leads to a higher incentive to invest for both firms on platform A. Consequently, the probability that one firm falls behind is

[29] One might expect that figure 4.1 should look perfectly symmetric in all directions. This is only correct along the Δ-intra axes, since there are three sources of asymmetry: First, Δ-intra varies only for platform A, not for platform B (see previous footnote). Second, weakly increasing competition means that competition will stay either the same or increase. Weakly decreased competition means that competition will stay the same or decrease, so these sets overlap. Finally, to a small extent the boundary conditions (meaning that quality differences are bound from above and below) in our model lead to somewhat different incentives when a platform is ahead as compared to when it is behind.

low. Conversely, when platform A falls behind, a smaller platform market share reduces incentives to invest. This, in turn, increases the probability that one firm falls behind. When both firms are at the same quality level, it is impossible to increase within-platform competition, and inter-platform competition dominates.

Similar forces drive the elimination of quality differences between platforms. Consider, first, the case when within-platform competition is strong (Δ-intra = 0). The more platform A lags behind, the higher the probability that between-platform competition increases, as firms on the lagging platform try to catch up. This holds also for the case when platform A is slightly ahead. However, once platform A's advantage is large enough (Δ-inter≥2), we observe an outcome similar to the classic tipping result. In this case, the more platform A is ahead, the greater is the likelihood that platform differences will increase. We see similar patterns when intra-platform differences exist (Δ-intra > 0). However, whether we observe more or fewer cases where inter-platform competition increases depends on the level of within-platform competition: the higher are the quality differences within platforms, the less likely the platform is to keep its lead or to catch up with the leading platform. This relationship is driven by the competitive effect: competitive efforts are highest when firms are of similar strength, which in turn increases the probability of winning the competition between platforms.

Given our parameterization, the symmetric industry structure is not sustainable in the long run. Sooner or later, one of the firms on one of the platforms might have a string of bad luck. Once this bad luck lasts long enough to open a large enough gap in firms' quality, the industry will reach the region of the state space where competition decreases, rather than increases. The industry would then snowball and standardize on the leading platform.[30]

Discussion. As Markovich (2004) has shown, whether we see standardization or whether two platforms can coexist depends on particular parameter values of the model. Focusing on a specific parameter value,

[30] Markovich (2004) gives the condition under which the symmetric market structure is stable.

δ=0.5, we complement this long-run result with an explanation of short-run mechanisms that take place during the process. Firms base their investment decisions solely on expected discounted future profits. Profit expectations depend on a firm's current quality level and the quality levels of its competitors on the same, as well as on the competing, platform. If there are no quality differences within-platforms and both platforms start with the same market shares, total investment on the leading platform is always higher than on the platform that lags behind. The competitive effect induces competitors on the leading platform to fight for that large overall market share, increasing investment on that platform. Competitors on the lagging platform have to wait for one or more periods until they can gain the platform lead—inducing lower investment on the lagging platform. This favors standardization. The more similar are the quality levels on one platform, the more firms invest. This again strengthens the platform, regardless of whether it is ahead or behind. However, lower levels of investment produce more uneven outcomes, since the probability that only one firm on a platform succeeds increases with lower levels of investment. This is again in favor of the leading platform, since levels of investment are higher on this platform.

Given these forces that favor the leading platform, why do we still observe comparatively high probabilities of weakly stronger competition? The intuition behind this result is two fold: First, when one platform gets far ahead, it does not regard the second platform as a relevant competitor. Investment on this platform falls, increasing the chance of catch-up by the lagging platform. Moreover, high levels of investment also tend to cement the current within-platform structure: since high investment leads to a high probability of success, close competitors stay close, while existing within-platform differences are likely to increase. However, this weakens the leading platform, increasing the likelihood of catch-up.

These observations can be summarized as follows: in our model, the network effect increases as quality differences between platforms decrease. The network effect generally induces higher competitive efforts for all players. The competitive effect increases with the intensity of competition within platforms: the closer the quality levels are, the higher the investment on a platform. Increased investment, however, leads to more persistence of the existing competitive situation. Consequently, the network effect and the competitive effect are *aligned* with each other, and combined they *slow down* the forces towards standardization in situations where all software firms produce similar qualities. Once this similarity is broken across platforms, some consumers want to switch platforms. But they cannot, since they have just recently bought new hardware. This also slows down standardization, at least until all consumers are able to switch to the platform of their choice. At the same time, the fight for a larger market increases competitive efforts on the leading platform and lowers them on the lagging platform, strengthening the forces favoring standardization. These forces, however, may be weakened if the leading platform supports firms with very different quality levels while the firms on the lagging platform are of similar quality. In this case, the competitive effect would favor the lagging platform and reversal of the tendency towards standardization is possible.

It is worthwhile to compare these results to the traditional literature on indirect network effects with respect to increased variety instead of quality upgrading. There are three major differences between our results and this literature. First, in our model, the network effect and competitive effects are aligned with each other. In variety models, they work in opposite directions. Second, in our model, the network effect is the strongest when platforms are roughly equally strong and competition is most intense. In models of variety, the network effect is strongest when there are few varieties on a platform, and weakens as an increasing number of varieties becomes available. For example, in the model of Church and Gandal (1992), the network effect is already dominated by the competitive effect when platforms are of equal size. Therefore, in their model, the network effect only matters when its magnitude is relatively insignificant. Third, when network effects and competitive effects are strong, they lead to more persistent market structures in the case where platforms are equally strong. Thus, shifts in platforms' market shares are reversible. In variety models, even a small advantage of one platform over the other induces *all* new entrants to join the stronger platform, a process generally referred to as tipping. The discussion above, therefore, strongly suggests that in order to make correct analyses and predictions, it is important to distinguish the major source of innovation in a model with indirect network effects: increases in variety (like CDs and DVDs) versus quality upgrades (like software).

5. CONCLUSIONS

In this paper, we study how the existence of competing platforms influences competition. We analyze two drivers of competition: quality levels on the same platform and quality levels across platforms. Within platforms, we find that indirect network effects tie together the fate of firms on the same platform, and that this tie is stronger the more equally strong the platforms are. When network effects are strong, firms on the same platform not only increase their competitive efforts due to a quality upgrade of a firm on their platform, they may also receive a windfall increase in market share and market value as a result of the competitor's upgrade. Network effects are weak when there are large differences in the strength of platforms. Competitive effects on a platform are stronger the larger the market share of the platform is and the more similar the firms on that platform are. The network effect, the competitive effect, and the delay in the replacement of hardware all favor prolonged, fierce competition as long as platforms are equally strong. In our model, we consequently do not find an equivalent to the tipping result of the variety literature. The competitive effect favors the leading platform once a platform has taken the lead. If a firm (or platform) leads in terms of quality, it reduces its level of investment and thus reduces competitive pressures for potential entrants. Excess inertia therefore can also be overcome in our model without extraordinary effort.

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. This type of analysis can be further used to study additional issues that appear once innovative activities and dynamics are taken into account in industries with network effects. For instance, 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.

REFERENCES

Bresnahan, T. and S. Greenstein, 1999, "Technological Competition and the Structure of the Computer Industry ", *The Journal of Industrial Economics*, XLVII: 1-40.

Campbell-Kelly, M., 1995, "Development and Structure of the International Software Industry, 1950-1990", *Business and Economic History*, 24(2): 73-110.

Chou, C. and O. Shy, 1990, "Network Effects without Network Externalities", *International Journal of Industrial Organization*, 8: 259-270.

Church, J., and N. Gandal, 1992, "Network Effects, Software Provision, and Standardization", *Journal of Industrial Economics*, 40: 85-104.

Doraszelski, U., 2003, "An R&D race with knowledge accumulation", *RAND Journal of Economics*, 34(1): 20-42.

Ericson, R. and A. Pakes, 1995, "An Alternative Theory of Firm and industry dynamics", *Review of Economic Studies*, 62: 53-82.

Farrell, J., and G. Saloner, 1985a, "Standardization, and Variety", *Economic Letters*, 20: 71-74.

Farrell, J., and G. Saloner, 1985b, "Standardization, Compatibility, and Innovation", *RAND Journal of Economics*, 16: 70-83.

Farrell, J., and G. Saloner, 1986, "Installed Base and Compatibility: Innovation Product Preannouncements, and Predation", *American Economic Review*, 76: 940-955.

Farrell, J., and G. Saloner, 1992, "Converters, Compatibility and the Control of Interfaces", *Journal of Industrial Economics*, 40: 9-35.

Gandal, N., S. Greenstein and D. Salant, 1999, “Adoptions and Orphans in the Early Microcomputer Market,” *The Journal of Industrial Economics*, XLVII: 87-106.

Gandal N., M. Kende and R. Rob, 2000, "The Dynamics of Technological Adoption in Hardware/Software Systems: The Case of Compact Disc Players, " *RAND Journal of Economics*, 31: 43-61.

Gandal, N. and D. Dranove, 2003, “The DVD vs. DIVX Standard War: Network Effects and Empirical Evidence of Preannouncement Effects,” *Journal of Economics and Management Strategy*, 12: 363-386.

Grossman, G. and C. Shapiro, 1987, "Dynamic R&D Competition", *Economic Journal*, 97:372-387.

Harris, C. and J. Vickers, 1985, "Patent Races and the Persistence of Monopoly", *Journal of Industrial Economics*, 33: 461-81.

Judd, K. 1985, "On the Performance of Patents", *Econometrica*, 53: 567-585.

Katz, M. and C. Shapiro, 1985, "Network Externalities, Competition and Compatibility", *American Economic Review*, 75: 424-440.

Katz, M. and C. Shapiro, 1986, "Technology Adoption in the Presence of Network Externalities", *Journal of Political Economy*, 94: 822-841.

Katz, M. and C. Shapiro, 1992, "Product Introduction with Network Externalities", *Journal of Industrial Economics*, 40: 55-83.

Kwak, M and D. Yoffie, 1999, "Apple Computer 1999", HBS case 9-799-108.

Loury, G., 1979, "Market Structure and Innovation", *Quarterly Journal of Economics*, 93: 395-410.

Markovich, S. 2004, "Snowball: A Dynamic Oligopoly Model with Network Externalities", Tel- Aviv University, *mimeo*.

Reinganum, J. 1981, "Dynamic Games Innovation", *Journal of Economic Theory*, 25(August): 21-41.

-----------, 1982, "A Dynamic Game of R&D: Patent Protection and Competitive Behavior", *Econometrica*, 50(May): 671-688.

-----------, 1983, "Uncertain Innovation and the Persistence of Monopoly", *American Economic Review*, 73: 741-748.

Shaked, A. and J. Sutton, 1982, "Relaxing Price Competition through Product Differentiation", *Review of Economic Studies,* 49 (1), 3-13.

US Census Bureau, 2004, "Computers and Office and Accounting Machines: 2003", *Current Industrial Reports*, MA334R(03)-1 (December)

Wilson, L. 2001, "Software Development Industry Study", Business and Research Services, SBTDC