Strategic Innovation and Technology Adoption in an Evolving Industry*

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Abstract

We introduce a racing model with multiple product generations, product innovation, spin-outs, and licensing. Industry conditions and innovation characteristics affect who wins the race and who markets the resulting product. Small firms market their innovations when they pioneer a new generation or improve quality in a young generation and license their innovations in mature generations. If old generation leaders ever market improvements in young generation goods, they do so early on. Leadership in mature generations persists. Tests on the rigid disk drive industry (1977-97) provide empirical support. The results have implications for antitrust policies and policies governing employee non-compete agreements.

JEL Codes: K31: Labor Law; **L41**: Antitrust Policy; **L63**: Industry Studies: Disk Drives; **O31**: Innovation Processes and Incentives; **O38**: Innovation Policies.

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1. Introduction

Effective policy analysis requires an effective positive model of behavior. In this paper, we consider some important facts about innovation that have been under-emphasized in previous models. We introduce a model that considers these facts and test the model on the rigid disk drive industry during the period 1977-97. Our results lead us to criticize certain features of antitrust policies and policies governing employee non-compete agreements.

Three facts have been under-emphasized in models of innovation races (Reinganum 1989, Gans and Stern 2000) and industry evolution (Jovanovic and MacDonald 1994, Klepper 1996, Filson 2001, 2002, Franco and Filson 2002): First, small firms rarely grow by attempting to compete head-to-head with industry leaders in a given product market. Instead, small firms grow by differentiating themselves from current industry leaders.[1] For example, small software firms do not pursue competition with Microsoft in personal computer operating systems, word processors, or spreadsheets. Instead, they produce different products in an effort to become leaders in the market for their good.

Second, firms with the "best" technologies are not always the most profitable firms or the ones with the largest market shares. In many formal models of innovation and technology adoption, firm size and firm profits are monotonic functions of a summary technological "know-how" variable. In contrast, real-world large firms often appear to have relatively mediocre technology compared to their smaller competitors. Marketing and connections with important buyers often appear to trump technological know-how.

Third, many resources are mobile. This implies that small high-tech firms can be important even when they do not grow large. Models where employees leave existing firms to create new "spin-out" firms have been developed and tested by Franco and Filson (2002) and Klepper and Sleeper (2002). Acquisitions and licensing are also important in many industries (Salant 1984, Gans and Stern 2000). Large firms may acquire innovative small firms or license from them, as in the biotechnology industry.

We adapt the standard single-prize racing model (Reinganum 1989) to allow for product

[1] Some attempts to formally explain different innovation strategies exist, such as Nelson (1988) and Eeckhout and Jovanovic (2002). However, the distinction between strategies is typically quite simple, such as that between "innovators" and "followers."

differentiation, spin-out formation, and licensing. Doing so yields a richer description of initial industry conditions, outcomes, and policy impacts than previous models. Innovation involves new products instead of the cost reductions that are typically analyzed in racing models. This facilitates our empirical analysis, which focuses on product innovation. We consider two types of innovation: quality improvements and new product generations. Distinguishing between the two is useful in many industries. For example, in the computer industry, mainframes, minicomputers, desktops, laptops, notebooks, and hand-held devices are all product generations. New generations have different impacts on existing goods than quality improvements. The richness in our model involves some tradeoffs. For example, the model considers only one innovation at a time, and players do not look beyond the current race. Insights for industries with a sequence of innovations are obtained by considering how initial conditions at the beginning of each race change as the industry evolves.

Analytical results and numerical computations suggest several intuitive testable hypotheses, and tests on the rigid disk drive industry provide empirical support. First, small firms are more likely to market than license when they pioneer a new product generation. Second, these firms market quality improvements in an existing generation only when firms in the generation are small and the business stealing effects on the older generation goods are small. These conditions are likely to hold only early in the evolution of the new generation. Small firms who improve quality in mature generations profit by licensing instead of marketing.

The results clarify how market share leadership evolves in new product generations. In general, new generations pass through at most three stages. In the first stage, an entrant or another small firm pioneers the generation. In the second stage, the leader in the old generation either wins the race to improve quality in the new generation or licenses the quality improvement from the innovator. In the third stage, the leader in the new generation either wins the race or licenses the quality improvement. If the business stealing effect associated with the new generation is high when it is first introduced, then the first stage is skipped. If the business stealing effect associated with the new generation is low when it is first introduced but rises quickly thereafter because of rapid exogenous growth in demand or rapid quality improvements, then the second stage is skipped.

Our results have implications for antitrust policies. Antitrust policy in the U.S. favors competition between many small competitors. High product market concentration and price markups are causes for concern. The impacts of market structure and firm behavior on innovation have been considered in more cases since the introduction of the 1995 Department of Justice/Federal Trade Commission *Antitrust Guidelines for the Licensing of Intellectual Property,* but this consideration appears to have been one-sided. Gilbert and Tom (2001) present evidence that the consideration of innovation effects has not affected the outcomes of most cases, but when it has affected outcomes it has led to challenges in more markets and broader remedies. In contrast, our results suggest that innovation effects should often be mitigating factors that cause the agencies to permit greater product market concentration and higher price markups. Persistent concentration and high markups in an environment with licensing can allow all innovators (including small start-ups) to appropriate a greater amount of the social benefits generated through innovation. This may lead to more rapid innovation, which benefits consumers.

Further, our results suggest that analyses of entry barriers and potential competition in innovation markets should consider barriers to employee mobility and spin-outs (start-ups founded by former employees of existing firms). Thus, our paper adds to the recent literature on policies governing employee non-compete agreements in high-tech industries (Gilson 1999, Cooper 2001). Under California law, non-compete agreements are not enforced. Most other states enforce these agreements. Our analysis suggests that non-compete agreements are socially harmful because they discourage the emergence of small start-ups that can compete in innovation races and market goods in new product generations.

1.1. Innovation and New Product Generations in the Rigid Disk Drive Industry

IBM introduced the first rigid disk drive in 1956. The first drives, 14" in diameter, were either sold in mainframe computers or sold directly to computer users. When the minicomputer market emerged in the mid 1970's an original equipment market developed, and disk drive manufacturers began selling drives to computer manufacturers.

Our analysis covers the period 1977 to 1997. Innovation occurred rapidly during this period and took three main forms. First, several new product generations were introduced in the form of smaller diameter drives. When first introduced, the new drives served new customers; 8”, 5.25”, 3.5”, 2.5”, and 1.8” drives were first used in minicomputers, desktops, laptops, notebooks, and handheld devices respectively. Second, several improvements in technical features improved storage capacities and access times. Third, several improvements in design and manufacturing techniques improved costs and reliability.

We focus on the first two forms of innovation (new diameters and improvements in storage capacities within a diameter) because our data is best-suited to address these two. Tables 1-5 examine the top ten storage capacity leaders in each diameter (or fewer if less than ten make the diameter). Each firm’s highest capacity drive in each diameter each year is used to determine the leaders (data sources are discussed in Subsection 3.1). Within the group of leaders, we focus on three subgroups: *old generation manufacturer-marketers* are firms whose sales exceeded $50 million 1983 dollars for at least three years at some point during their life and achieved $50 million 1983 dollars for at least one year before the firm introduced drives in the diameter; *recent entrants* are firms who entered in the past three years and have not yet achieved $50 million 1983 dollars in sales; *new generation manufacturer-marketers* are firms whose sales exceeded $50 million 1983 dollars for at least three years only after the firm introduced drives in the diameter.

In general, the new diameters are pioneered by recent entrants and small firms and then two patterns emerge. First, some old generation market share leaders become storage capacity leaders in the new diameter. Second, some of the early storage capacity leaders grow to become large manufacturer marketers. The relative importance of each of these two patterns varies by diameter, but in either case as the new product generation matures the list of storage capacity leaders and market share leaders becomes more similar. However, some recent entrants still make the list of storage capacity leaders even as the diameter matures.

Of course, generating product market revenue is not essential for generating value in high-tech industries. Many small firms profit by licensing their technology instead. For a sample of publicly traded U.S. specialized disk drive manufacturers, Table 6 provides simple OLS regressions of the natural log of market capitalization on market share and a normalized measure of storage capacity described in Subsection 3.1. The results suggest that market share leadership and technological leadership have independent effects on firm value.

Why do small firms pioneer new generations? Why do some small firms grow in some generations but not in others? What factors affect the rate of old generation innovation in the new generation? In the next two sections, we introduce and test a simple model of innovation with different product generations. The results explain why technology leadership is not always equivalent to market leadership and how the two are related over the evolution of a new product generation.

The model oversimplifies innovation in two main ways. First, it considers only one innovation at a time. All firms compete for the same innovation, and the winner can either license it or market the resulting product. In real markets multiple innovations occur in sequence and several may occur simultaneously. We implicitly assume that firms have a limited time horizon when making decisions or that they cannot forecast beyond the current innovation. Second, the model has a partial equilibrium setting with a few large incumbents. Adjusting the technology and market sizes of these large firms yields testable hypotheses that relate industry conditions to which types of firms innovate.

2. The Model

The model is a partial equilibrium model of a single-prize innovation race. Initially, there are four firms in the industry, and each produces one good. The product space has two dimensions: a horizontal dimension (product generation) and a vertical dimension (quality within a generation). Initially, there are two product generations, A and B, and two firms produce in each generation: firms $1a$ and $2a$ produce generation A and firms $1b$ and $2b$ produce generation B. The goods produced within each generation have different levels of quality: $\theta_{2a} \geq \theta_{1a}$ and $\theta_{2b} \geq \theta_{1b}$, where θ_i denotes firm i's quality. Because we lack data on production costs, our model focuses on product innovation and ignores cost differences. All firms have identical marginal costs of production, c.

Initially, there are two groups of consumers. Two groups is sufficient to allow for the possibility that some consumers tend to prefer goods in generation A while others prefer goods in B. To simplify notation, we identify each group with the generation its members tend to prefer consuming. Each consumer purchases at most one good. Consumer i in group A buys good j in generation A if doing so maximizes i's utility:

$$U_{ij} = \alpha_{aa}\theta_j - p_j + \varepsilon_{ij} \tag{2.1}$$

where α_{aa} is a preference parameter, θ_j and p_j are the quality and price of good j, and ε_{ij} is an individual-specific shock. When consumer i in group A buys a good in generation B, the good's quality is weighted by α_{ab}. Consumers in group B have parameters α_{bb} and α_{ba}. We discuss restrictions on these parameters below. A consumer can purchase none of the industry's goods, and this option has an expected utility of zero. Under the standard assumption in the discrete choice literature that the individual-specific shocks are independently and identically distributed according to the distribution $e^{-e^{-\varepsilon_{ij}}}$, the probability that a consumer in group A purchases good $1a$ in generation A is

$$\lambda_{a,1a} = \frac{e^{\alpha_{aa}\theta_{1a} - p_{1a}}}{1 + e^{\alpha_{aa}\theta_{1a} - p_{1a}} + e^{\alpha_{aa}\theta_{2a} - p_{2a}} + e^{\alpha_{ab}\theta_{1b} - p_{1b}} + e^{\alpha_{ab}\theta_{2b} - p_{2b}}} \tag{2.2}$$

The other probabilities, $\lambda_{a,2a}$, $\lambda_{a,1b}$, $\lambda_{a,2b}$, $\lambda_{b,1a}$, $\lambda_{b,2a}$, $\lambda_{b,1b}$, and $\lambda_{b,2b}$, are similar.

There are n_a consumers in group A and n_b in group B. Firm j's profits are

$$\pi_j^0 = \max_{p_j}(p_j - c)(n_a\lambda_{a,j} + n_b\lambda_{b,j}) \tag{2.3}$$

All firms choose their prices simultaneously and in equilibrium every player best responds. Each incumbent j earns π_j^0 up to the point where some firm innovates. In the analysis of innovation, we consider B to represent the newer of the two product generations; firms 1a and 2a produce old generation goods and 1b and 2b produce young generation goods.

2.1. Innovation

Beginning from the initial state, one of two possible opportunites for innovating occurs. First, there may be an opportunity to improve quality in the young generation: an opportunity to develop a good in B with quality $\theta_{3b} > \theta_{2b}$. Second, there may be an opportunity to pioneer a new generation C. Denote the quality of the good in C by θ_{1c}. With the introduction of C, a group of n_c consumers who had no demand for goods in A or B enters the market. These group C consumers value quality in C using the parameter α_{cc} and never purchase goods in A or B ($\alpha_{ca} = \alpha_{cb} = -\infty$). Consumers in groups A and B value quality in C using the parameters α_{ac} and α_{bc}, respectively.

After the opportunity for innovating occurs, each incumbent can enter the race or not. If an incumbent enters the race, it pays a race entry cost f_e. New firms may also enter the race. We assume the new firms are spin-outs because spin-outs are important in the disk drive industry, but this assumption is not critical for most of our analysis. Each of the four firms can generate one spin-out. This reflects the fact that few employees in any given firm acquire sufficient know-how to found their own firm. If a spin-out forms, it pays a spin-out formation cost f_s in addition to f_e. After entry decisions are made, there are zero to eight firms in the race. If no firms enter the race the industry remains in the initial state.

The race has several features that are standard in the literature (Reinganum 1989). First, the race takes place in continuous time. This allows us to ignore ties where two or more firms obtain the innovation at the same time. Second, once one firm innovates, the race is over. Third, the innovation production function is memoryless. Given that no firm has successfully innovated, firm i's probability of succeeding in the next instant is $h_i(x_i)$, where x_i is firm i's investment in the next instant. Because the race is memoryless, the firm's problem is a stationary one, and the optimal level of x_i does not change during the race. Each firm i chooses x_i to maximize its value.

If firm j wins the race it has two options. First, j can manufacture and market the new good. If j does so, all firms simultaneously choose their prices to maximize profits. In equilibrium, firm j earns $\frac{\pi_j^j}{r}$ from its original good (if it is an incumbent, zero otherwise) and $\frac{\pi_I^j}{r}$ from the new good, where r is the continuous time discount rate and the superscript indicates which firm markets the innovation. In the case of incumbents, the new product does not replace the marketer's old one but simply extends the marketer's product line.

Alternatively, j can license (sell) the innovation to another firm. When firm j licenses the innovation, it gives up the profits from the new good in return for a one-time payment from the licensee. Its profits from its orginal good may also change when it licenses because product market prices depend on who markets the new good. We assume that the licensor selects the efficient licensee in the sense that there are no further gains from trade. Licensing involves a transaction cost f_l.[2] Denote firm j's per period profit from its original good when firm k markets the new product by π_j^k. Gains from trade must be positive in order for j to license, which implies that the following condition must be satisfied for at least one firm k:

$$\frac{\pi_k^k + \pi_I^k}{r} + \frac{\pi_j^k}{r} - f_l \geq \frac{\pi_j^j + \pi_I^j}{r} + \frac{\pi_k^j}{r} \tag{2.4}$$

We assume that the two parties Nash bargain over the gains from trade (net of f_l) and that the relative bargaining power of licensors and licensees may be unequal. The outside option is to allow j to market the new product. When j licenses to k, j receives

$$\frac{\pi_j^j + \pi_I^j}{r} + \gamma \left[\frac{\pi_k^k + \pi_I^k}{r} + \frac{\pi_j^k}{r} - f_l - \left(\frac{\pi_j^j + \pi_I^j}{r} + \frac{\pi_k^j}{r} \right) \right] \tag{2.5}$$

and k receives

$$\frac{\pi_k^j}{r} + (1-\gamma) \left[\frac{\pi_k^k + \pi_I^k}{r} + \frac{\pi_j^k}{r} - f_l - \left(\frac{\pi_j^j + \pi_I^j}{r} + \frac{\pi_k^j}{r} \right) \right] \tag{2.6}$$

where γ measures the relative bargaining power of the licensor.

We focus on subgame perfect Nash equilibria. To compute the subgame perfect Nash equilibria, we use generalized backward induction.

2.2. Marketing the New Product

In the marketing stage, one firm has the innovation, either by winning the race or by acquiring a license. All firms choose their prices simultaneously. All of the goods are substitutes (cross-price elasticities are non-negative) and all best response functions are upward sloping. The firms choose lower prices than a monopolist would because they ignore the negative impact of their price reductions on their competitors' demands. Because of these business stealing effects, firms who do not market the new product prefer whoever does to set a high price.

New firms choose the lowest price for the new product because they do not internalize any of the business stealing effects. If a new firm i markets the new product it chooses its

[2] It is useful to think of the innovation as a prototype of the new product. The transaction cost would include the cost of verifying that the new product works and that it is manufacturable at reasonable cost.

price p_I^i by maximizing

$$\max_{p_I^i} \pi_I^i = (p_I^i - c)(n_a\lambda_{a,I} + n_b\lambda_{b,I} + n_c\lambda_{c,I}) \tag{2.7}$$

which yields the first-order condition

$$n_a\lambda_{a,I} + n_b\lambda_{b,I} + n_c\lambda_{c,I} - (p_I^i - c)[n_a\lambda_{a,I}(1-\lambda_{a,I}) + n_b\lambda_{b,I}(1-\lambda_{b,I}) + n_c\lambda_{c,I}(1-\lambda_{c,I})] = 0 \tag{2.8}$$

If an established firm j markets the new product it considers the effect of p_I on the demand for its original product. This adds the following expression to the first-order condition:

$$(p_j^j - c)[n_a\lambda_{a,j}\lambda_{a,I} + n_b\lambda_{b,j}\lambda_{b,I} + n_c\lambda_{c,j}\lambda_{c,I}] \tag{2.9}$$

Expression (2.9) is positive, which implies that p_I^j exceeds the p_I an entrant would choose.

2.3. Licensing the Innovation

In the licensing stage, firms look ahead and anticipate the outcome of the marketing stage. If the business-stealing effects are non-zero and the licensing transaction cost is sufficiently low, then new firms never market the new product. There are gains from trade from transferring the innovation to an incumbent because the incumbent marketer internalizes the business stealing effect between its original good and the new product. The incumbent marketer increases the prices of the two goods, which through the best-response functions causes the other incumbents to increase their prices. The profit of every good rises.

Intuition suggests that gains from trade are exhausted when the firm who would set the highest p_I obtains the innovation, because the business stealing effects of the new product are minimized. We do not have a formal proof that this must always occur, but all of our numerical computations yield this outcome, which implies that if licensing occurs, the firm who obtains the license is the one who would set the highest p_I. In the discussion that follows, we assume that this always occurs. Note that this implies that licensing may or may not preserve leadership in a particular product generation. The firm who markets the innovation would normally be the one that experiences the most negative externality from a low market price on the innovation. While this would ordinarily be a large firm, it may be an old generation or young generation firm. New firms never obtain the license.[3]

Numerical results also show which winners license and which ones market. If $f_l = 0$, licensing always occurs unless the firm who would set the highest p_I wins the race. This is because there are gains from trade. For $f_l > 0$, the gains from trade must exceed f_l in order for licensing to occur. If we list firms in order of how high they would set p_I, from highest to lowest, the firm at the top of the list is the licensee if licensing occurs. The gains from trade are highest in the transaction where the firm at the bottom of the list licenses. Thus, if we begin from a high no-licensing level of f_l and reduce the transaction cost, the lowest firm on the list (a new firm) licenses first, then as the transaction cost continues to fall eventually the second lowest firm licenses, and so on.

2.4. The Innovation Race

In the innovation race firms look ahead and realize what their payoffs will be after licensing and marketing occurs. For simplicity we assume that the licensing stage takes no time. Each firm i in the race chooses its investment x_i to maximize

$$V_i^0 = \int_0^\infty e^{-rt} e^{-\sum_j h_j(x_j)t} \left[\pi_i^0 - x_i + h_i(x_i) V_i^i + \sum_{j \neq i} h_j(x_j) V_i^j \right] dt \tag{2.10}$$

where V_i^j is the value firm i receives if j wins. Simplifying,

$$V_i^0 = \frac{\pi_i^0 - x_i + h_i(x_i) V_i^i + \sum_{j \neq i} h_j(x_j) V_i^j}{r + \sum_j h_j(x_j)} \tag{2.11}$$

Firm i's first-order condition is

$$-r - \sum_j h_j(x_j) + h_i'(x_i) \left[r V_i^i - \pi_i^0 + \sum_{j \neq i} h_j(x_j)(V_i^i - V_i^j) + x_i \right] = 0 \tag{2.12}$$

[3] In some industries, new firms may obtain licenses to help them enter a market. This is optimal only if the firm has some complementary assets that will give it a competitive advantage after acquiring the license. We do not consider complementary assets because they are not important in the disk drive industry: the most prominent entrants were spin-outs.

The model yields the familiar replacement and efficiency effects, $rV_i^i - \pi_i^0$ and $\sum_{j \neq i} h_j(x_j)(V_i^i - V_i^j)$ (see Reinganum 1989).

If no licensing occurs, then for incumbents,

$$\begin{aligned} V_i^i &= \frac{\pi_i^i + \pi_I^i}{r} \\ V_i^j &= \frac{\pi_i^j}{r} \end{aligned} \tag{2.13}$$

For new firms, $\pi_i^0 = 0$, $V_i^i = \frac{\pi_I^i}{r}$, and $V_i^j = 0$.

If no licensing occurs, the replacement effect is highest for spin-outs and laggards $1a$ and $1b$. The new product reduces the profits of all original products because of the business stealing effects. Thus, $\pi_i^i < \pi_i^0$ for incumbents. The replacement effect is highest for spin-outs because they have no original good. Industry laggards are hurt less than the leaders because their goods have smaller demands to begin with. In contrast, the value terms in the efficiency effect (the $V_i^i - V_i^j$) are highest for the industry leaders $2a$ and $2b$. These are the firms that suffer the most when a competitor who sets a low p_I markets the new product.

Now consider the impact of licensing. First, consider the impact of licensing on the V_i^j terms, which appear in the efficiency effect. Suppose firm i is the licensee. Then the first-order condition implies that i's incentive to win the race falls when it can license because V_i^j rises; firm i licenses from j only if the value i receives exceeds the value of letting firm j market the good. Note that all other incumbents are also better off when they lose the race because they prefer firm i to market the good rather than any of their other competitors (because i sets the highest p_I). Thus, other incumbents invest less. However, the incentives of a new firm cannot fall because $V_i^j = 0$. Thus, when licensing is possible the effects on the V_i^j terms favor new firms over incumbents and cause industry investment to fall.

Now consider the impact of licensing on the V_i^i terms. If firm i is the licensee then V_i^i does not change; if i wins the race it markets the new product. If j wins the race and i has all of the bargaining power, then firm j is indifferent between licensing and marketing. As a result, V_j^j does not change. Thus, if the licensee has all of the bargaining power then the V_i^i terms do not change. If the licensor has some bargaining power, then V_j^j rises for firms other than the licensee. This causes firms other than the licensee to have a greater incentive to invest. Thus, when licensing is possible the effects on the V_i^i terms lead to more investment as long as the licensors have bargaining power.

2.5. Spin-out Formation and Race Entry

Incumbents enter the race if the value of expression (2.11) minus f_e exceeds the value of expression (2.11) when $x_i = 0$. Spin-outs form if expression (2.11) exceeds $f_s + f_e$. If f_s and f_e are sufficiently low, spin-outs always form and all firms enter the race. As f_e rises, fewer firms enter the race. As f_s rises, fewer spin-outs form. When f_e and f_s are positive, there may be multiple equilibria in the race entry stage. For example, it may be optimal for three firms to enter the race but several configurations of three firms satisfy the equilibrium entry conditions. To break ties, we first select the equilibria where the number of racers is maximized. Then within that group we select the equilibrium that maximizes total firm value. These assumptions are not critical for our results.

2.6. Numerical Examples

Obtaining analytical results for racing models with heterogeneous firms is difficult. Changing a parameter or the identity of the innovation marketer affects the entire vectors of prices and investments. The systems of equations that determine equilibrium prices and investments (the first-order conditions) consist of several nonlinear equations. These difficulties account for the tendency of the previous literature on racing to explore environments where either firms are identical or the differences are minimized (for example, one entrant and one incumbent). In this subsection, we present numerical results from our model. We attempt to choose parameters to fit the rigid disk drive industry.

In the rigid disk drive industry, customers are segmented according to the size of the computers they manufacture. Firms who make small computers cannot substitute a larger drive, but firms who make large computers can substitute a smaller drive if storage capacities and prices favor doing so. In the data, we measure storage capacities using areal densities, which measure how much information can be stored on each square inch of disk. To convert areal density to megabytes we compute $a_i \pi (\frac{d_i}{2})^2$, where a_i is the drive's areal density, measured in megabytes per square inch and d_i is the diameter of the drive. This implies that to compare areal densities across diameters, large-computer manufacturers will weight the areal density in a small drive by $\frac{d_i^2}{d_j^2}$ (π and the $(\frac{1}{2})^2$ drop out). The average ratio (8/14, 5.25/8, 3.5/5.25, 2.5/3.5, 1.8/2.5) is roughly 0.66. Given this,

$$\begin{bmatrix} \alpha_{aa} & \alpha_{ab} & \alpha_{ac} \\ \alpha_{ba} & \alpha_{bb} & \alpha_{bc} \\ \alpha_{ca} & \alpha_{cb} & \alpha_{cc} \end{bmatrix} = \begin{bmatrix} 1 & (.66)^2 & (.66)^4 \\ -\infty & 1 & (.66)^2 \\ -\infty & -\infty & 1 \end{bmatrix} \tag{2.14}$$

We set $c = 1$, $r = .04$, $f_e = 0$, $f_s = 0$, $f_l = 50$, $\gamma = .5$, and $\theta_{1a} = 1$. The other qualities are functions of θ_{1a}. For example, $\theta_{1b} = \omega * \theta_{1a}$, where ω is a constant. The average areal density in a small diameter drive is 25% greater than that of a large diameter drive, so as a base case we set ω equal to 1.25. We will consider the effects of changing ω below. To compute θ_{2a} and θ_{2b}, we compute the ratio of the highest areal density in a given diameter to the average areal density in that diameter on an annual basis. The ratio gives us an estimate of the gap between the storage capacity leader and a typical follower. On average (across diameters and years), the areal density of the leader is twice that of the areal density of the average firm. This implies that $\theta_{2a} = 2 * \theta_{1a}$ and $\theta_{2b} = 2 * \theta_{1b}$. On average, the highest areal density improves by 50% each year. Given this, $\theta_{3b} = \theta_{2b} * 1.5$. The highest areal density of a new product generation drive in the year it is introduced is roughly equal to the highest areal density of the adjacent larger diameter drive that year, so we set $\theta_{1c} = \theta_{2b}$.

We need to specify n_a, n_b, and n_c. These values represent the size of the main customer base for each product generation. We set $n_a = 100$. As product generation B matures, n_b rises relative to n_a because of exogenous growth in the demand for smaller computers. We consider the effect of increasing n_b on the equilibrium of the game in order to obtain testable hypotheses about the impact of the age of the product generation on who innovates and who markets. We note that when a new product generation is first introduced, demand is typically very low relative to the demand for the older generations' goods.[4] Given this, we

[4]This is typical: new generations take time to diffuse before they pose a threat to old generations. In the disk drive industry, sales of new diameter drives were much lower than the sales of old diameter drives in the early years of life of the new diameter. For 5.25", 3.5", and 2.5" drives, revenue exceeded 2% of the revenue of larger drives for the first time in the fourth year after the drive was first introduced. For 1.8"

set $n_c = 1$ to focus on cases where n_c is small relative to n_a and n_b.

For now, assume that all firms have the same innovation production function: $h_i(x) = \alpha x^{1/2}$ for all i. We set $\alpha = .01$. Increasing a firm's α causes it to invest more. Increasing the scale of all of the firms' α's can affect the results because all of the h_i's rise and the efficiency effect becomes more important. This causes firms $2a$ and $2b$ to invest more.

To obtain testable hypotheses, we consider changes in n_b to allow for exogenous growth in the demand for goods in generation B and we consider changes in ω to allow for improvements in the quality of B goods relative to A goods over time.

Consider an innovation in generation B. Table 7 shows how different values of n_b affect which firms are most likely to win the innovation race and whether licensing occurs. When n_b is low, spin-outs are most likely to innovate, the old generation leader is next most likely to innovate, and licensing never occurs. As n_b rises, the new generation leader becomes more likely to innovate. Eventually, when n_b is sufficiently high, the new generation leader and spin-outs are the firms most likely to innovate and everyone licenses to the new generation leader. In general, spin-outs tend to be among the most likely innovators because the replacement effect is highest for spin-outs. The efficiency effect is highest for the firm that experiences the highest business stealing effect, which is either $2a$ or $2b$.

Table 8 shows that increasing the relative quality of the young generation has an effect similar to increasing n_b. We increase ω, which increases θ_{1b} and θ_{2b}. This affects which firms are most likely to win the innovation race and whether licensing occurs. When $\omega = 1.5$, the old generation leader is most likely to innovate, followed by spin-outs. No licensing occurs. When $\omega = 1.75$, the old generation leader and spin-outs are still the most likely firms to innovate, but now spin-outs license the innovation to the old generation leader. As ω continues to rise, eventually the new generation leader displaces the old generation leader as the firm most likely to innovate, and all firms license to the new generation leader.

Now consider which firms are most likely to pioneer new product generations. As long as new product generations have a small impact on existing generations, then the efficiency effect is low and the most likely innovators are determined by who has the strongest replacement effect. Suppose $n_b = 10$. In this case, spin-outs are most likely to pioneer a new product

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drives, revenue never exceeded this mark; for 8" drives, revenue exceeded this mark in the second year.

generation, followed by the laggards in each generation, $1b$ and $1a$, and then the leaders, $2b$ and $2a$. No licensing occurs. For other values of n_b the pattern is similar, as long as the new good has a small impact on existing goods. If the new good has a higher impact then the efficiency effect becomes more important, and the existing leaders become more likely to win the race or license from the winner. Which leader has the greater incentive depends on which one experiences the highest business stealing effect.

2.7. The Know-How Effect and Spin-outs

In addition to efficiency and replacement effects, a "know-how effect" may also affect who wins the race by changing the innovation production function. The know-how effect is that a firm with higher know-how has a higher probability of innovating for a given investment, and the marginal effect of an additional dollar spent may be higher at every point on the innovation production function. In our model, the high quality firms $2a$ and $2b$ would have higher α parameters. Their spin-outs may also have high α's if the spin-outs transfer firm-specific know-how from their parents (Franco and Filson 2002 and Klepper and Sleeper 2002 present evidence that this occurs). The know-how effect also explains why spin-outs may be more successful than other types of entrants: non-spin-outs lack the know-how of the best spin-outs. We consider the know-how effect in the empirical analysis below.

3. Empirical Results

3.1. Data

The main data source is the *Disk/Trend Report* on Rigid Disk Drives (1977-1997). The dataset contains 193 firms, 1189 firm/year observations, and 11644 model/year observations. Annual sales of disk drives are reported for several firms.[5] The data includes model characteristics and introduction dates. The level of detail allows us to construct measures of product quality and keep track of which product generations each firm produces.

[5] Sales of other products, including licenses and disk drive components, are not included in the measure of disk sales. Only sales of drives are counted.

We measure quality using areal densities. The areal density measures how much information can be stored on each square inch of disk (megabytes/in^2). To compare across years, we normalize areal densities using z scores. First, we select each firm's highest areal density drive in each diameter in each year.[6] Then, for each diameter/year group, we compute the mean and standard deviation of this best-drive measure across firms. We use these means and standard deviations to compute z scores for each firm/diameter/year measure, and this is our main quality measure. In tests where the appropriate diameter is not clear, a firm's diameter quality is averaged across the diameters the firm produces to obtain an average measure of the firm's quality (this is used in Table 6, described in Subsection 1.1).

To test hypotheses about innovation in young product generations, we divide firms into old generation firms and young generation firms for each adjacent diameter pair: {14",8"}, {8",5.25"}, {5.25",3.5"}, {3.5",2.5"}, and {2.5",1.8"}. In each pair, the larger diameter is the old generation and the smaller one is the young generation. If a firm produces only the young drives in a given year it is coded as YPG (young product generation) for that pair/year; if it produces only the old drives it is coded as OPG (old product generation); if it produces both it is coded as BOTH.[7]

To test hypotheses about new firm success, we distinguish between spin-outs and non-spin-outs. Spin-outs and their parents were identified using information in the *Disk/Trend Report*, press releases and articles provided by James Porter (editor of the *Disk/Trend Report),* the *Directory of Corporate Affiliations,* the *International Directory of Company Histories,* and Christensen (1993). There are 40 cases of one or more employees leaving one or more disk drive firms to found a new firm in the period 1977-1997. To determine the parent firms we focus on the background of the founders and not on other employees, for which data is unavailable. The implicit assumption is that founders had considerable influence on the products and strategies of the start-up; evidence from firm press releases and the *Disk/Trend Report* supports this assumption.

[6] Only drives that have been shipped are used when making these calculations. Drives that have been announced but not yet put into production (and may never actually be produced) are not included.

[7] Firms who produce neither the young or the old drives are left out of the analysis of the pair, but this is irrelevant; such firms rarely innovate in the young generation. For example, firms who produce only smaller diameter drives innovate in larger diameter drives in only four cases in the 20 year period we are examining.

We focus on U.S. entrants. All but two of the spin-outs are U.S. firms. We use press releases obtained through *Lexis-Nexis* to identify licensing agreements and acquisitions, and coverage of U.S. firms exceeds coverage of non-U.S. firms. We exclude two entrants who make drives only for their own use. We do not count changes in ownership or name changes as new entry. We group the entrants into three categories. Those who eventually achieve $50 million 1983 dollars in at least three years are *large manufacturer-marketers*. Those who are not in this category but eventually license to or get purchased by a large manufacturer-marketer are *licensors*. Those who are not in either category and exit before 1997 are *failures*. Only one late entrant does not fall into one of these three categories; we exclude it. Although the first two categories do not describe all of the ways entrants might generate value, they do capture the two ways that our model emphasizes. They also capture the two main types of success in our data; *failures* typically exited without generating substantial revenue.

3.2. Quality Improvements in Young Product Generations

We consider quality improvements in young product generations on an annual basis using probit models. The dependent variable is a binary variable that takes the value 1 if, in a particular year, a firm introduces a young generation drive with an areal density higher than the industry-best areal density in the generation in the previous year.[8] We consider only firms who were in the market in the previous year; this allows us to measure the initial quality of the potential innovators. The model suggests that the most likely incumbents to improve quality in the young generation are the leaders in the old and young generations. The know-how effect reinforces this conclusion, because it implies that high quality firms are more likely to innovate. The model also suggests that if leaders in the old generation ever innovate in the young generation, they do so early on and when the quality in the young generation is relatively low compared to the quality in the old generation.

The following independent variables are included. We include the firm's quality in the

[8] Thus, we focus on only those firms who improve on last year's best quality. This is the type of innovation our model and most racing models emphasize. Lerner (1997) takes a different approach and measures whether each firm improves on its own drives each year. He finds that laggards are more likely to introduce improvements than leaders, but this mainly measures a tendency of laggards to catch up to leaders, not surpass them.

previous year to test the hypothesis that higher quality makes the firm more likely to innovate. We include the age of the young generation to test the hypothesis that old generation firms are more likely to innovate in the young generation early on. To test the hypothesis that old generation firms are more likely to innovate in the young generation when the quality of the young generation goods is relatively low compared to the quality of the old generation goods, we compute the megabytes associated with the highest areal density drive in each generation each year. Then we compute a ratio $\frac{MB_{YPG}}{MB_{YPG}+MB_{OPG}}$ for each old/young pair (discussed in the previous subsection) in each year. As this ratio rises, the quality of the young generation drive rises relative to the quality of the old generation drives. The lagged value of the megabyte ratio is included in the probit analysis in order to measure the relative qualities at the start of the innovation race.

We interact the know-how, age, and megabyte ratio variables with dummy variables that indicate whether the firm produces drives in the young generation, old generation, or both. This allows us to assess whether an increase in age, for example, makes young generation firms more likely to innovate. As additional control variables, we include dummy variables for young and old generation firms and year effects. Table 9 reports summary statistics.

The results in Table 10 support the hypotheses. Higher initial quality makes the firm more likely to innovate, as predicted. This effect is stronger for firms that produced the young generation or both in the previous period, but all three effects are positive and statistically signficant. The marginal effects show that a one standard deviation increase in quality increases the probability that a firm innovates by 1.4, 3.7, and 3.9 percentage points for old, young, and both firms, respectively. An increase in the megabyte ratio or the diameter's age makes young generation firms more likely to innovate, as predicted. For example, an increase in the megabyte ratio from .25 to .5 increases the likelihood that an young generation or a both firm innovates by 8.2 and 2.1 percentage points, respectively. In contrast, the likelihood that an old generation firm innovates falls by 1.8 percentage points. An increase in drive age of one year decreases the likelihood that a young generation firm innovates by 0.63 percentage points, but it decreases the likelihood that an old generation firm innovates by 2.3 percentage points. The likelihood that a both firm innovates rises by 1.8 percentage points.

3.3. New Product Generations

The model suggests that new entrants and industry laggards in the young and old generations are the most likely pioneers of new product generations. Tables 1-5 provide some initial support for this view; many of the technology leaders early on are entrants. To analyze this further, we focus on the firms Franco and Filson (2002) define as "early movers" in the new diameters: firms that introduced drives in the diameter within the first three quarters of the introduction of the diameter. Table 11 lists these firms by diameter. For incumbents, the firm's quality in its closest larger diameter in the previous year is listed. For spin-outs, the parent's quality in its closest diameter in the year before the spin-out is born is listed. These quality measures capture the technological position of the firm (or the parent, where the spin-out gets its know-how) before the introduction of the new diameter.

The first firms to introduce all of the new diameters were spin-outs: International Memories, Seagate, Rodime, Prairietek, and Integral Peripherals were the first firms to introduce 8", 5.25", 3.5", 2.5", and 1.8" drives, respectively. Table 11 shows that the other early pioneers were primarily low quality laggards in either the old or young generation. Of the firms listed in Table 11, only two, IBM and Control Data, were large manufacturer-marketers with high quality and high market shares at the time they introduced their drives. On the whole, the results support the hypothesis: spin-outs and laggards are the main pioneers.

3.4. Entrant Success vs. Failure

The model suggests that exit without licensing or marketing is associated with failure to innovate. New firms are more likely to fail when attempting to improve quality in mature product generations because of the strong incentives the leading incumbents have to win the race. The know-how effect suggests that spin-outs have an advantage over other entrants.

To test these hypotheses we estimate probit models. The dependent variable is a binary variable that takes the value 1 if the entrant experiences either type of success (licensing or marketing). We include the following independent variables. First, we use the quality of the entrant's first drive to measure how successful it was in its first effort to innovate. Second, we use the age of the product generation of the entrant's first drive to test for age effects.

Because 14" drives were introduced long before the beginning of our sample period, we consider the age of this generation separately, using 1976 as the initial year. Using different initial years for 14" drives has no effect on the results. Finally, we include a dummy variable that takes the value 1 if the entrant is a spin-out. Table 12 reports summary statistics.

The results in Table 13 support the hypotheses. Entrants with higher initial quality are more likely to experience success. The estimated marginal effects in Equation 1 show that a one standard deviation increase in quality increases the likelihood of experiencing success by 10 percentage points. Entrants who attempt to innovate in more mature product generations are less likely to experience success. Equation 1 shows that a one-year increase in the age of the product generation reduces the probability of success by 11 percentage points. Equation 2 shows the probability of success rises by 25 percentage points if the entrant is a spin-out. Equation 3 re-estimates Equation 1 including only spin-outs to confirm that quality and the age of the product generation continue to have the predicted effects.

3.5. Entrant Licensing vs. Marketing

The model suggests that if a new firm wins the innovation race, there are two possible outcomes, licensing and marketing. Conditional on winning the race, entrants are more likely to become large manufacturer-marketeters if they pioneer a new product generation or improve quality early on in a young product generation. Entrants are more likely to license or be acquired if they improve quality in a mature product generation. To test this hypothesis we focus on only those entrants who experienced one of the two types of success. The dependent variable is a binary variable that takes the value 1 if the entrant became a large manufacturer-marketer, 0 if the entrant licensed. The independent variables are identical to those used in the previous subsection.

The results in Table 14 support the hypothesis; entrants who innovate in more mature product generations are more likely to license. Although the effects are statistically insignificant (the sample size is small), the point estimates are large. Equation 1 shows that a one year increase in the age of the product generation increases the probability that the entrant licenses by 14 percentage points. Entrants with higher quality are more likely to market, but this effect is relatively weak. Equation 2 shows that if the entrant is spin-out its probability of growing large increases by 11 percentage points. Equation 3 shows the considering only spin-outs does not change the conclusion about the effect of product generation age.

3.6. The Role of Licensing

The model suggests that early in the life of a young product generation, old generation firms may improve quality in the young generation by licensing innovations from other firms, particularly entrants. Thus, licensing early on is associated with entry into the young generation. As the young product generation matures, the licensees tend to be firms who already produce the young generation's goods. To test this hypothesis, we sort licensees into those who did not produce the product generation in the year before obtaining the license and those who did. The average age of the product generation at the time of the license in the first group is 3.67 years; the average age in the second group is 5.89 years. The difference is significant at the 10% level. This supports the hypothesis.

The model also suggests that licensees are likely to be large. To test this hypothesis, we note that 55% of the licensees in our sample are large manufacturer-marketers.[9] In the sample of all firm-year observations, only 36% are large manufacturer-marketers. These proportions are significantly different at the 5% level. This supports the hypothesis; large manufacturer-marketers are over-represented in the group of licensees.

4. Policy Implications

In this section we discuss the implications of our findings for antitrust policies governing licensing agreements and policies governing employee non-compete agreements. We use our model to examine the effects of prohibiting licensing and spin-outs. Our empirical results help clarify the role of licensing and the potential impacts of non-compete agreements.

Racing models typically yield ambiguous welfare results: there may be too little or too much investment relative to the social optimum. There may be too little because the inno-

[9] We exclude broad cross-licensing agreements and acquisitions of large firms from the sample of licenses because these are not the type of transaction our model emphasizes. Including these would add more transactions between large firms. We also exclude a particular type of license that resulted from Rodime patenting the 3.5" diameter design. All producers of 3.5" drives had to obtain licenses from Rodime.

vation marketer does not appropriate all of the social benefit from the innovation as long as consumer surplus is positive. There may be too much because there is a single prize; the investment of the non-winners is wasted. Each firm invests without internalizing the negative externalities of its investment on its competitors (they are less likely to win).

One way to assess the relative importance of these two offsetting factors is to impose structure on consumer demand, as we have done. Anderson, de Palma, and Thisse (1992) describe how to compute consumer surplus in a discrete choice model with no consumer heterogeneity. It is straightforward to extend their approach to the case with three types of consumers. We assume that utility shocks are i.i.d. with distribution $e^{-e^{-\varepsilon_{ij}}}$. The pre-innovation expected consumer surplus of consumers in group A is

$$n_a \ln(1 + e^{\alpha_{aa}\theta_{a,1a} - p_{1a}} + e^{\alpha_{aa}\theta_{a,2a} - p_{2a}} + e^{\alpha_{ab}\theta_{a,1b} - p_{1b}} + e^{\alpha_{ab}\theta_{a,2b} - p_{2b}}) \tag{4.1}$$

The expected consumer surplus of consumers in group B can be calculated in a similar fashion. Total consumer surplus is the sum of these two surpluses. Adding an extra good (the new product) adds an additional $e^{\alpha\theta - p}$ term to the expression in brackets, and if the good pioneers a new product generation then the surplus of group C consumers is also added. The present value of consumer surplus can be computed in a manner similar to the present value of a firm (described above in Subsection 2.4).

4.1. Antitrust Policies Governing Licensing

Antitrust policy occasionally limits licensing from potential product market entrants to incumbents on the grounds that entry would improve product market competition.[10] In our model, the welfare impacts of such policies depend critically on how they effect entry into the innovation race. If allowing licensing induces entry into the race, then industry investment rises. The social benefit of faster innovation may outweigh the social loss from market power in the product market. The results suggest that antitrust authorities should assess the impact of forbidding licensing on incentives to innovate.

[10] Gilbert and Tom (2001) provide an excellent summary of U.S. antitrust agencies' policies and practices in recent cases involving innovation concerns.

Relative bargaining power is important. In Subsection 2.4 we argued that the incentive provided by the efficiency effect is reduced when licensing is allowed; the V_i^j terms rise for every incumbent i. Further, if the licensee has all of the bargaining power, then the replacement effects do not change. This yields a general conclusion: if the licensee has all of the bargaining power, then licensing reduces investment. We also noted that as the licensor's bargaining power rises, the replacement effect leads to increased innovation from firms other than the licensee. The game is one of strategic complements; thus, the licensee also increases its investment. This effect offsets the impact of the efficiency effect. The licensor with more bargaining power can appropriate more profits for itself, and this yields greater incentives to enter the race and invest.

Considering relative bargaining power yields a policy conclusion that is counter to the current approach of the U.S. antitrust agencies. The agencies view high payments from the licensee to the licensor as a sign that the licensor could have entered the product market. The agencies' pro-competitive stance causes them to prefer entry to licensing, and as a result they frown on licensing agreements with high payments to the licensor. In contrast, our model suggests that licensing agreements where the licensor obtains a higher percentage of the gains from trade (a higher payment) may be associated with more competition in the race, greater investment in innovation, and higher welfare.

Payments to the licensor are higher if the licensor can profitably enter, but our analysis suggests that the ability of a firm to enter does not imply that entry generates higher welfare than the best licensing agreement. After the innovation is available, welfare is maximized by improving product market competition, and this is what the agencies focus on. In doing so, they ignore the impact of their policies on the incentives to innovate in the first place.

4.2. Policies Governing Employee Non-Compete Agreements

A non-compete agreement, or covenant not to compete, is a contract entered into by an employee and employer whereby upon termination of employment the employee is restricted from competing in the same business as the employer for a particular period of time in a certain geographical location. Non-compete agreements are designed to protect employers from unfair competition caused by former employees working for a competitor or starting a similar business. This type of competition is deemed unfair because the former employee can use confidential knowledge of the former employer to gain an advantage in the market.

A small minority of states do not enforce non-compete agreements unless they are used in conjunction with a sale of a business, dissolution of a partnership, or other very specialized cases. This is important for our analysis because the vast majority of the spin-outs in the rigid disk drive industry were initially located in California, the most prominent non-enforcer. Thus, the rigid disk drive industry shows what can happen if employee mobility is permitted.

In typical racing models, an increase in the number of firms in the race causes a winner to emerge sooner (Reinganum 1989). Our model is no exception to this general result, which implies that spin-outs lead to higher industry investment and higher welfare. Thus, in our model, preventing spin-outs through non-compete agreements or other means lowers total welfare, primarily because it reduces the present value of consumer surplus. However, preventing spin-outs may increase total firm value as the incumbents avoid having to compete with the spin-out entrants in the innovation race. Thus, firms may have an incentive to prevent spin-outs even when doing so reduces total welfare.

Our numerical results suggest that if the business stealing effects of the new product are small then total firm value may rise when spin-outs enter the innovation race. This occurs because the positive effect of generating additional customers outweighs the negative effect of enhanced competition in the product market. This is most likely to happen when the spin-out intends to pioneer a new product generation. This suggests that non-competes would have the primary objective of preventing competition in races to improve quality in existing product generations. When total firm value rises, a prospective spin-out might be able to buy out its non-compete agreement by offering its parent a share of its value. Of course, in reality it may not be possible for a firm to assess which type of innovation its departing employee intends to pursue. In this case, the firm may refuse to renegotiate. Thus, the presence of a non-compete agreement and the possibility of its enforcement may deter employees from founding firms even when they do not intend to compete head-to-head against their parents in the product market.

We find little evidence of spin-outs forming to compete head-to-head with their parents in the product market. Most of the spin-outs who grew to become large manufacturer-marketers were pioneers of new product generations or early followers. The most successful of this group was Seagate, the first firm to introduce a 5.25" drive and the market share leader at the end of our sample. Of the group of spin-outs that grew large, only Quantum entered to compete head-to-head against its parent. Quantum entered with a low end 8" drive that imitated its parent Shugart Associates' 8" drive.

On the whole, our theoretical and empirical results suggest that spin-out formation has beneficial effects. Our results add to a growing literature that questions whether non-compete agreements should ever be enforced. Gilson (1999) argues that California's policy of not enforcing non-compete agreements contributed to high employee mobility in Silicon Valley and that this mobility encouraged growth. Cooper (2001) argues that non-competes are a double-edged sword if all firms use them: each firm gets to keep its own employees but cannot get other firms' employees. The resulting labor allocation is sub-optimal.

5. Conclusion

In this paper, we introduce a racing model with multiple product generations, product innovation, spin-outs, and licensing. Tests of the model's predictions using data from the rigid disk drive industry (1977-97) provide empirical support. In the model, new product generations pass through at most three stages. First, they are typically pioneered by spin-outs and lagging firms. Second, old product generation leaders innovate or license to become leaders in the new product generation. Third, as the new product generation matures, eventually the new generation leaders maintain their leadership, either through innovation or licensing. The first stage is skipped if the business stealing effect of the new generation goods on the old generation goods is high immediately. The second stage is skipped if the business stealing effect is low initially, but the market for the new generation goods grows rapidly thereafter, either through exogenous demand growth or rapid innovation.

The results clarify the role of spin-outs. If a spin-out innovates in a mature product generation, it licences its innovation to a current market leader. Spin-outs only market and grow large if they enter new product generations early on and those product generations experience the favorable shocks that allow spin-outs to maintain their leadership in the face of potential entry from the old product generation leaders.

The theoretical and empirical results lead us to question certain aspects of U.S. antitrust policies on licensing and policies governing employee non-compete agreements. Our model suggests that in innovative environments, high product market concentration encourages investment unless the leading firms' market power prevents potential technology licensors from appropriating any of the gains from trade from licensing. When the licensor is able to appropriate gains from trade from licensing, high market power in the product market raises potential licensors' payoffs from innovating. This provides incentives to enter the innovation race and invest and may increase welfare. Our model suggests that spin-outs have beneficial welfare impacts, and our empirical analysis supports this view. Spin-outs in the rigid disk drive industry played the two roles described above: market pioneers in new product generations and licensors in mature product generations.

Current U.S. antitrust policy in innovative environments, as expressed in the 1995 Department of Justice/Federal Trade Commission *Antitrust Guidelines for the Licensing of Intellectual Property*, tends to implicitly assume that the number of firms in the product market today affects the number of firms in future innovation races. Thus, a horizontal merger between two innovative firms is questioned not just because it reduces product market competition, but because it reduces competition for future innovations. Our analysis suggests that if spin-out formation is possible then this concern is unwarranted.

Extending the model to incorporate multiple innovations and diffusion would be a useful next step. Our model focuses on innovations that advance the technological frontier within a product generation or pioneer a new product generation. To simplify the analysis, we ignore introductions of less-than-frontier products and improvements that allow laggards to catch up with current industry leaders. We also ignore future innovations. Evidence shows that it is difficult to forecast the success of new product generations, but if it is possible to do so then future payoffs might dominate the short-term concerns we focus on. Incorporating these factors should yield insights into strategy and policy.

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Table 1. Storage Capacity Leaders in the 8" Diameter

	Year																	
Number of:	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96
Leaders	6	10	10	10	10	10	10	10	10	10	10	10	10	10	8	5	4	1
Leaders who are Old Generation Large Manufacturer/Marketers	1	3	4	4	4	6	8	8	6	6	6	6	6	6	4	2	2	1
Leaders who are New Generation Large Manufacturer/Marketers	0	0	0	0	1	2	1	0	0	0	0	0	0	0	0	0	0	0
Leaders who are Recent Entrants	4	6	4	2	3	2	0	0	0	1	0	1	1	1	1	0	0	0

Table 2. Storage Capacity Leaders in the 5.25" Diameter

	Year																
Number of:	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96
Leaders	3	10	10	10	10	10	10	10	10	10	10	10	10	10	10	8	7
Leaders who are Old Generation Large Manufacturer/ Marketers	0	2	0	2	1	3	0	4	5	4	7	5	6	6	3	2	2
Leaders who are New Generation Large Manufacturer/ Marketers	0	0	0	0	2	4	5	2	3	2	3	2	1	2	3	3	2
Leaders who are Recent Entrants	3	8	8	5	6	1	1	0	0	0	0	2	1	1	0	1	0

Table 3. Storage Capacity Leaders in the 3.5" Diameter

	Year													
Number of:	83	84	85	86	87	88	89	90	91	92	93	94	95	96
Leaders	3	5	10	10	10	10	10	10	10	10	10	10	10	10
Leaders who are Old Generation Large Manufacturer/Marketers	1	0	4	2	2	5	4	7	7	6	6	7	8	7
Leaders who are New Generation Large Manufacturer/Marketers	0	1	0	1	3	2	3	2	1	1	2	1	0	1
Leaders who are Recent Entrants	2	4	6	4	3	1	1	0	1	0	0	0	1	1

Table 4. Storage Capacity Leaders in the 2.5" Diameter

	Year								
Number of:	88	89	90	91	92	93	94	95	96
Leaders	1	2	5	9	9	9	10	10	10
Leaders who are Old Generation Large Manufacturer/Marketers	0	1	3	8	6	6	7	7	6
Leaders who are New Generation Large Manufacturer/Marketers	0	0	0	0	0	0	0	0	0
Leaders who are Recent Entrants	1	1	2	0	0	1	1	1	0

Table 5. Storage Capacity Leaders in the 1.8" Diameter

	Year					
Number of:	91	92	93	94	95	96
Leaders	1	7	10	10	4	4
Leaders who are Old Generation Large Manufacturer/Marketers	0	4	6	5	1	0
Leaders who are New Generation Large Manufacturer/Marketers	0	0	0	0	0	0
Leaders who are Recent Entrants	1	3	4	3	1	1

Table 6. OLS Regression: Firm Value on Market Share and Drive Quality, including only U.S. Firms that Specialize in the Rigid Disk Drive Industry

The dependent variable is the natural log of market capitalization (White standard errors in parentheses)

	Equation 1	Equation 2	Equation 3
Variable	Coefficient	Coefficient	Coefficient
Intercept	12.48*** (0.40)	12.03*** (0.25)	11.99*** (0.25)
Market Share	-	18.81*** (2.31)	16.86*** (2.25)
Quality	0.58*** (0.11)	-	0.35*** (0.097)
YR1977	-1.79*** (0.51)	-1.56*** (0.42)	-1.57*** (0.39)
YR1978	-1.64** (0.63)	-1.40* (0.74)	-1.56** (0.68)
YR1979	-1.83*** (0.59)	-1.10* (0.65)	-1.38*** (0.51)
YR1980	-0.96* (0.55)	-0.77* (0.42)	-0.65 (0.42)
YR1981	-0.77 (0.55)	-0.35 (0.40)	-0.31 (0.39)
YR1982	-0.90 (0.58)	-0.44 (0.42)	-0.36 (0.46)
YR1984	-1.13** (0.52)	-0.75** (0.37)	-0.62* (0.37)
YR1985	-1.40*** (0.50)	-1.00*** (0.36)	-0.97*** (0.37)
YR1986	-0.88* (0.46)	-1.05** (0.50)	-0.54* (0.31)
YR1987	-0.67 (0.60)	0.073 (0.31)	0.21 (0.31)
YR1988	-0.68 (0.58)	-0.083 (0.33)	-0.02 (0.33)
YR1989	-0.54 (0.55)	-0.53 (0.43)	-0.48 (0.43)
YR1990	-0.63 (0.58)	-0.11 (0.50)	-0.41 (0.48)
YR1991	-0.51 (0.62)	-0.21 (0.34)	-0.30 (0.34)
YR1992	0.10 (0.54)	-0.21 (0.32)	-0.32 (0.34)
YR1993	-0.27 (0.60)	-0.50* (0.30)	-0.50* (0.30)
YR1994	0.79 (0.58)	-0.51 (0.32)	-0.35 (0.36)
YR1995	0.73 (0.55)	-0.49 (0.34)	-0.27 (0.37)
YR1996	0.68 (0.65)	-0.33 (0.63)	-0.20 (0.62)
Number of Observations	181	142	137
R-Squared	0.33	0.55	0.60
Adjusted R-Squared	0.24	0.48	0.52

*, **, and *** indicate significant at the 10%, 5%, and 1% levels

Year Dummies are included with 1983 as the base year

Table 7: Investment and Licensing Under Alternative Values of n_b

	Ranking, from left to right, in order of who invests most				
n_b	1	2	3	4	5
$n_b = 1$	Spin-out	2a	1b	1a	2b
Licensing	No licensing occurs				
$n_b = 5$	Spin-out	2a	1b	2b	1a
Licensing	No licensing occurs				
$n_b = 10$	Spin-out	2b	2a	1b	1a
Licensing	No licensing occurs				
$n_b = 20$	2b	Spin-out	1a	1b	2a
Licensing	Everyone licenses to 2b except 1b				
$n_b = 50$	2b	Spin-out	1a	1b	2a
Licensing	Everyone licenses to 2b				

Table 8: Investment and Licensing Under Alternative Values of ω

	Ranking, from left to right, in order of who invests most				
ω	1	2	3	4	5
$\omega = 1.5$	2a	Spin-out	2b	1b	1a
Licensing	No licensing occurs				
$\omega = 1.75$	2a	Spin-out	1b	1a	2b
Licensing	Spin-outs license to 2a; other firms market				
$\omega = 2$	2a	Spin-out	1b	1a	2b
Licensing	Spin-outs license to 2a; other firms market				
$\omega = 3$	2b	Spin-out	1a	1b	2a
Licensing	Everyone licenses to 2b				

Table 9. Summary Statistics. 1934 Observations

	Mean	**Standard Deviation**	**Minimum**	**Maximum**
Dependent Variable:				
The Firm Innovates in the Young Generation This Year	0.082	0.27	0.00	1.00
Independent Variables:				
The Firm's Drive Quality Last Year*	-0.054	0.97	-2.07	4.45
The Megabyte Ratio Last Year	0.33	0.077	0.22	0.61
The Age of the Young Generation Last Year	5.34	3.78	0.00	16.00
Dummy Variables:				
The Firm Produced Both the New and Old Generations Last Year	0.27	0.44	0.00	1.00
The Firm Produced Only the New Generation Last Year	0.33	0.47	0.00	1.00
The Firm Produced Only the Old Generation Last Year	0.40	0.49	0.00	1.00

* The Firm's Drive Quality is measured using its quality in the young generation if it produces the young generation; otherwise its quality in the old generation is used

Table 10. Probit Model: Innovation in Young Product Generations
The dependent variable takes the value 1 if the firm introduces a young generation drive with a higher areal density than last year's best drive in the diameter (standard errors in parentheses)

	Equation 1	
	Probit Estimation	Marginal Effects
Variable	Coefficient	Coefficient
Constant	-1.93*** (0.42)	-0.16*** (0.046)
YPG Dummy	-0.84* (0.45)	-0.070* (0.039)
OPG Dummy	0.21 (0.64)	0.017 (0.054)
YPG * Lagged Quality	0.45*** (0.074)	0.037*** (0.0089)
OPG * Lagged Quality	0.17* (0.093)	0.014* (0.0080)
BOTH * Lagged Quality	0.46*** (0.078)	0.039*** (0.010)
YPG * Lagged Megabyte Ratio	3.90*** (1.16)	0.33*** (0.11)
OPG * Lagged Megabyte Ratio	-0.88 (1.86)	-0.074 (0.16)
BOTH * Lagged Megabyte Ratio	1.00 (1.14)	0.083 (0.097)
YPG * Lagged Drive Age	-0.075*** (0.027)	-0.0063** (0.0025)
OPG * Lagged Drive Age	-0.28** (0.14)	-0.023*** (0.0078)
BOTH * Lagged Drive Age	0.22* (0.13)	0.018** (0.0082)
Number of Observations	1934	
Log Likelihood	-440.49	

*, **, and *** indicate significance at the 10%, 5%, and 1% levels
Year Dummies are included with 1983 as the base year

Year Effects are reported on the following page

Table 10, continued

	Probit Estimation	Marginal Effects
Variable	Coefficient	Coefficient
YR1980	-0.11 (0.51)	-0.0088 (0.043)
YR1981	0.57 (0.35)	0.048 (0.031)
YR1982	0.44 (0.33)	0.037 (0.029)
YR1984	0.16 (0.33)	0.013 (0.028)
YR1985	0.43 (0.31)	0.036 (0.027)
YR1986	0.23 (0.33)	0.019 (0.027)
YR1987	0.61** (0.31)	0.051* (0.027)
YR1988	0.25 (0.34)	0.021 (0.028)
YR1989	0.14 (0.33)	0.012 (0.028)
YR1990	0.40 (0.33)	0.033 (0.028)
YR1991	0.47 (0.34)	0.039 (0.029)
YR1992	0.52 (0.33)	0.044 (0.028)
YR1993	0.80** (0.33)	0.067** (0.030)
YR1994	0.38 (0.36)	0.031 (0.030)
YR1995	0.60* (0.36)	0.050 (0.031)
YR1996	0.65* (0.38)	0.055* (0.033)
YR1997	1.12*** (0.36)	0.093*** (0.034)

Table 11. Early Movers
(Firms are in alphabetical order in each category)

Diameter	Firm	Introduction Date	Did The Firm Spin-Out To Introduce This Diameter?	Parent If Spin-Out	Closest Diameter Previously Produced	Closest Diameter Previously Produced by Parent	Know-How In Closest Diameter Previously Produced	Parent Know-How In Closest Diameter Previously Produced
8”	BASF	Q4, 1979	No	-	14”	-	-0.117	-
	IBM	Q1, 1979	No	-	14”	-	0.873	-
	International Memories	Q1, 1979	Yes	Memorex	-	14”	-	-
	Micropolis	Q4, 1979	Yes	Pertec	-	14”	-	-
	New World Computer	Q3, 1979	No	-	None	-	-	-
	Pertec	Q4, 1979	No	-	14”	-	-1.378	-
	Shugart	Q4, 1979	No	-	14”	-	-0.940	-
5.25”	Computer Memories	Q2, 1981	Yes	Pertec	-	8”	-	0.265
	International Memories	Q1, 1981	No	-	8”	-	-0.830	-
	New World Computer	Q3, 1980	No	-	8”	-	-1.571	-
	Rodime	Q2, 1981	Yes	Burroughs	-	14”	-	1.444
	Rotating Memory Systems	Q2, 1981	Yes	Shugart, Memorex	-	14”, 14”		-0.983, 2.414
	Seagate	Q3, 1980	Yes	Shugart,	-	14”	-	-0.940
	Tandon	Q4, 1980	No	-	None	-	-	-
3.5”	Control Data	Q3, 1983	No	-	8”	-	0.757	-
	Micro-computer Memories	Q1, 1984	Yes	Alpha Data	-	14”	-	-1.019
	Micro-science International	Q2, 1984	No	-	5.25”	-	0.289	-
	Rodime	Q3, 1983	No	-	5.25”	-	1.067	-
2.5”	PrarieTek	Q4, 1988	Yes	Mini-scribe	-	3.5”	-	0.594
1.8”	Integral Peripherals	Q3, 1991	Yes	PrarieTek	-	2.5”	-	0.707

An early mover is defined to be a firm that introduces a drive in the diameter within 3 quarters after the first introduction date. The introduction date is the date the product was first shipped. Announced products that were still in the development stage, and had not shipped, are not included.

Table 12. Summary Statistics for Entrants. 63 Observations

	Mean	**Standard Deviation**	**Minimum**	**Maximum**
Dependent Variables:				
The Firm Either Licenses or Becomes a Large Manufacturer/Marketer	0.35	0.48	0.00	1.00
The Firm Becomes a Large Manufacturer/Marketer	0.21	0.41	0.00	1.00
Independent Variables:				
The quality of the firm's first drive	0.34	1.26	-1.57	4.45
Age of the product generation when the entrant introduces its first drive (excluding 14" drives)	2.63	2.73	0.00	10.00
Age of the 14" generation when the entrant introduces its first drive, using 1976 as year zero	0.52	1.38	0.00	7.00
Dummy Variables:				
The Firm is a Spin-Out	0.59	0.50	0.00	1.00

Table 13. Probit Model: Entrant Success vs. Failure.
The dependent variable takes the value 1 if the entrant becomes a large manufacturer/marketer or sells technology (standard errors in parentheses)

	Equation 1		Equation 2		Equation 3 (Spin-Outs Only)	
	Probit Estimation	Marginal Effects	Probit Estimation	Marginal Effects	Probit Estimation	Marginal Effects
Variable	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
Constant	0.29 (0.30)	0.099 (0.10)	-0.13 (0.38)	-0.042 (0.12)	0.51 (0.38)	0.20 (0.15)
Initial Quality	0.31** (0.14)	0.10** (0.047)	0.25* (0.15)	0.081* (0.048)	0.27 (0.17)	0.10 (0.067)
Generation Age	-0.33*** (0.12)	-0.11*** (0.035)	-0.35*** (0.12)	-0.11*** (0.035)	-0.29** (0.13)	-0.12** (0.050)
14” Generation Age	-0.20 (0.15)	-0.069 (0.048)	-0.20 (0.14)	-0.064 (0.046)	-0.23 (0.16)	-0.088 (0.064)
Spin-Out	-	-	0.75* (0.40)	0.25* (0.13)	-	-
Number of Observations	63		63		37	
Log Likelihood	-33.45		-31.62		-21.29	

*, **, and *** indicate significance at the 10%, 5%, and 1% levels

Table 14. Probit Model: Type of Entrant Success.
The dependent variable takes the value 1 if the entrant becomes a large manufacturer/marketer, and 0 if it sells technology – failures are excluded (standard errors in parentheses)

	Equation 1		Equation 2		Equation 3 (Spin-Outs Only)	
	Probit Estimation	Marginal Effects	Probit Estimation	Marginal Effects	Probit Estimation	Marginal Effects
Variable	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
Constant	0.80 (0.48)	0.31* (0.17)	0.60 (0.71)	0.23 (0.27)	0.90 (0.53)	0.35* (0.19)
Initial Quality	0.039 (0.27)	0.015 (0.11)	0.0058 (0.29)	0.0023 (0.11)	-0.086 (0.30)	-0.033 (0.12)
Generation Age	-0.36 (0.25)	-0.14 (0.096)	-0.37 (0.25)	-0.14 (0.096)	-0.29 (0.25)	-0.11 (0.096)
14” Generation Age	-0.13 (0.29)	-0.049 (0.11)	-0.11 (0.29)	-0.041 (0.11)	-0.27 (0.33)	-0.10 (0.13)
Spin-Out	-	-	0.28 (0.73)	0.11 (0.28)		
Number of Observations	22		22		17	
Log Likelihood	-13.28		-13.21		-10.10	

*, **, and *** indicate significance at the 10%, 5%, and 1% levels