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# Industry Evolution: New Technologies and New Firms

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**Abstract**

This paper investigates the effects of employee mobility on industry evolution and technology diffusion by testing a dynamic industry equilibrium model introduced in Franco and Filson (1999). The model focuses on a particular type of employee mobility: researchers can leave existing firms and attempt to form new firms (spin-outs). The model has four testable results: First, spin-outs are an important source of entry. Second, spin-out founders come from firms with high know-how. Third, firms with high know-how are more likely to survive. Fourth, spin-outs whose parents have high know-how are more likely to survive. Using data from the rigid disk drive industry (1977-1997), we find support for the first three results and mixed support for the fourth.

JEL codes: **L10**: Market Structure, Firm Strategy, and Market Performance **L63**: Industry Studies: Microelectronics **O31**: Innovation and Invention

Keywords: spin-off, industry dynamics, technological change, innovation, research and development

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## 1. Introduction

Employee mobility has long been considered to be one of the most important ways that technology diffuses. However, analyzing the effects of employee mobility on diffusion is difficult because distinguishing the employee's know-how from know-how already possessed by the receiving firm is difficult. In Franco and Filson (1999), a dynamic equilibrium model of industry evolution is presented that investigates one type of employee mobility: an employee can learn his employer's technological know-how and may be able to create a new firm using the know-how (a spin-out).[1] Focusing on spin-outs simplifies the analysis of employee mobility because the receiving firms are new, and spin-out founders typically make key strategic decisions about products, marketing strategies, and other strategies. This mechanism for technological diffusion is identifiable in the data, and the model produces several testable results.

In this paper, our main goal is to test some of the implications of Franco and Filson's model. To do this, we use data from the rigid disk drive industry (1977-1997). The disk drive industry is a good example of a high-technology industry in which much of the entry and technological diffusion has occurred through spin-outs. The data allow us to measure technological know-how, and link spin-out founders with their former employers. We test theoretical results pertaining to spin-out formation, firm survival, and spin-out survival.

In Section 2, the theoretical model is reviewed. As in other models of technological diffusion, the main drivers of the industry's evolution are innovation and imitation.[2] While innovation and imitation have been studied before, the specific mechanism by which information spreads and imitation occurs has been missing from previous models. Franco and Filson open this "black box" by focusing on spin-out creation - an endogenous source of both entry and imitation. The model allows for entry, exit and spin-outs. Each period, each

[1] Below, we refer to several types of entrants. A "start-up" is a new firm. A "pre-existing diversifying firm" is not a new firm, but is new to the industry. A "spin-out" is a start-up created when an employee leaves one firm to found a new and independent firm. This is a better description for the firms we discuss than "spin-off". A spin-off is created when a corporation establishes a part of itself as a separate corporation. Although a few of the spin-outs in our data maintained some licensing arrangements with the parent firms, they were all independent start-ups that obtained private financing and developed their own products.

[2] The model is related to previous work on industry evolution that includes Hopenhayn (1992), Jovanovic and Lach (1989), and Jovanovic and MacDonald (1994a, 1994b).

agent can work outside the industry, work inside the industry as a researcher at an existing firm, or become an entrepreneur and run a firm. An agent has technological know-how that can be improved in one of two ways. First, an agent who runs a firm can employ researchers and improve his know-how by innovating (innovation). Second, an agent who works as a researcher has a chance of learning his employer's know-how, and subsequently founding a spin-out (imitation).

We test the following four theoretical implications, presented formally in Franco and Filson (1999). First, existing firms provide training grounds for future entrepreneurs. In equilibrium, if an agent does not already run a firm, then in order to become an entrepreneur the agent must first become a researcher, improve his know-how by imitating, and then create a spin-out. Second, spin-out founders come from the most successful firms in the industry (those with the highest know-how). Third, firms with higher know-how are more likely to survive. Fourth, spin-outs whose parents have higher know-how are more likely to survive.

Before proceeding to the tests, we present a brief history of the rigid disk drive industry, from its beginning in 1956 until 1997. We simulate the model, and use the results to intrepret several facts that have been established in previous work on the disk drive industry. For example, Lerner (1997) establishes that in the 1970's and 1980's, while the industry was expanding, profits were low, and rose as the industry matured. During this time, technological laggards who were close behind the leaders were more likely to introduce new products and tended to catch up to leaders, and laggards who were far behind were more likely to exit. The simulation results show that these patterns can be explained by the model. The results suggest that the model can explain several of the broad trends that have occurred in the disk drive industry over time.

To proceed to our empirical tests, we require measures of know-how. Previous work suggests that product design, manfacturing, and marketing know-how have all been important in the disk drive industry. Lerner (1997) emphasizes high-tech know-how associated with designing, manufacturing, and introducing high-end drives. Christensen (1993, 1997) emphasizes know-how associated with designing new drives, manufacturing them reliably, and finding new customers. Christensen focuses on large new market segments that were associated with smaller diameter drives. Minicomputers used 8" drives, microcomputers used

5.25" drives, laptops used 3.5" drives, notebooks used 2.5" drives, and handheld devices used 1.8" drives.

In an attempt to allow for the know-how discussed by Lerner and Christensen, we measure know-how using two variables. First, *technical know-how* measures the firm's ability to design and manufacture high-end drives. Second, *early-mover know-how* is a dummy variable for firms that were early movers in introducing drives in a new diameter. *Early-mover know-how* is a proxy for the know-how that Christensen emphasizes - the firms that were able to design new drives, manufacture them reliably, and find new customers were often the early movers in the new market segments.[3] Below, we describe several cases of spin-outs imitating and use some simple descriptive statistics to show that *technical know-how* and *early-mover know-how* were both imitated by spin-outs. It is clear that other types of know-how that we cannot measure have also been important. Our case studies suggest that it would be useful to have separate measures of low-cost manufacturing know-how, product reliability know-how, and marketing know-how, to name a few examples. Unfortunately, our data does not allow us to construct such measures.

Given our measures, we find support for the first three theoretical results, and mixed support for the fourth. Spin-outs were the single most important type of entrant in the rigid disk drive industry in the 1977-1997 period, and were more likely to come from firms with higher know-how. Firms with higher know-how were more likely to survive. Our fourth test shows that parent *early-mover know-how* is associated with longer spin-out lifetimes, and parent *technical know-how* is not. This is true even though spin-outs that manage to obtain high *technical know-how* are more likely to survive. A possible interpretation of our test results is that *technical know-how* was more difficult to imitate than the other types, and firms that attempted to do so were less likely to be successful. The firms that did obtain high *technical know-how* were more likely to survive, but because the know-how was difficult to imitate, parents with high *technical know-how* were less likely to produce long-lived spin-outs.

[3] As a proxy for know-how, the early-mover dummy is not perfect - in some cases some of the late movers in the new diameter markets were better at designing and marketing drives than the early movers, and in most cases some early movers were more successful than other early movers. However, it is reasonable to assume that early movers had some know-how that other firms did not have, since they were the first firms to design, manufacture and ship the new diameter drives.

Christensen (1997) provides evidence that supports this conclusion.

The rest of the paper proceeds as follows: Section 2 presents the model and the theoretical results, Section 3 summarizes the history of the rigid disk drive industry and presents the simulation results, Section 4 presents the empirical work, and the final section concludes.

## 2. The Model

The model describes the evolution of a single industry in a discrete time, infinite horizon, competitive framework. There is a continuum of infinitely lived agents with unit mass. Each agent has a level of technological know-how, given by $\theta \in [\theta_L, \theta_H]$. The distribution of know-how at time $t$ is given by $\nu_t(\theta)$, a probability measure, where $\nu_0$ is given.

At the beginning of each period, each agent observes his own know-how and the distribution of know-how $\nu(\theta)$. Each period, each agent decides whether to work outside the industry, work in the industry as a researcher at an existing firm, or run a firm in the industry. An agent who works outside the industry receives a wage $w^0$ This outside wage is constant over time. If an agent works outside the industry, his know-how does not improve.

An agent who works as a researcher must decide for which firm to work. All researchers are assumed to be identical in the innovation production function, and firms differ only by the level of know-how of their founder, represented by $\theta_f$.[4] A researcher with know-how $\theta$ who works for a firm with know-how $\theta_f$ receives a wage $w(\theta, \theta_f, \nu)$. With probability $\lambda$, a researcher learns his employer's know-how, and can use the know-how in the following period.[5]

[4]These two simplifying assumptions deserve a brief comment, since both depart from reality in potentially important ways. The first assumption is that all researchers are equally capable of producing innovations, no matter what their know-how is. This assumption simplifies the analysis of the labor market considerably. Since, in equilibrium, Franco and Filson show that employers always have higher know-how than their employees, this assumption is equivalent to one that states that all of a firm's employees produce innovations using their employer's know-how, and not their own. Below, in our empirical work, we acknowledge that not all potential spin-out founders are identical. In particular, we explore the possibility that some have more entrepreneurial ability than others, and that this has independent effects on spin-out success not accounted for by our model.

The second assumption is that firms differ only by the level of know-how of their founder. In reality, a firm's know-how is likely some aggregation of the know-how of its employees. Again, this assumption simplifies the analysis, and is equivalent to one that states the know-how of a firm is equal to the know-how of the agent with the highest know-how in the firm. In equilibrium, that agent is the entrepreneur.

[5]Note that each researcher receives a fixed wage, and firms makes no attempt to use contracts to prevent

An agent who runs a firm chooses how many researchers to hire, $l$, and how much to produce, $q$. Firms produce a homogeneous product, with an inverse demand curve $D(Q)$, where $Q$ is the aggregate quantity produced. $D$ is downward sloping and continuous in $Q$. For simplicity, the demand curve is assumed to be constant over time.[6] All firms are price takers.

Suppressing time subscripts, a firm with know-how $\theta$ that chooses $q$ and $l$ obtains the net revenue

$$p(\nu)q - c(q,\theta) - lw(\theta_r, \theta, \nu),$$

where $p(\nu)$ is the market price, $c(q,\theta)$ is the production cost function, and $w(\theta_r, \theta, \nu)$ is the wage the firm pays to its researchers who are assumed to be of the same type, $\theta_r$. Note that production costs $c(q,\theta)$ and research costs $lw(\theta,\nu)$ are separable. The market price depends only on the distribution of know-how because the good is homogeneous. There are no fixed costs. The function $c(q,\theta)$ is strictly increasing and convex in $q$ and strictly decreasing in $\theta$ where $q > 0$: the greater the value of $\theta$, the lower the costs of production.

The transition function of a firm's $\theta$ is given by a cumulative distribution function $\Psi(\theta'|l,\theta)$ that measures the probability of obtaining future know-how $\theta'$ given current know-how $\theta$ and labor $l$. The properties of $\Psi$ are as follows.

(i) Innovation is not guaranteed. ($\Psi(\theta|l,\theta) > 0$).

(ii) Innovation is costly. ($\Psi(\theta|0,\theta) = 1$).

(iii) There is no forgetting. ($\Psi(\theta'|l,\theta) = 0$ if $\theta' < \theta$).

(iv) Increasing effort and know-how improves prospects (If $\widehat{\theta} \geq \theta$, $\widehat{l} \geq l$, then $\Psi(\theta' \left| \widehat{l}, \widehat{\theta}\right.)$ first order stochastically dominates $\Psi(\theta'|l,\theta)$).

(v) $\Psi(\theta'|l,\theta)$ is multplicatively separable in $l$ and $\theta$ : $\Psi(\theta'|l,\theta) = F(\theta'|\theta)G(l)$. $G(l)$ is

researchers from leaving. In the competitive environment of the model, this is a natural result: each agent is so small that there is no marginal effect of any one firm's actions on any other firm's payoffs. Therefore, when an employee leaves a firm to start up a new firm, the parent firm's profits are unaffected. In this setting, the parent has no incentive to attempt to prevent departures.

[6] Clearly, this assumption is unrealistic - the disk drive industry has had several different market segments and changes in demand over time. This assumption is useful because it simplifies the analysis of the model and allows us to obtain precise theoretical results. Future work could explore introducing market segmentation into a framework like ours.

the probability that the firm obtains a new level of know-how. $F(\theta'|\theta)$ is the cumulative distribution function of the firm's next period know-how given this period's know-how, given that the firm obtains a new level of know-how.

(vi) $G(l)$ is concave.

The first four assumptions are similar to those of Jovanovic and MacDonald (1994a), but the imitative possibilities are suppressed. This isolates the mechanism through which imitation occurs: imitation occurs only through researchers who work for firms in the industry. Assumption v is used only to prove theoretical result 3, discussed below. Assumption vi guarantees that firms with the same know-how hire the same number of researchers.

### 2.1. The Agent's Problem

Firm innovation and researcher imitation results in a future distribution of agent know-how. Let $\Phi(\nu)$ denote next period's distribution of know-how, given the current distribution of know-how $\nu$.[7] The agent's value function is given by a solution to the functional equation:

$$V(\theta,\nu) = \max\left\{\begin{array}{l} w^0+\beta V(\theta,\Phi(\nu)), \\ \max_{f\in[L,H]}\left\{\begin{array}{c} [w(\theta,\theta_f,\nu)+\beta[\lambda V(\theta_f,\Phi(\nu)) \\ +(1-\lambda)V(\theta,\Phi(\nu))],\ \text{if } \theta_f\geq\theta \\ \left[w\left(\theta,\theta_f,\nu\right)+\beta V\left(\theta,\Phi(\nu)\right)\right],\ \text{otherwise} \end{array}\right\}, \\ \max_{(q,l)}\{p(\nu)q-c(q,\theta)-lw(\theta_r,\theta,\nu) \\ +\beta\int V(\theta',\Phi(\nu))d\Psi(\theta'\,|q,l,\theta)\,\} \end{array}\right\} \quad (1)$$

[7]In computing $\Phi(\nu)$, both the transitions of firms and researcher imitation must be taken into account. The details of how this is done are provided by Franco and Filson (1999).

where $\beta$ is the discount factor and $V(\theta, \nu)$ is the value function. The three branches represent the lifetime income associated with the three possible current choices. The first branch is the lifetime income associated with taking a job outside the industry. Note that in this case the agent's knowledge doesn't change in the following period. The second branch is the lifetime income associated with becoming a researcher in the industry. In this case, the agent's future knowledge becomes the same as his employer with probability $\lambda$ if the agent's initial knowledge was less than his employer's knowledge. Otherwise, his knowledge remains unchanged. The third branch is the lifetime income associated with becoming an entrepreneur. Here the agent's future knowledge, $\theta'$, is determined by the transition function $\Psi$.

### 2.2. Equilibrium

Equilibrium is given by agents selecting optimal policies, supply equaling demand in the goods market and the labor market, and know-how evolving according to the law of motion $\Phi(\nu)$. The equilibrium is a special case of the one presented in Jovanovic and Rosenthal (1988). Since there is no aggregate uncertainty and the sufficient conditions for such an equilibrium to exist are satisfied, this equilibrium exists.

### 2.3. Theoretical Results

Four testable theoretical results, presented in detail in Franco and Filson (1999), are summarized here. All hold under the assumption that some agents work outside the industry every period. Before presenting the testable results, one additional result is worth noting. In each period, there is a critical value of know-how $\tilde{\theta}_t$ such that all agents with $\theta \geq \tilde{\theta}_t$ run firms in period $t$ and others do not. This implies that all researchers have know-how no higher than their employers. Further, the value of a researcher is constant, regardless of his level of knowledge, and each firm owner's value is increasing in his know-how.

The four theoretical results are as follows.

1. *Established firms are training grounds for future entrepreneurs.* Formally, given the above assumptions, the *only* way that an agent can enter the industry and run a firm is by

first working for an existing firm, learning the entrepreneurs know-how, and then leaving. The intuition is that if some agents work outside the industry in every period, then the distribution of know-how must be such that agents who are not currently running firms lack the know-how required to run a firm now and in the future. To run a firm, an agent must improve his know-how, and the only way to do so is to work as a researcher and imitate.[8]

Successful imitators learn their former employer's firm-specific know-how, rather than just industry-specific know-how. This suggests that a spin-out's know-how can be compared to its parent's know-how, and that the success of a spin-out depends in an important way on its parent's know-how.

2. *Spin-out founders come from firms with high know-how.* Recall that spin-outs in the model have the same know-how that the parent had in the previous period. This implies that researchers in period $t$ who work for firms with know-how less than $\tilde{\theta}_{t+1}$ do not incorporate in the following period even if they are successful at imitating.

3. *Firms with high know-how are more likely to survive.* Formally, the probability that an agent who currently runs a firm also runs a firm in the following period is weakly increasing in the agent's know-how.

4. *Spin-outs whose parents have higher know-how are more likely to survive.* Formally, the probability of a spin-out surviving beyond the first period of its life is increasing in its parent's know-how. Since a new spin-out has its parent's know-how, result 3 implies that the probability of a spin-out surviving to the period after its founding is weakly increasing in its parent's know-how. Unfortunately, since all of the spin-outs in our data except two survive beyond their first year, this result does not lead to an interesting empirical test with

[8] Clearly, spin-outs are not the only type of entrant in high-tech industries. In part, the result follows from two assumptions. First, the assumption that the demand curve is fixed over time implies that no new firms enter as a result of exogenous demand growth, a common feature in new high-tech industries. If the demand curve was continually shifting out, new firms could enter without having to improve their know-how first. Given that spin-out founders improve their know-how by imitating before founding a new firm, we would still expect that spin-outs would be the most successful type of entrant, even though they would not be the only type of entrant.

The second assumption is that there is no opportunity to improve know-how outside the industry. In some industries, outside firms might be able to acquire know-how without entering the industry. For example, a supplier might learn enough about its customers' products to imitate.

our data. Therefore, we test a broader hypothesis below. We conjecture that the effects of parent know-how persist in the long run. Persistence is unlikely to be perfect, both because innovation is uncertain and leapfrogging can occur. However, if parent know-how has lasting effects, then a spin-out's expected lifetime is increasing in its parent's know-how. We test this hypothesis below, along with the other theoretical results.

## 3. The Rigid Disk Drive Industry

This section presents a brief history of the rigid disk drive industry, and then presents a simulation of the model that shows that the model can explain several industry facts. We refer the interested reader to Christensen (1993, 1997), Lerner (1997), and the *Disk/Trend Report* for a more complete description of the industry's history. The industry began in 1956 when IBM introduced the first rigid disk drive. Followers began entering in the 1960's, and were of two main types. Captive producers (Burroughs, Control Data, and Univac) were vertically integrated computer manufacturers that produced drives for inhouse use. Plug-compatible market (PCM) firms were independent drive producers that made drives that were plug-compatible with IBM's computers. PCM firms sold drives directly to users of IBM computers. Christensen (1993) reports that many of the early PCM firms were IBM spin-outs, including Century Data, Memorex, Pertec and Storage Technology Corporation.

Innovation and imitation in the disk drive industry occurred at an extremely rapid rate in the period 1956-1997, and took several forms. First, several improvements in technical features improved capacities and access times. Second, several improvements in design and manufacturing techniques improved costs and reliability. Third, several architectural innovations occurred - drives with smaller diameters were introduced, beginning with 8" and 5.25" drives in the late 70's, and continuing with 3.5", 2.5", and 1.8" drives later on. When first introduced, the new drives served new buyers - 8", 5,25", 3.5", 2.5", and 1.8" drives were first used in minicomputers, personal computers, portable computers, notebook computers, and smaller portable devices respectively. When the minicomputer market began growing rapidly in the mid 1970's, an original equipment market (OEM) emerged. OEM firms served as either primary or secondary sources of drives for computer manufacturers. Net entry occurred in response to the profit opportunities generated from rapid technological change and market growth. As described further below, many of the entrants were spin-outs. Firm numbers continued to rise until the mid 80's, then roughly leveled off for a short time before falling in the early 1990's (Lerner (1997)).

### 3.1. Simulation Results

In order to simulate the model, functional forms and parameter values must be specified. We do not attempt to estimate these, but simply choose values so that the simulated series roughly match some of the broad trends in the disk drive industry. Three types of agents are considered. Agents can either be low-tech, medium-tech, or high-tech, denoted by $\theta_l$, $\theta_m$, and $\theta_h$ respectively. This isolates imitation: low-tech researchers can imitate medium-tech firms, but no other imitation occurs. No agent can improve his know-how by working for a low-tech firm, and, given the choice of parameters, high-tech firms hire no researchers.[9]

We assign the following values: $\theta_l = 1$, $\theta_m = 4$, $\theta_h = 5$, $w^0 = 0.15$, $\beta = 0.9$, and $\lambda = 0.1$. The production cost function is quadratic in output:

$$c(q;\theta) = \frac{q^2}{2\theta}$$

The market demand function is linear:

$$Q = 2 - 2.5p$$

The firm's transition function is specified as follows. Firms obtain a new $\theta$ with a probability that depends on their labor usage, and is determined according to the function

$$\begin{array}{ll} 0.4l^{0.9} & \text{if } 0.4l^{0.9} \leq 1, \\ 1 & \text{otherwise,} \end{array}$$

[9] Since high-tech firms have the highest possible know-how, they have no incentive to hire researchers. However, under some parameter values, equilibrium can involve all non-high-tech agents working for the high-tech firms for a wage of 0. In this case, imitation occurs, but no innovation occurs.

where $l$ represents the firm's labor choice.

Low-tech firms that obtain a new $\theta$ become medium-tech agents with probability .5, high-tech agents with probability .1, and remain low-tech agents otherwise. Medium-tech firms that obtain a new $\theta$ become high-tech agents with probability .5 and remain medium-tech agents otherwise.

Figures 1 through 8 graph various simulated series. Figure 1 shows that as innovation and imitation occur, the percentage of agents with low-tech know-how falls, the percentage of agents with medium-tech know-how rises initially and then falls later on, and the percentage of agents with high-tech know-how rises over time. Figure 2 shows that the percentage of agents who run firms follows a similar pattern. Given the parameters, as know-how improves, net entry occurs - this roughly matches the empirical trend in net entry discussed above. Figure 3 shows the percentage of agents that work as researchers. Low-tech researchers at medium-tech firms imitate at rate $\lambda$, and start up new medium-tech firms the following period. Most spin-outs are formed in periods $4-10$. These periods correspond to the early-mid 1980's in the data, the period when most of the disk drive spin-outs were formed. Figure 4 shows that as know-how improves, the price and average cost fall, and the market quantity rises. This matches another general trend in the disk drive industry during the period under study: cost-per-megabyte fell dramatically, and the market size grew. Figure 5 shows that the simulated value of know-how is highest before it becomes widely diffused.

The simulation results match a trend in industry profitability documented by Lerner (1997). Lerner (1997) shows that industry profits were low in the late 70's and later rose in the 80's and 90's as the market matured. We report two profit series that allow for different R&D accounting methods.[10] Figure 6 graphs revenue minus production costs minus R&D expenses. Figure 7 graphs revenue minus production costs. The two series differ only by the R&D expenses, which are presented in Figure 8. The basic pattern Lerner described, that average profits were low initially and then rose over time, occurs in the simulation results.

Further, during the period Lerner analyzed, technological laggards who were close behind

[10] Much R&D activity in firms in rapidly evolving industries is not considered separately from other costs - every employee may play a role in improving products and processes. Therefore, reported profits likely include some of what is R&D in the model as part of production costs.

the leaders had a tendency to innovate more than the leaders, and laggards who were far behind were more likely to exit.[11] The simulation results exhibit this pattern. The probability that a low-tech firm becomes high-tech in the following period is higher than the probability that a medium-tech firm does so in both periods 2 and 3. This does not always occur. In periods 4 and 5, medium-tech firms are more likely to become high-tech than low-tech firms.

Leapfrogging can occur in the model for two reasons. First, just because the firm's learning technology is stochastic, laggards in a given period may leapfrog because of large positive shocks. Second, a systematic tendency for leapfrogging occurs if low-tech firms invest much more than medium-tech firms. Since medium-tech firms in the simulation have values that are much closer to that of high-tech firms, as seen figure 5, they have lower marginal benefits from improving their technology than low-tech firms. As a result, low-tech firms invest much more than medium-tech firms in the periods mentioned above.

In summary, the model can explain many of the basic patterns in innovation, entry, and profitability that have been described in the previous literature. However, there are several important features of the industry that are not in the model. For example, the technological substitution from one diameter to another that occurred in the disk drive industry is not explicitly modeled. More generally, our analysis below reveals that entering spin-outs innovated as well as imitated, while entering spin-outs are only imitators in the model.

## 4. Empirical Analysis

### 4.1. The Data

The main data source is the *Disk/Trend Report* on Rigid Disk Drives (Porter (1977-1997)). The reports cover the period 1977-1997, and include detailed product characteristics of the drives produced by different firms each year, the dates that the drives were introduced, and the date the firm was founded. There are 195 firms and 11653 model/year observations in the

[11] Close laggards were more likely to introduce a new drive that improved on previous models from year to year. Further, the improvement in density tended to be larger, and the time between the shipment of drives with improved density was shorter for close laggards.

data set. Observations on optical drives were removed, as optical drives were substantially different from other rigid disk drives. The remaining dataset contained 192 firms, 11644 model/year observations, and 1190 firm/year observations.

For several firms, the *Disk/Trend Report* reports each firm's total sales of disk drives each year.[12] For new firms, information about the background of the founders is provided. For all firms, historical information and recent news is summarized. To determine spin-out-parent relationships, the histories from the *Disk/Trend Report* were supplemented with company press releases and articles provided by James Porter, the editor of the *Disk/Trend Report,* along with the *Directory of Corporate Affiliations,* the *International Directory of Company Histories,* and a study by Christensen (1993).

There were 40 cases of an employee or employees leaving a rigid disk drive manufacturer or manufacturers to found a new firm in the period 1977-1997. Table 1 sorts the spin-outs by year of entry, and lists the firm the founders came from, the founding year of the spin-out, and the spin-out's life span.[13] In most cases, spin-out founders came primarily from a single parent. In a few cases, founders came from two firms. Although a typical startup employed several people other than the founders, we focus on the background of the founders, and not on other employees, who might have had some influence in the development of the firm by for which there is no consistent data. Implicitly, the assumption is that spin-out founders had considerable influence on the products produced and the manufacturing and marketing strategies used. The anecdotal evidence that is available from company press releases and the *Disk/Trend Report* suggests that this is a reasonable assumption.

As the start-ups were initially private companies, we lack financial information, but the firm histories in the *Disk/Trend Report* suggest that survival is a reasonable proxy for success. There were predominantly two forms of exit: acquisition and failure. Although acquisitions occurred for a variety of reasons, failure was associated with failure to introduce new products, obtain financing, or obtain customers. Typically, a firm that failed in the first

[12]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.

[13]We start our analysis in the late 70's, after the industry was well into its takeoff stage. All of the non-captive parent firms of the early spin-outs in our data were also spin-outs (Christensen (1993)). Memorex, Pertec, and Storage Technology Corporation were IBM spin-outs, and Shugart Associates was a Memorex spin-out.

few years of its life failed in the development stage. A firm that failed later on typically had some period of success in the market, but subsequent problems with design, manufacturing and/or marketing led to failure. In Table 1, we categorize spin-outs three ways: firms are either still active as of 1997, have been acquired, or they have exited through failure.

In order to test theoretical results 2-4, measures of know-how are required. Since in the model, know-how is anything that allows a firm to earn relatively high profits, a broad measure of know-how would be useful. Ideally, we would like to include all of the capabilities that help a firm perform the functions necessary for success: R&D, manufacturing, marketing, etc. Given our data, we use two measures of know-how, and several other control variables. The first measure of know-how is *technical know-how*: a measure of the firm's technical expertise. A single measure of *technical know-how* is difficult to derive, because disk drives have several characteristics, and new products may improve on old products along some dimensions and not in others.[14] Following Lerner (1997), we use areal densities to compute the measure. Roughly, the areal density measures how much information can be stored on each square inch of the disk, and has long been considered to be the main measure of drive quality.

To compute a firm's *technical know-how*, we first divide the areal density of the firm's best drive in each diameter in each year by the highest areal density in that diameter in that year.[15] This generates a measure of the firm's know-how in each diameter relative to the best available know-how in that diameter. Second, the average of this measure across diameters in each year is computed to obtain a single measure of the firm's technical expertise in each year. Averaging over several diameters results in a single measure for each firm. Since the theoretical results pertain to firm-level decision-making (exit, spin-out formation, and survival) rather than product line choices, this is an essential requirement.[16] For some of the results presented here on spin-outs, *technical know-how* averaged over the three years

[14]We assume that improvements in technical know-how are rapidly embodied in new products. Lerner (1997) argues convincingly that this is the case in the disk drive industry.

[15]We use only drives that have been shipped when making our calculations. Drives that have been announced but not yet put into production are not included.

[16]Lerner (1997) treats each diameter separately in most of his analysis, but reports some results using this average measure.

surrounding the spin-out's entry is used.[17] This allows for imitation that is somewhat broader than implied by the model. It allows for the possibility that spin-outs imitate know-how embodied in the parent's products, as well as know-how under development at the parent.

The second measure of know-how is *early-mover know-how*: a dummy variable for firms that were early movers into markets served by smaller diameter drives. This is a proxy for the product design, product reliability, and marketing know-how associated with designing, manufacturing, and marketing new drives. Only the major diameters introduced in the period 1977-1997, the 8", 5.25", 3.5", 2.5", and 1.8" drives are considered. A firm is an early mover if it introduced a drive of a new diameter within the first year that drives of that diameter were shipped.

Before proceeding, let us briefly consider how intellectual property rights may affect our analysis. Know-how can be protected using various devices, such as patents, contracts that forbid a departing employee from working in the industry for a given period of time, and trade secret laws. These institutional devices might reduce an employee's ability to imitate. The model allows for the existence of such barriers to imitation, but in an abstract way. Employees who attempt to imitate are successful with probability less than one. The probability of successful imitation is exogenous, and changes in this probability could correspond to different institutional regimes.

To what extent have institutional barriers to imitation been relevant empirically, and how have they affected spin-out creation and imitation? Although there is not a definitive answer to this question, there is evidence that institutional barriers to imitation have not been very important. First, Lerner (1997) provides evidence that patents were not widely used to protect some of the key aspects of disk drive technology. Second, an examination of the *Disk/Trend Report* shows that even when patents were used, licensing appears to have been widespread, and while the licensing fees raised the costs of entry and imitation, they did not prevent either one. For example, one of the key patents in the disk drive industry was granted to Rodime for the 3.5" drive design. Producers of 3.5" drives had to pay licensing

[17] In some cases the parents were either startups or exited during the three year period surrounding the spin-out's entry. In these cases, we used the data available to compute the average. If a spin-out had two parents, we computed the average parent technical know-how.

fees, but this did not prevent diffusion. The 3.5” design diffused rapidly and widely.

Further, much of product design, manufacturing and marketing know-how is tacit know-how that is not easily patented. Tacit know-how is not blueprints or knowledge about specific products, but is expertise that is learned within firms and is broadly applicable, not only to existing products and markets but to new products and markets as well. For example, a manager at a firm that is good at pioneering new markets may be able to leave and found a new firm that also has this ability. The specific products of the parent need not be imitated. Covenants not to compete and trade secret laws can be used to attempt to protect tacit know-how, but both mechanisms were largely ineffective in the disk drive industry. Most (80%) of the firms in this study were located in California, where covenants not to compete were prohibited by law, and were not enforced by the courts. Trade secret laws did not create much of an employee mobility barrier because of large contract negotiation costs, difficulties with enforcing the laws, and the Silicon Valley culture.[18]

### 4.2. Spin-out Entry

According to theoretical result 1, spin-outs are the only source of entry.[19] Focusing on U.S. firms, Christensen (1993) shows that while spin-outs were not the *only* source of entry, they were the most important source.[20] Most entrants were spin-outs, and that the most successful entrants were spin-outs. First, Christensen shows that only 3 out of 28 non-spin-out firms that entered between 1976 and 1989 survived until 1989. In contrast, 16 out of 40 spin-outs that entered between 1976 and 1989 survived until 1989. By 1989, seven of the world OEM/PCM market’s ten largest firms were spin-outs. Further, the vast majority of start-ups in the period, 1956-1989, were spin-outs. All of the 16 start-ups that survived until 1989 were spin-outs and are listed in Table 1 below. Spin-outs accounted for all but four of the start-ups that were successful at generating revenue, and accounted for 99.4 percent of

[18] Gilson (1998) discusses covenants not to compete and trade secret law, with a particular focus on the Silicon Valley environment.

[19] It is clear that this is not the case in every industry, for reasons discussed in footnote 7 above. However, it is still interesting to see whether or not it is a reasonable claim in the industry studied here.

[20] Our data yields the same results (spin-outs are listed in Table 1). Christensen provides a much more detailed analysis of entry than provided here. All of the spin-out parents were U.S. firms - this suggests that institutional and cultural differences played a role in whether or not spin-outs were generated. Below, we check the robustness of our results by performing tests with only U.S. firms.

the total cumulative revenues generated by the start-up group in the period that Christensen analyzed. Overall, the data provide strong support for the first theoretical result.

### 4.3. Spin-outs and Imitation

It is clear that spin-outs were an important source of entry in the disk drive industry, but that by itself does not establish that the mechanism described in Franco and Filson (1999) led to spin-out generation. Were spin-outs imitators? Did spin-out founders imitate firm-specific know-how of their former employer, as in the model, or did they simply learn industry-specific know-how? In this subsection, we present several case studies and some simple descriptive statistics that clarify the extent to which spin-out formation occurred in the manner described in the model.[21] We begin by presenting evidence that supports the model, and then present evidence that is inconsistent with or counter to the model's predictions.

The *Disk/Trend Report* describes several examples of technical expertise being imitated. After acquiring high-performance drive experience at Storage Technology Corporation, founders of Amcodyne produced high-performance drives. After learning how to improve technical features at Maxtor, the leading high-end drive producer at the time, founders of Areal Technology developed drives with extremely high areal densities. After acquiring state-of-the-art expertise in thin film heads while working at IBM, founders of Dastek developed drives using the technology. After helping to develop the Reflex I and II drives at Microdata, founders of Tecstor initially produced 14" drives that were similar to the Microdata drives.

Was *early-mover know-how* imitated? In Table 2 the early movers in each of the major new diameters introduced in the period 1977-1997 are listed, organized by diameter. What is immediately noticeable is that almost all of the firms on this list were either spin-outs, parents, or both, with the exception of BASF, New World Computer, and Control Data,

[21] Some alternative models from the labor economics literature, though not specifically developed to explain spin-outs, may provide some possible alternative explanations of spin-out formation. The model presented here is similar in spirit to a stepping stone mobility model, in which an agent works at one firm and acquires skills that allow him to move up the career ladder, possibly at another firm. In some matching models, there may be no connection between the type of firm and the type of worker who might leave. If such a model was used to describe spin-out formation, there would be no connection between the parent firm's know-how and the spin-out's know-how.

since Tandon was a Pertec spin-out formed prior to 1977. Many of the firms shown were extremely successful. International Memories, the first mover in 8" drives, became one of the most prominent OEM manufacturers in the early 80's. Seagate, the first mover in 5.25" drives, rapidly became the most prominent OEM firm, and continued to hold this position as of 1997.

Many of the spin-outs and parents in Table 2 are related to each other. In order to perform a rough test, Table 3 shows the spin-outs from early mover parents, along with whether or not the spin-out was an early mover, and if so, in which diameter. Note that of 15 spin-outs from early mover parents, 5 were early movers themselves. The point estimate of the probability that a randomly selected spin-out from an early mover parent was also an early mover is $\frac{5}{15} = .33$. Of the 177 firms that were not spin-outs from early-mover parents in the period 1977-1997, only 12 were early movers, resulting in a point estimate of $\frac{12}{177} = .068$ of the probability that, conditional on not being a spin-out of an early mover, a randomly selected disk drive firm was an early mover. Although the sample of early movers is small, the point estimates differ substantially, and the difference between the two proportions is statistically significant at the 1% level (using a $t$ test, the test statistic is 3.5, and the critical value is 2.33).[22]

*Technical know-how* and *early-mover know-how* attempt to measure the two types of know-how most emphasized in the previous literature on the disk drive industry. However, it is clear that these measures cannot account for the success of some of the firms. It appears as though other types of know-how were imitated as well. For example, Conner Peripherals, a Seagate/Miniscribe spin-out, set a record for the highest sales ever achieved by a corporation in its first year of business. Although not an early mover, Conner improved on previous 3.5" drives, established that its products were reliable and could be manufactured at reasonable cost, and convinced Compaq to become a major customer. Conner's strength was in product reliability, manufacturing, and marketing, and these strengths were also strengths of Seagate

[22] If we include Syquest (a spin-out of Seagate and a pioneer of the small disk cartridge drive market) as an early mover, the point estimates become even more compelling. Syquest is excluded because our test includes only early movers in the main diameters.

We might also note that other firms in Table 2 are also related. Tandon was an early spin-out of Pertec, and Pertec was an early spin-out of IBM, but both were founded prior to the start of our sample.

and Miniscribe, two of the largest OEM producers.

Another example is Seagate, a Shugart Associates spin-out. Shugart was an early mover in low end 8" rigid drives, but was mainly known for its success in producing 5.25" floppy drives. Shugart's main strengths were its manufacturing and marketing abilities. Seagate was an early mover in low end 5.25" rigid drives, and its main strengths were also its manufacturing and marketing abilities. Seagate consistently found customers and successfully produced very reliable cost-effective low-end drives. Seagate did not pursue advances in storage capabilities or speed in 5.25" drives as much as most firms, but was very successful at becoming the low-cost producer.

Quantum, another Shugart Associates spin-out, did not emphasize high storage capabilities either, and was never an early mover, but was always a strong late mover in the low-end market. Quantum is a good example of the type of imitation described in our model. Shugart Associates originally dominated the market for low-end 8" drives with its SA 1000, a 10 MB drive. Quantum's first products were designed to compete with its parent's drives. Quantum achieved early success by introducing 20, 30, and 40 MB 8" drives that provided additional capacity with the same interface and file organization as the Shugart drives. Quantum continued to increase the capacity of its drives at a rapid rate, but remained a low-end drive producer. By 1985, Quantum had branched out into 5.25" and 3.5" drives, but was not an early mover in those markets either.

There are several of the cases in Table 1 where the mechanism of spin-out formation differed from that in the model. For example, in the model, spin-outs come from successful firms. In some cases in Table 1, spin-out formation occurred when a parent was prominent, but then suddenly declined. Employees abandoned the firm, and some started up new companies. For example, in 1985-86, Computer Memories lost its largest customer when IBM decided to supply more of its needs inhouse. As Computer Memories began a rapid decline, employees left, and two spin-outs were formed - Peripheral Technology and Brand Technologies. In another case, when Lapine failed after its brief success, employees abandoned it and founded new firms - Comport and Kalok. The learning described by the model may still be present, but the departure may be partly forced rather than entirely voluntary. In several of the equations below, we include firm sales growth in order to determine whether this type of spin-out formation was the main type or not, and whether spin-outs of this type were more or less likely to survive than other spin-outs.[23]

Another type of spin-out formation involved entrepreneur mobility. In several cases in Table 1, one or more of the spin-out founders were also founders of the parent firm.[24] Although typically the parent-founder's know-how was combined with other spin-out founders' know-how to determine the spin-out's know-how, this still suggests that in addition to the know-how described above, expertise in founding start-ups was useful. This "entrepreneurial know-how" is less likely to diffuse in the manner described by the model, because it is more likely to be obtained from experience at founding start-ups than from working for other firms. Although this differs somewhat from the explicit structure in the model, it is consistent with our main point that experience at an existing firm may allow an agent to leave and found a new firm. All of the founders in our data had distinguished careers at existing firms before founding their first spin-out. Below, we check the robustness of our results on spin-outs by using an *entrepreneur dummy*. This dummy takes the value 1 if one of the spin-out founders was also a founder of the parent firm.

In many cases, spin-outs were both imitators and innovators. A founder of Conner Peripherals combined his 3.5" drive technical expertise from Miniscribe with innovations of his own to create Conner's first product, a high performance 3.5" drive. Syquest imitated by using the same capacity, interface and file organization as its parent Seagate's basic 5.25" drive, and innovated by being the first firm to design and manufacture 4" removable cartridge

[23] We compute sales growth as follows. Using $g_t$ to denote the growth rate and $s_t$ to denote firm sales in period $t$, we use the following formula:

$$g_t = \frac{s_t - s_{t-1}}{\frac{s_t + s_{t-1}}{2}}.$$

This formula allows for observations in which either $s_t$ or $s_{t-1}$ is 0, which allows us to compute a finite growth rate in cases in which the firm exits in period $t$ or is a new entrant and has no sales in period $t-1$. In cases in which the firm was a new entrant that had 0 sales in period $t$ and period $t-1$, we set $g_t = 0$.

In our analysis of spin-outs (Tables 7-9), we averaged the parent's sales data if the spin-out had two parents. Two parents were acquired prior to the spin-out's birth (Irwin's parent, Sycor, and Lapine's parent, Irwin), so sales data was unavailable for these two parents.

[24] These spin-outs were Micropolis, Irwin International, Seagate, Applied Information Memories, Maxtor, Syquest, Epelo, Brand Technologies, Conner Peripherals, PrairieTek, Areal Technology, and Ecol.2. In two cases, Irwin International and Seagate, the spin-out founder sold the parent firm before founding the new firm. In the case of Brand Technologies, the spin-out founder left a failing firm to found a new one. In all of the other cases, the founder left a viable firm to found the spin-out.

drives. The first firms to introduce all of the major new diameters in the period 1977-1997, the 8", 5.25", 3.5", 2.5", and 1.8" inch drives, were all spin-outs.[25]

The process of developing a new diameter drive required an interesting mix of imitation and innovation. Christensen points out that the new drives, though novel, were not technically difficult to develop, typically cost less than two million dollars to develop, and used widely available proven components. Our point estimates described above also suggest that know-how related to finding new customers and introducing products in new markets was passed from parents to spin-outs. Further, the spin-out founder had typically worked on developing the new diameter drive while at his former employer.

However, Christensen's explanation for spin-out formation and success differs somewhat from the model, and is only in part a know-how-based explanation. While the spin-out founder did learn know-how while at the parent firm, this know-how was in part developed by the founder. Further, even though the parents knew about the new diameter drives, the parents chose not to produce them - most of the parents were unwilling to pursue the new markets because the new markets were small. Thus, in part, the explanation for spin-out success is just that they were spin-outs - the new small firms were able to maintain focus on the new small markets.

Although most early movers were spin-outs, some established firms were early movers too. When the new drives emerged, these firms refocused some part of their organization to market the new drives. The know-how involved included an ability to find new customers, convince them to buy the new drive, and maintain focus on a new, small market. Christensen's point is that it was easier for spin-outs to do this because they did not face the same opportunity costs as large firms, who were focused on their large existing markets. This is a significant departure from the model presented here that would be worth exploring. In the model here, different market segments are not explicitly modeled, and all entrepreneurs face the same opportunity costs - the foregone opportunity is always the opportunity to work either as a researcher or outside the industry.

[25] These firms were International Memories, Seagate, Rodime, PrairieTek, and Integral Peripherals.

### 4.4. Spin-out Formation

According to theoretical result 2, spin-outs come from firms with the relatively high know-how. This hypothesis is tested using several probit models. The dependent variable is a dummy variable that takes the value 1 if the firm generates a spin-out in the current year, and 0 if the firm does not. In the model, the probability of a firm generating a spin-out in period $t$ depends only on the firm's know-how in period $t-1$ and the distribution of know-how. Therefore, our main independent variables are lagged *technical know-how* and *early-mover know-how*. We use year dummies to account for changes in the distribution of know-how from year to year.[26] We also include lagged sales growth and the lagged number of drives in some of the equations. Summary statistics for our variables are presented in Table 4.

A preliminary examination of Table 1 reveals that several of the parent firms were among the most successful firms in the industry - IBM, Memorex, Pertec, Shugart Associates, Burroughs, Storage Technology Corp., Quantum, Seagate, Maxtor, etc. If success in the disk drive industry was due to "know-how", then these firms clearly had high know-how. Just from examining the list of parents, it appears as though the hypothesis has some support. The statistical analysis confirms this impression.

The estimation results are reported in Table 5. In equation 5$a$, only the two know-how measures are used. Both coefficients are positive and statistically significant. This supports the hypothesis. In equation 5$b$, lagged sales growth is included. This allows us to determine whether failing firms were more likely to generate spin-outs. The coefficients on know-how continue to be positive and significant, and the coefficient on lagged sales growth is also positive and significant. This suggests that spin-outs are more likely to come from firms that are doing well in the market rather than those that are re-trenching or declining.

In equation 5$c$, we include year dummies.[27] Observations in years in which no spin-outs were generated were dropped (1989, 1992, 1994-1997), and observations in 1977 were dropped because lagged know-how measures were unavailable. The results continue to support the

[26] Note that year dummies capture all changes in industry-level variables from year to year. In the model, all industry-level changes depend on changes in the distribution of know-how.

[27] In all of our estimates with year dummies, in this and the following subsections, we use 1983 as a base year.

hypothesis. Further, the coefficients on the year dummies have reasonable signs. During the early 80's, when much of the entry and spin-out creation was occurring, the coefficients are higher. In equation 5*d*, the sample is limited to only U.S. firms. The motivation for considering only U.S. firms is that only U.S. firms generated spin-outs in the disk drive industry. It is likely that institutional differences between the U.S. and Japan, the country in which most foreign firms were based, made spin-out generation more likely in the U.S. The estimates of equation 5*d* show that when only U.S. firms are included, the results do not change.

Finally, in equations 5*e* and 5*f*, equations 5*c* and 5*d* are reestimated while controlling for both lagged sales growth and the lagged number of drives. The lagged number of drives variable is a proxy for firm size. A simple hypothesis about spin-out generation is that spin-outs are more likely to come from larger firms, simply because larger firms have more employees who can leave. The results do not support this simple hypothesis - the coefficient on lagged number of drives is negative and insignificant. The coefficients on know-how continue to be positive, although the coefficient on *early-mover know-how* is insignificant in equation 5*f*. In both equations, the coefficient on lagged sales growth is positive but statistically insignificant.

### 4.5. Firm Survival

According to theoretical result 3, the probability of a firm surviving until the following period is increasing in its current know-how. This hypothesis is tested using several probit models. As above, we use year dummies to allow for changes in the distribution of know-how over time. If a firm exits in period $t$ because it is acquired, we treat the observation as censored. Only failures are counted as exits.

The estimation results are reported in Table 6. In equation 6*a*, only the two know-how measures are included. Both coefficients are positive and statistically significant. This supports the hypothesis. In equation 6*b*, we include year dummies. Observations from 1977, 1980, 1995, and 1997 were dropped, because no exits occurred in those years once missing observations were removed. In equation 6*b*, the coefficient on *technical know-how* is positive and significant, while the coefficient on *early-mover know-how* is positive and insignificant.

The coefficients on the year dummies have reasonable signs. They start to become more negative as the industry matures, and the 1991, 1992, 1993, and 1994 coefficients are negative and significant at the 5% level. This is when the industry entered its shakeout phase. In equation 6$c$, equation 6$b$ is run including only U.S. firms. The results are essentially the same. In equation 6$c$, both know-how coefficients are positive and statistically significant.

In Table 7, we focus on spin-outs. The results suggest that the probability of a spin-out surviving is increasing in the spin-out's *technical know-how*, but the effect of *early-mover know-how* is not precisely estimated. In equation 7$a$, only the two know-how measures are included. The coefficient on *technical know-how* is positive and significant, while the coefficient on *early-mover know-how* is positive and insignificant. In equation 7$b$, we include year dummies. The coefficient on *technical know-how* continues to be positive and significant, while the coefficient on *early-mover know-how* is negative and insignificant.

In equation 7$c$, we include parent know-how measures as well as firm know-how measures. The coefficient on *technical know-how* is positive and significant, the coefficient on *early-mover know-how* is negative and insignificant, and the coefficients on parent know-how are both significant. In the theoretical model, once current know-how and the distribution of know-how are controlled for, no other variables have any explanatory power. Clearly, this assumption is violated in the data. Parent know-how appears to have persistent effects. Interestingly, the coefficient on parent *technical know-how* is negative and significant at the 5% level. This result is discussed further below.

### 4.6. Spin-out Survival

According to theoretical result 4, a spin-out's expected lifetime is increasing in its parent's know-how. We test this hypothesis using several duration models in which we specify that spin-out lifetime is a function of parent know-how. The last result in the above subsection suggests that this hypothesis can be rejected - parents with higher *technical know-how* produce spin-outs that are less likely to survive. Our goal here is to explore this conclusion further. In some of the equations, we use parent sales growth and the entrepreneur dummy as control variables. Summary statistics on spin-out lifetimes, parent know-how, and the other variables are provided in Table 8.

There are two kinds of censoring in the data. First, some firms are still alive at the end of our sample. Second, some firms have been acquired. We do not distinguish between the two types of censoring.[28] We estimated several duration models, and obtained the best fit using a Weibull survival function $(\exp(-(\phi t)^{\frac{1}{\sigma}})$, in which the hazard function, the probability that a firm exits given that it has survived until time $t$, is given by

$$\frac{\phi}{\sigma}(\phi t)^{\frac{1}{\sigma}-1},$$

where $\phi = \exp(-\beta' x_i)$, and where $\beta$ and $\sigma$ are parameters to be estimated, while $x_i$ represents firm $i's$ parent's know-how.

Estimation results are reported in Table 9. In equation $9a$, we include only the two parent know-how measures. Although the signs are the same as in the above probit model, both coefficients are statistically insignificant. We obtained more precise estimates using a 3-year average of parent *technical know-how*. In equation $9b$, using the 3-year average, the coefficient is still negative but is significant at the 10% level, while the coefficient on *early-mover know-how* is positive and significant at the 10% level. This confirms the results reported in Table 7. Spin-out survival is decreasing in parent *technical know-how*! However, as we showed in Table 7, the probability of a spin-out surviving is increasing in its own *technical know-how*. The results suggest that *technical know-how* was more difficult to imitate than *early-mover know-how* - spin-outs that came from firms with high *technical know-how* were less likely to learn the know-how, and therefore were less likely to survive, but if they were successful at learning the know-how, they were more likely to survive. Christensen's analysis supports this conclusion. Many of the advances that improved areal densities, such as thin film technology, were extremely expensive (and time-consuming) to develop. Only the large established firms were successful with these development projects - new small firms that tried had an extremely high failure rate. On the other hand, introducing a new diameter drive was relatively cheap.

[28] While checking the robustness of the results, we estimated a Markov chain model that allowed for the two types of censoring explicitly. The results did not change - it appears as though general statements about how the probability of being acquired depends on know-how and our other controls cannot be made. This conclusion makes sense given the history of the industry - all types of firms have been acquired, including new small firms still in the development stage, large successful firms, failing firms, etc., and acquisitions have occurred throughout the life cycle.

In equation 9*c*, we add parent sales growth as an explanatory variable. As mentioned above, some spin-outs were formed when the parent was failing. Our estimates in equation 9*c* show that spin-outs from failing firms were less likely to have long lives than those from growing firms. The coefficients on parent know-how do not change substantially.

As discussed above, many of the spin-outs had one or more founders with experience at founding spin-outs. In equation 9*d* we include the *entrepreneur dummy* to control for the impacts of such experience. Interestingly, the coefficient on the *entrepreneur dummy* is negative and statistically insignificant. Although the estimate is imprecise, it suggests that past experience at founding start-ups may have no impact or even a negative impact on the lifetime of a new start-up. This may be the case in rapidly evolving industries - past experience at founding a start-up may not be as important as having the right design, manufacturing, and marketing know-how for the current environment. Including this dummy does not change our conclusions about the effects of know-how on spin-out survival.

## 5. Conclusion

In this paper we have shown that spin-outs are an important source of entry and technological diffusion. We have presented theoretical, simulation, and empirical results that provide insight into the role that spin-outs play in an industry's evolution. Gort and Klepper (1982) suggest that the main source of entry and technological diffusion in a new industry is from sources outside the new industry. Our theoretical and simulation results show that this is not always the case. Our historical analysis and empirical results show that, at least in the disk drive industry, existing firms provided a training ground for employees who later left to found new start-ups. The new start-ups were, at least in part, imitators.

We believe that our results have an important policy implication: they suggest that restrictions on employee mobility, such as covenants not to compete, may create considerable barriers to firm entry.[29] If such covenants would have been used and enforced in California during the period that the disk drive industry was evolving, the spin-outs we have studied

[29] The results also suggest that employee mobility barriers should be included on the list of firm entry barriers in standard industrial organization textbooks.

would not have been formed. Since spin-outs were the most important type of entrant in the industry since its inception in 1956, the industry's evolution would have been very different.

It is clear that in some industries, spin-outs are the main source of entry, whereas in others, other types of firms are. This fact could be further investigated in a framework like ours, in which firms require know-how in order to enter the industry. The links we have established between parent firms and spin-outs likely apply to other types of employee mobility as well (those that do not involve establishing a new firm). It is likely that even established firms that enter a new industry rely to some extent on previous employees of firms in the new industry.

It would also be useful to explore the rates of imitation of the different types of know-how that are important for success. Our empirical results, along with evidence provided by Christensen (1993, 1997), suggest that some types of know-how are more difficult to imitate than others. Along this line, other types of imitation could be explored along with employee mobility, and tradeoffs between the different types could be examined.

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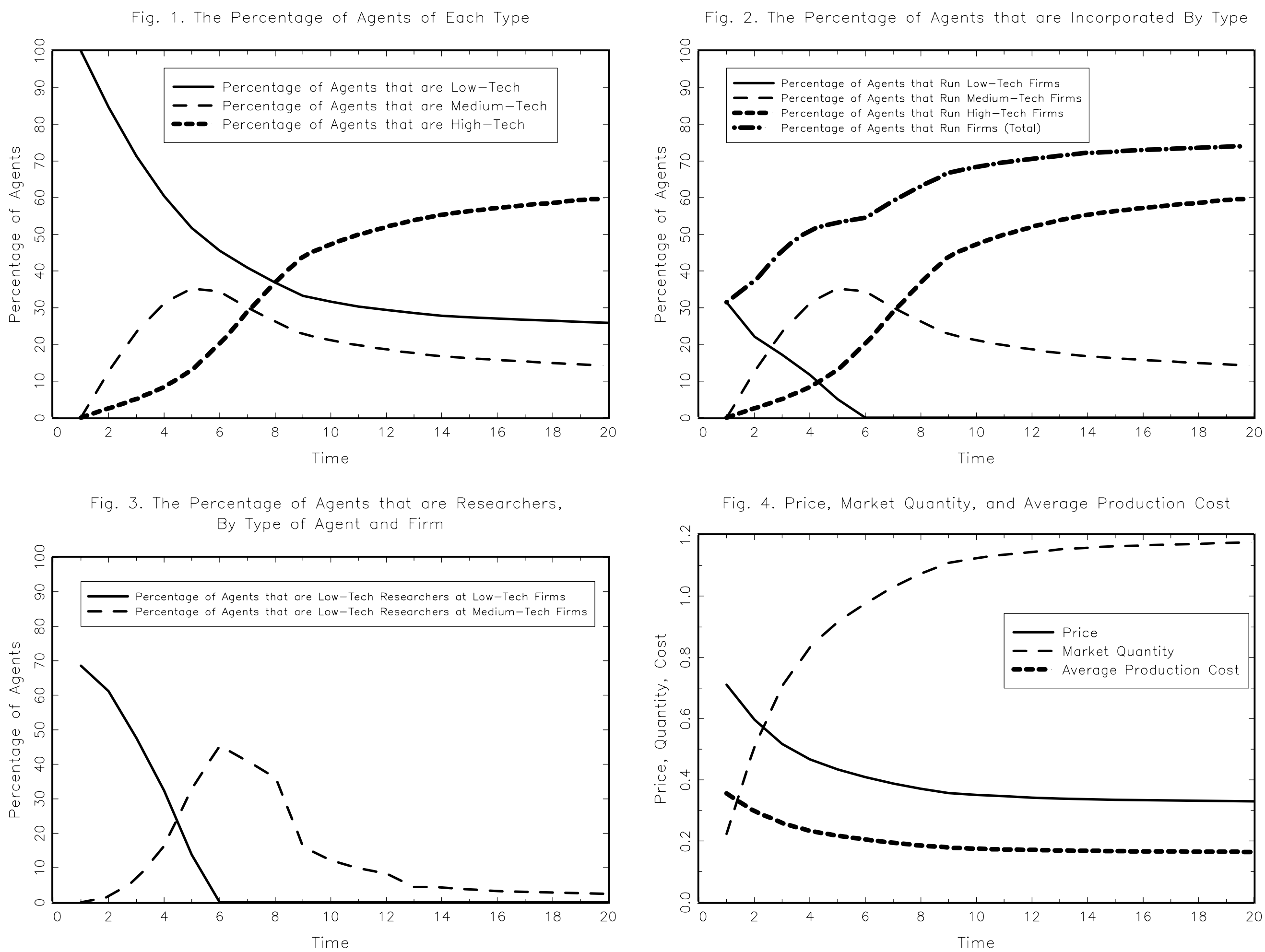
Fig. 1. The Percentage of Agents of Each Type
Percentage of Agents
Time
Percentage of Agents that are Low–Tech
Percentage of Agents that are Medium–Tech
Percentage of Agents that are High–Tech
Fig. 2. The Percentage of Agents that are Incorporated By Type
Percentage of Agents
Time
Percentage of Agents that Run Low–Tech Firms
Percentage of Agents that Run Medium–Tech Firms
Percentage of Agents that Run High–Tech Firms
Percentage of Agents that Run Firms (Total)
Fig. 3. The Percentage of Agents that are Researchers,
By Type of Agent and Firm
Percentage of Agents
Time
Percentage of Agents that are Low–Tech Researchers at Low–Tech Firms
Percentage of Agents that are Low–Tech Researchers at Medium–Tech Firms
Fig. 4. Price, Market Quantity, and Average Production Cost
Price, Quantity, Cost
Time
Price
Market Quantity
Average Production Cost

Figure 5.1:

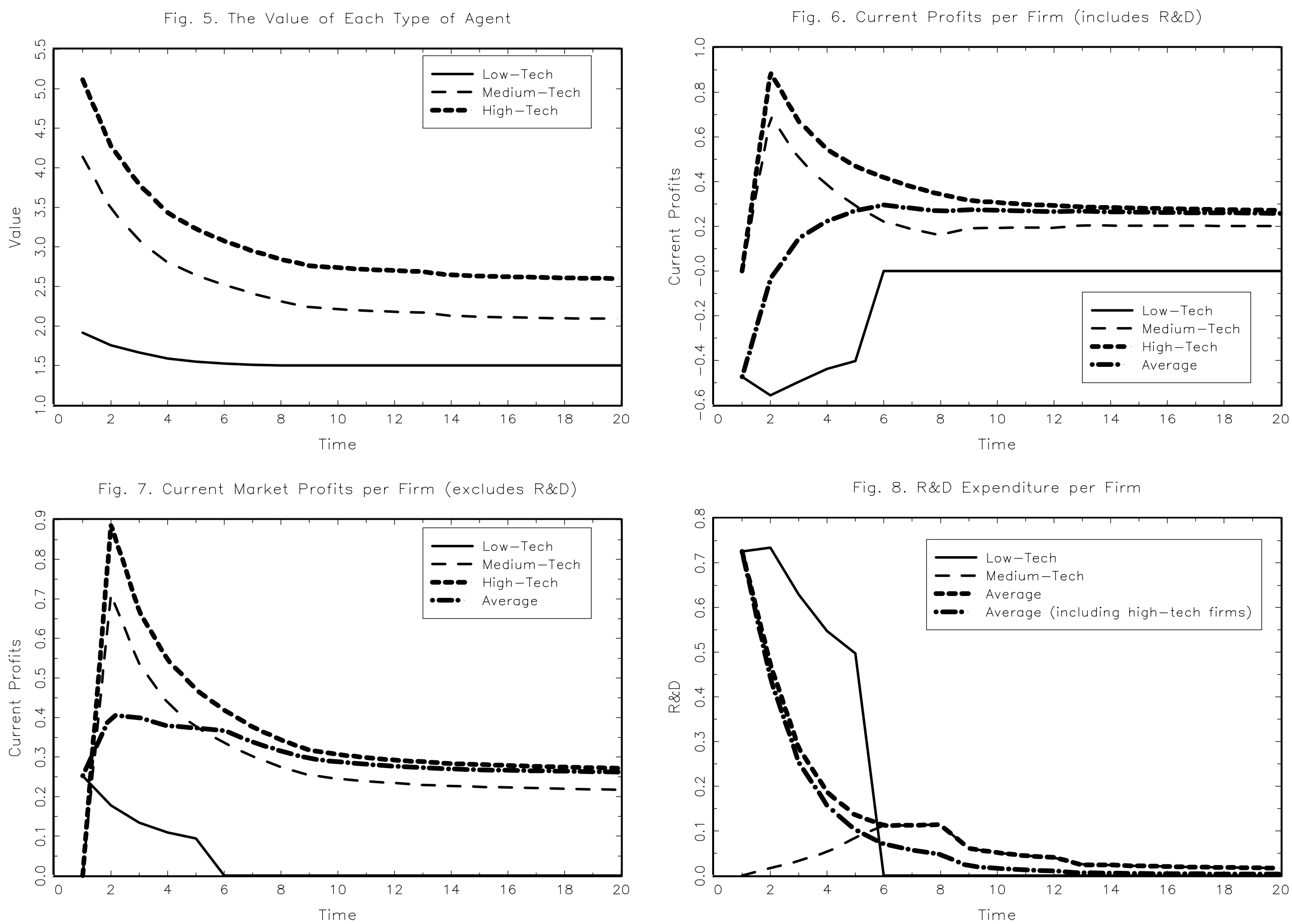
Fig. 5. The Value of Each Type of Agent
Value
Time
Low−Tech
Medium−Tech
High−Tech
Fig. 6. Current Profits per Firm (includes R&D)
Current Profits
Time
Low−Tech
Medium−Tech
High−Tech
Average
Fig. 7. Current Market Profits per Firm (excludes R&D)
Current Profits
Time
Low−Tech
Medium−Tech
High−Tech
Average
Fig. 8. R&D Expenditure per Firm
R&D
Time
Low−Tech
Medium−Tech
Average
Average (including high−tech firms)

Figure 5.2:

**Table 1. Spin-outs, Parents, Founding Years, and Life Spans**

| **Spin-Out** | **Parent(s)** | **Founding Yr.** | **Life Span** |
|---|---|---|---|
| International Memories | Memorex | 1977 | 8, Exited |
| Micropolis | Pertec | 1977 | 19, Acquired |
| Dastek | IBM | 1978 | 3, Acquired |
| Priam | Memorex | 1978 | 12, Exited |
| Irwin International Industries, Inc. | Sycor | 1979 | 3, Acquired |
| Seagate | Shugart Associates | 1979 | 18, Still Active |
| Computer Memories | Pertec | 1980 | 6, Exited |
| Ibis | Burroughs, Memorex | 1980 | 10, Exited |
| Miniscribe | Storage Technology Corp. | 1980 | 10, Acquired (by Maxtor) |
| Quantum | Shugart Associates | 1980 | 17, Still Active |
| Rodime | Burroughs | 1980 | 11, Exited |
| Rotating Memory Systems | Shugart Associates, Memorex | 1980 | 2, Acquired |
| Amcodyne | Storage Technology Corp. | 1981 | 5, Acquired |
| Atasi | International Memories | 1981 | 6, Acquired |
| Evotek | Memorex, Data General | 1981 | 2, Exited |
| Tecstor | Microdata | 1981 | 6, Acquired |
| Applied Information Memories | Ibis | 1982 | 3, Exited |
| Cogito | IBM | 1982 | 6, Exited |
| Maxtor | Quantum | 1982 | 14, Acquired |
| Microcomputer Memories | Alpha Data | 1982 | 5, Exited |
| Microscience International | Datapoint | 1982 | 10, Exited |
| Syquest | Seagate | 1982 | 15, Still Active |
| Vertex Peripherals | Shugart Associates | 1982 | 3, Acquired (by Priam) |
| Lapine | Irwin International | 1983 | 4, Exited |
| Tulin | Ampex, Qume | 1983 | 5, Exited |
| Epelo | Atasi | 1984 | 1, Exited |
| Josephine County Technology | Tandon | 1984 | 4, Exited |
| Micro Storage Corp. | Syquest | 1984 | 2, Exited |
| Peripheral Technology | Computer Memories | 1985 | 2, Acquired |
| Brand Technologies | Computer Memories | 1986 | 6, Exited |
| Conner Peripherals | Seagate, Miniscribe | 1986 | 10, Acquired (by Seagate) |
| PrairieTek | Miniscribe | 1986 | 5, Exited |
| Comport | Lapine | 1987 | 3, Exited |
| Kalok | Lapine | 1987 | 7, Acquired |
| Areal Technology | Maxtor | 1988 | 3, Acquired |
| Ecol.2 | Areal Technology | 1990 | 1, Exited |
| Integral Peripherals | PrairieTek | 1990 | 7, Still Active |
| Orca Technology | Maxtor, Priam | 1990 | 2, Exited |
| MiniStor | Maxtor | 1991 | 4, Exited |
| Gigastorage International | Aura Associates | 1993 | 4, Still Active |

The exit date is the date the firm stops manufacturing and selling new drives. Spin-outs either exit through failure (denoted by exited in the life span column), are acquired (denoted by acquired), or are still active as of 1997 (denoted by still active). If the firm was acquired by another spin-out, we note the acquiring firm.

**Table 2. The Early Movers, by Diameter**
(firms are in alphabetical order in each category)

| Diameter | Early Mover | Introduction Date |
|---|---|---|
| | | |
| 8” | BASF | Q4, 1979 |
| | IBM | Q1, 1979 |
| | International Memories | Q1, 1979 |
| | Micropolis | Q4, 1979 |
| | New World Computer | Q3, 1979 |
| | Pertec | Q4, 1979 |
| | Shugart Associates | Q4, 1979 |
| | | |
| 5.25” | Computer Memories | Q2, 1981 |
| | International Memories | Q1, 1981 |
| | New World Computer | Q3, 1980 |
| | Rodime | Q2, 1981 |
| | Rotating Memory Systems | Q2, 1981 |
| | Seagate | Q3, 1980 |
| | Tandon | Q4, 1980 |
| | | |
| 3.5” | Control Data | Q3, 1983 |
| | Microcomputer Memories | Q1, 1984 |
| | Microscience International | Q2, 1984 |
| | Rodime | Q3, 1983 |
| | | |
| 2.5” | PrairieTek | Q4, 1988 |
| | | |
| 1.8” | Integral Peripherals | Q3, 1991 |
| | | |

An early mover is defined to be a firm that introduces a drive in the diameter within 3 quarters after the first introduction. 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 3. Imitation of Early-mover Know-how in the Period 1977-1997

| Early Mover Parent | Spin-Out | Is the Spin-Out an Early Mover? |
|---|---|---|
| | | |
| Computer Memories, 5.25” | Brand Technologies | NO |
| | Peripheral Technology | NO |
| | | |
| IBM, 8” | Cogito | NO |
| | Dastek | NO |
| | | |
| International Memories | Atasi | NO |
| | | |
| Pertec, 8” | Computer Memories | YES, 5.25” |
| | Micropolis | YES, 8” |
| | | |
| | | |
| PrairieTek, 2.5” | Integral Peripherals | YES, 1.8” |
| | | |
| Seagate, 5.25” | Conner Peripherals | NO |
| | Syquest | NO, (but was the first mover in 4” removable cartridge drives) |
| | | |
| Shugart Associates, 8” | Quantum | NO |
| | Rotating Memory Systems | YES, 5.25” |
| | Seagate | YES, 5.25” |
| | Vertex Peripherals | NO |
| | | |
| Tandon, 5.25” | Josephine County Technology | NO |
| | | |

## Table 4. Summary Statistics

| | Mean | Standard deviation | Minimum | Maximum | Cases |
|---|---|---|---|---|---|
| Technical Know-How | 0.44 | 0.25 | 0.0084 | 1.00 | 1039 |
| Lagged Technical Know-How | 0.45 | 0.24 | 0.0084 | 1.00 | 877 |
| Early-Mover Know-How | 0.15 | 0.36 | 0.00 | 1.00 | 1190 |
| Lagged Number of Drives | 11.31 | 15.06 | 1.00 | 119 | 886 |
| Lagged Sales Growth | 0.21 | 0.65 | -2.00 | 2.00 | 846 |
| U.S. Firm Dummy | 0.62 | 0.49 | 0.00 | 1.00 | 1190 |
| Spin-Out Generation Dummy | 0.032 | 0.18 | 0.00 | 1.00 | 1190 |
| Survival Dummy | 0.91 | 0.29 | 0.00 | 1.00 | 1172 |

Definitions of technical know-how, early-mover know-how, and sales growth are provided in the text. Technical Know-How and Lagged Technical Know-How range from 0 to 1. Early-Mover Know-How is a dummy variable. Lagged Sales Growth ranges from -2 to 2.

Lagged Number of Drives measures the number of drives produced by the firm in the previous period. The U.S. Firm Dummy takes the value 1 if the firm is an American firm, and 0 otherwise. The Spin-Out Generation Dummy takes the value 1 if the firm generates a spin-out in the current period, and 0 otherwise. The Survival Dummy takes the value 0 if the firm exits through failure in the following period, and 1 otherwise.

**Table 5. The Probability of Generating a Spin-Out as a Function of Know-How**
Probit Model (Standard Errors in Parentheses)

| | Equation 5a. | Equation 5b. | Equation 5c. | Equation 5d. (US firms) | Equation 5e. | Equation 5f. (US firms) |
|---|---|---|---|---|---|---|
| Variable | Coefficient | Coefficient | Coefficient | Coefficient | Coefficient | Coefficient |
| | | | | | | |
| Constant | -2.26*** (0.19) | -2.18*** (0.21) | -2.67*** (0.44) | -2.46*** (0.46) | -2.58*** (0.45) | -2.37*** (0.47) |
| Lagged Technical Know-How | 0.74** (0.31) | 0.71** (0.34) | 1.12*** (0.37) | 1.04*** (0.39) | 1.08*** (0.40) | 0.94** (0.43) |
| Early-Mover Know-How | 0.51*** (0.18) | 0.38** (0.18) | 0.49** (0.19) | 0.35* (0.20) | 0.47** (0.21) | 0.33 (0.22) |
| Lagged Sales Growth | - | 0.25* (0.13) | - | - | 0.12 (0.15) | 0.14 (0.16) |
| Lagged Number of Drives | - | - | - | - | -0.0096 (0.0080) | -0.0069 (0.0083) |
| YR1978 | - | - | 0.44 (0.57) | 0.44 (0.59) | 0.57 (0.57) | 0.47 (0.58) |
| YR1979 | - | - | 0.15 (0.61) | 0.16 (0.64) | 0.077 (0.62) | 0.10 (0.64) |
| YR1980 | - | - | 0.82* (0.49) | 0.89 (0.51) | 0.80* (0.49) | 0.88* (0.51) |
| YR1981 | - | - | 0.84* (0.48) | 0.89 (0.51) | 0.85* (0.48) | 0.91* (0.51) |
| YR1982 | - | - | 0.83* (0.48) | 0.95 (0.50) | 0.81* (0.48) | 0.89* (0.51) |
| YR1984 | - | - | 0.25 (0.51) | 0.25 (0.53) | 0.22 (0.51) | 0.26 (0.54) |
| YR1985 | - | - | -0.14 (0.59) | -0.14 (0.61) | -0.13 (0.59) | -0.12 (0.61) |
| YR1986 | - | - | 0.32 (0.50) | 0.41 (0.52) | 0.37 (0.50) | 0.45 (0.53) |
| YR1987 | - | - | -0.083 (0.58) | -0.035 (0.61) | -0.037 (0.59) | 0.036 (0.63) |
| YR1988 | - | - | -0.059 (0.60) | 0.0052 (0.65) | 0.053 (0.62) | 0.12 (0.66) |
| YR1990 | - | - | 0.67 (0.49) | 0.85 (0.53) | 0.89* (0.51) | 1.02* (0.55) |
| YR1991 | - | - | -0.12 (0.59) | -0.011 (0.63) | 0.17 (0.62) | 0.22 (0.66) |
| YR1993 | - | - | 0.0013 (0.60) | 0.070 (0.64) | 0.50 (0.66) | 0.50 (0.69) |
| Number of Observations | 877 | 634 | 673 | 432 | 556 | 379 |
| Log Likelihood | -136.27 | -127.30 | -117.03 | -105.15 | -112.19 | -101.72 |

The dependent variable is the spin-out generation dummy.
*Significant at the 10% level. **Significant at the 5% level. ***Significant at the 1% level.
When year dummies are included, 1983 is the base year.

**Table 6. The Probability of Surviving to the Following Period as a Function of Know-How**

Probit Model (Standard Errors in Parentheses)

| | Equation 6a. | Equation 6b. | Equation 6c. (US firms) |
|---|---|---|---|
| Variable | Coefficient | Coefficient | Coefficient |
| | | | |
| Constant | 0.86*** (0.10) | 0.96*** (0.25) | 1.05*** (0.29) |
| Technical Know-How | 0.88*** (0.23) | 0.99*** (0.25) | 0.63** (0.30) |
| Early-Mover Know-How | 0.36** (0.18) | 0.27 (0.20) | 0.36* (0.22) |
| | | | |
| YR1978 | - | 0.50 (0.50) | - |
| YR1979 | - | 0.11 (0.38) | -0.066 (0.41) |
| YR1981 | - | 0.81* (0.48) | - |
| YR1982 | - | 0.30 (0.35) | 0.31 (0.42) |
| YR1984 | - | -0.21 (0.30) | -0.44 (0.33) |
| YR1985 | - | -0.17 (0.31) | -0.44 (0.35) |
| YR1986 | - | -0.37 (0.30) | -0.11 (0.38) |
| YR1987 | - | -0.010 (0.33) | -0.19 (0.38) |
| YR1988 | - | 0.046 (0.33) | 0.20 (0.44) |
| YR1989 | - | -0.013 (0.33) | -0.25 (0.39) |
| YR1990 | - | -0.17 (0.32) | -0.20 (0.41) |
| YR1991 | - | -0.69** (0.29) | -0.62 (0.38) |
| YR1992 | - | -0.61** (0.31) | -0.37 (0.42) |
| YR1993 | - | -0.72** (0.31) | -0.28 (0.43) |
| YR1994 | - | -0.68** (0.33) | -0.48 (0.42) |
| YR1996 | - | -0.39 (0.37) | -0.28 (0.48) |
| | | | |
| Number of Observations | 1039 | 918 | 496 |
| | | | |
| Log Likelihood | -335.75 | -301.41 | -173.31 |

The dependent variable is the survival dummy. It is 0 if the firm exits through failure in the following period, and 1 otherwise.
*Significant at the 10% level.
**Significant at the 5% level.
***Significant at the 1% level.
When year dummies are included, 1983 is the base year.

**Table 7 The Probability of Surviving to the Following Period as a Function of Know-How - Spin-Outs Only**

Probit Model (Standard Errors in Parentheses)

| | Equation 7a. | Equation 7b. | Equation 7c. |
|---|---|---|---|
| Variable | Coefficient | Coefficient | Coefficient |
| | | | |
| Constant | 0.83***<br>(0.27) | 0.76<br>(0.59) | 0.49<br>(0.73) |
| Technical Know-How | 1.10**<br>(0.51) | 1.46**<br>(0.61) | 3.08***<br>(0.95) |
| Early-Mover Know-How | 0.064<br>(0.26) | -0.029<br>(0.29) | -0.47<br>(0.42) |
| Parent Technical Know-How | - | - | -1.36**<br>(0.62) |
| Parent Early-Mover Know-How | - | - | 0.68*<br>(0.37) |
| | | | |
| YR1984 | - | -.10<br>(0.62) | - |
| YR1985 | - | -0.11<br>(0.63) | 0.64<br>(0.76) |
| YR1986 | - | 0.22<br>(0.71) | 0.79<br>(0.82) |
| YR1987 | - | -0.13<br>(0.66) | 0.12<br>(0.73) |
| YR1988 | - | 0.32<br>(0.73) | 0.65<br>(0.82) |
| YR1989 | - | -0.21<br>(0.65) | 0.11<br>(0.72) |
| YR1990 | - | -0.60<br>(0.64) | -0.63<br>(0.70) |
| YR1991 | - | -0.81<br>(0.62) | -0.85<br>(0.68) |
| YR1992 | - | -0.70<br>(0.66) | -1.08<br>(0.71) |
| YR1994 | - | -0.32<br>(0.74) | -0.35<br>(0.82) |
| YR1996 | - | -0.28<br>(0.78) | -0.17<br>(0.97) |
| | | | |
| Number of Observations | 243 | 184 | 150 |
| | | | |
| Log Likelihood | -66.45 | -57.99 | -40.13 |

The dependent variable is the survival dummy. It is 0 if the firm exits through failure in the following period, and 1 otherwise.

*Significant at the 10% level.

**Significant at the 5% level.

***Significant at the 1% level.

When year dummies are included, 1983 is the base year.

## Table 8. Summary Statistics on Spin-outs

| | **Mean** | **Standard deviation** | **Minimum** | **Maximum** | **Cases** |
|---|---|---|---|---|---|
| Spin-Out Life Span | 6.60 | 4.80 | 1.00 | 19.00 | 40 |
| Parent Technical Know-How | 0.57 | 0.28 | 0.053 | 1.00 | 34 |
| Average Parent Technical Know-How in the 3 years surrounding the spin-out's entry | 0.48 | 0.23 | 0.019 | 1.00 | 38 |
| Parent Early-Mover Know-How | 0.39 | 0.50 | 0.00 | 1.00 | 40 |
| Parent Sales Growth in the 3 years surrounding the spin-out's entry | 0.085 | 0.67 | -1.86 | 1.6 | 38 |
| Entrepreneur Dummy | 0.30 | 0.46 | 0.00 | 1.00 | 40 |
| | | | | | |
| Number of Censored Observations | 19 | | | | |

Parent Technical Know-How and Average Parent Technical Know-How range from 0 to 1. Parent Early-Mover Know-How is a dummy variable. Parent Sales Growth ranges from –2 to 2. The Entrepreneur Dummy is a dummy variable.

The Censored Observations are spin-outs that have either been acquired or are still active at the end of the sample.

## Table 9. Spin-out Life Span as a Function of Parent Know-how

Duration Model using Weibull Specification (Standard Errors in Parentheses)

| | Equation 9a. | Equation 9b. | Equation 9c. | Equation 9d. |
|---|---|---|---|---|
| Variable | Coefficient | Coefficient | Coefficient | Coefficient |
| | | | | |
| Constant | 2.61***<br>(0.49) | 2.73***<br>(0.45) | 2.73***<br>(0.46) | 2.84***<br>(0.46) |
| Parent Technical Know-How | -0.71<br>(0.64) | - | | |
| Parent Early-Mover Know-How | 0.68<br>(0.43) | 0.78*<br>(0.41) | 0.66*<br>(0.40) | 0.79**<br>(0.40) |
| Average Parent Technical Know-How in the 3 years surrounding the spin-out's entry | - | -1.18*<br>(0.70) | -1.18*<br>(0.72) | -1.30*<br>(0.71) |
| Parent Sales Growth in the 3 years surrounding the spin-out's entry | - | - | 0.55*<br>(0.29) | 0.59**<br>(0.29) |
| Entrepreneur Dummy | - | - | - | -0.31<br>(0.39) |
| | | | | |
| Sigma | 0.73***<br>(0.22) | 0.70***<br>(0.41) | 0.65***<br>(0.19) | 0.64***<br>(0.19) |
| | | | | |
| Number of Observations | 34 | 38 | 38 | 38 |
| | | | | |
| Log Likelihood | -33.03 | -36.20 | -33.55 | -33.26 |

The dependent variable is the spin-out's life span (from Table 1).

The definitions of technical know-how, early mover know-how, other know-how, and the entrepreneur dummy are discussed in the text.

*Significant at the 10% level.

**Significant at the 5% level.

***Significant at the 1% level.