Whether and When? Probability and Timing of Incumbents' Entry into Emerging Industrial Subfields

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This paper examines the probability and timing of entry by industry incumbents into emerging technical subfields. When a new technical subfield of an industry emerges, an industry incumbent faces opposing entry incentives, either to wait until technical and market uncertainties subside or to stake out a strong position early. This paper argues that an incumbent is likely to enter a new subfield if the firm's core products are threatened or if it possesses industry-specialized supporting assets. The greater the competitive threat, the less likely an incumbent is to enter but the earlier it will do so. The predictions are supported with analysis of 30 years of entry data from five subfields of the American medical diagnostic imaging industry.•

As an industry evolves, new goods emerge. Many changes are incremental extensions of existing products (Sahal, 1981) and so can be easily adopted by firms participating in the existing industry (Abernathy and Utterback, 1978). Other new products, however, draw on new knowledge bases (Nelson and Winter, 1982). Goods that emerge following such a technological discontinuity (Tushman and Anderson, 1986) form a new technical subfield of an industry and are often difficult for industry incumbents to incorporate into existing product lines (Hannan and Freeman, 1977; Dosi, 1988). Nonetheless, if it possesses the specialized supporting assets required for successful commercialization of the new goods (Teece, 1986), an industry incumbent has competitive advantages. Hence, incumbents often do begin to manufacture the new goods. Variation in competitive conditions, however, influences whether and when an incumbent will enter a new technical subfield of its industry.

This paper investigates the probability and timing of entry by industry incumbents into emerging technical subfields. It argues that entry probability and timing will be influenced by threats to core products, possession of specialized supporting assets, and the extent of rivalry to secure the value of specialized assets. An industry incumbent will be likely to enter a new subfield if the firm possesses a broad base of assets required for successful commercialization of the new goods or if its core products are threatened. An incumbent will generally be less likely to enter if there are many potential rivals, but a firm facing threats to its core products will enter sooner when there are many potential rivals. Increases of potential rivalry will also speed the entry of an incumbent with a broad base of specialized supporting assets. The study tests these predictions by examining the entry probability and timing of industry incumbents in five emerging technical subfields of the American medical diagnostic imaging industry.

Imaging techniques, with which healthcare workers obtain pictures and other knowledge of physiological structures within the body, are important diagnostic medical tools. Since the late 1950s, five major technical subfields have augmented conventional x-ray and electrodiagnostic techniques. The emergence of nuclear medical, ultrasonic, computed tomographic, magnetic resonance, and digital radiographic imaging systems and the entry of over 300 manufacturers have expanded the diagnostic imaging industry and challenged its in-

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cumbents. Responses to the challenges have varied. Some incumbents have expanded into the new subfields early; others have waited or not entered at all. This paper explains some of the variation.

BACKGROUND

The development and marketing of a new good, particularly one drawing on new knowledge, involves large measures of luck (National Science Foundation, 1980). Simply because of the random element involved in technological change, therefore, an industry incumbent often will not be the first to develop a product. Once a new subfield has emerged, an incumbent's entry actions may vary. It may or may not enter the new subfield. If it does enter, it may enter quickly, even if it is not first, or wait to imitate early entrants.

Whether and when to enter a new subfield are critical issues for an incumbent. New goods provide opportunities for growth (Foster, 1986) but may reduce sales of existing products (Frankel, 1955; Reinganum, 1983) and reduce the value of existing skills and physical assets (Tushman and Anderson, 1986). In addition, acquiring necessary new skills and assets after changes occur in the technological environment may disrupt an incumbent's existing organization (Hannan and Freeman, 1977). Hence, entry questions are both important and complex.

Caves (1984) argued that two factors underlie a firm's strategies: the need to undertake irreversible investment and rivalry to secure the value of such investment. The two factors have implications for entry probability and timing. Developers of goods drawing on new knowledge bases typically face technical and demand uncertainty (Nelson and Winter, 1982). Although an early entrant may reap short-run profits because of market disequilibrium (Schumpeter, 1975; MacMillan, 1985), it risks investing in physical or knowledge-based assets that will have little value if the products do not work or no one will buy them (Williamson, 1985); hence, there are incentives to delay entry. The risk of losing the value of specialized supporting assets a firm already possesses, however, counteracts the incentive to wait.

Incumbents are often slow to enter new technical subfields. Sometimes, delaying permits technical and market turbulence to subside. In other cases, incumbents are constrained by structural and environmental inertia (Crozier, 1964; Stinchcombe, 1965; Hannan and Freeman, 1984). But industry incumbents sometimes do introduce new products. During the early 1980s, for example, incumbents of the diagnostic imaging industry were among the first to produce nuclear magnetic resonance imaging systems, even though the equipment differed significantly from other methods of producing medical images (Steinberg and Cohen, 1984). There is empirical evidence, therefore, that an incumbent's incentives to enter early sometimes outweigh those to enter late. How the incentives vary is an intriguing theoretical and empirical question.

Related Literature

The economic and organizational literatures and the fields, such as strategy, that draw on those bodies of work have shed considerable light on entry issues. Yet existing theories have been more successful in identifying reasons why incumbents are late entrants than in explaining why they are sometimes early. Moreover, researchers examining the advantages of early entry usually have not distinguished between cases in which early entry is possible and those in which it is necessary.

The ease with which a product can be imitated, the number of firms that might do so, and the likelihood that each firm could successfully market the new goods will influence entry probability and timing. Entry issues are relatively simple at the extremes of imitability. At one extreme, some new products cannot be imitated. If only one firm could both develop and introduce a nonimitable good, entry probability and timing will depend on its private incentives: the assessment of internal organizational factors, the likelihood of successful development, and the expected size of the market (Katz and Shapiro, 1987). If several firms could develop and market a nonimitable product, they will often race to do so (Gilbert and Newberry, 1982); the winner will dominate the market for the new good.

At another extreme, many firms can sometimes imitate, further develop, and quickly market a new product. The company that first develops and introduces the good often must incur costs that will not be borne by imitators (Mansfield, Schwartz, and Wagner, 1981). In many such cases, no initial development will take place, because few firms will be willing to undertake an investment that would be appropriated by followers.

The first extreme, however, occurs rarely. Most new products can be copied quickly, and there are often several firms that could do so. Levin et al. (1988: Table 10), for example, found that in 72 of 129 lines of business, major, patented new products could be copied within three years. The other extreme is also unusual. The ability to copy a good does not necessarily give a firm the ability to introduce it successfully into a market. Commercialization of a new good is often a complicated process. It must be developed, manufactured, and distributed to one or more sets of users, who may demand refinement (Finnegan and Goldscheider, 1981), and must often be coupled with supporting products and knowledge (Phillips, 1966; Scherer, 1980). A firm, therefore, must not only copy a new product but must incorporate it into a host of physical components and organizational systems.

Following Teece (1986), I refer to the supporting products required for successful commercialization as assets to which a new good is specialized or, simply, specialized assets. Because specialized assets often are difficult to replicate quickly, many firms that could imitate a product cannot undertake necessary improvements or distribute and service it. There is a crucial distinction, therefore, between a core product and the assets required to secure its potential value. When deciding whether and when to introduce new products, a firm's managers must consider both how many firms might potentially imitate a new good and whether they could replicate the supporting assets needed for its development and distribution. Product imitation and supporting asset replication often will occur at different speeds.

Entry questions are complex in the intermediate cases. A common empirical finding, though, is that the first companies to introduce major cost-reducing or quality-enhancing product innovations frequently are newcomers to an industry (Jewkes, Sawyers, and Stillerman, 1958; Abernathy and Utterback, 1978). Incumbents are more likely to be followers than to be the first to enter new product areas (Scherer, 1980). Most examinations of timing, therefore, have focused on late entry by incumbents.

Economic and organizational arguments have been used to explain the late entries. The costs of cutting into the sales of existing goods create a disincentive for industry incumbents to introduce new products (Arrow, 1962; Reinganum, 1983; Utterback and Kim, 1985; Tushman and Anderson, 1986). Katz and Shapiro (1987) noted that when a product can be easily imitated, an incumbent, or a dominant firm at least, will often benefit from delaying its entry. The firm will be able to copy a product introduced by a competitor but avoids introducing a product that would quickly be copied by other companies. The incentive to avoid cutting into sales may thus override incentives to compete. When a few firms dominate an industry, parallel action may lead to delayed entry by all or most participants (Bain, 1956; Caves, 1972).

Risk-aversion might also explain the tendency for late entry. Employees of firms that already participate in an industry often have more to lose than newcomers, should existing patterns be changed. If actors with more to lose are risk-averse (Singh, 1986; March, 1988), and if introducing major innovations is a risky activity, then incumbents may avoid introducing major innovations.

Incumbents may also be constrained by structural inertia (Burns and Stalker, 1961; Crozier, 1964). Like the slow competitive reaction induced by fear of cutting into the sales of existing products, structural inertia may extend beyond a single organization, such that tight links among several organizations may delay action by each (Granovetter, 1973). Such inertia may not be harmful, however. Hannan and Freeman (1977, 1984) argued that structural inertia may enhance organizational survival probabilities if expanding would incur reorganization liabilities. Thus, if expanding into a new technical subfield would involve major changes to an incumbent's core, early entrants to new subfields will tend to be industry newcomers.

But the cannibalization, risk-aversion, and inertia arguments do not explain why industry incumbents sometimes are first or early entrants, even when imitation is easy. Several other pieces of research directly or indirectly address early-entry incentives. Brittain and Freeman (1980) argued that an organization will be quick to expand when there is a significant overlap between its core capabilities and those needed to survive in a new market. This prediction was supported by Lambkin's (1988) empirical analysis of firms in the Profit Impact of Market Strategy (PIMS) data base.

An extensive literature examines links between market structure and such measures of innovativeness as R&D expenditure and product development (reviewed in Scherer, 1980, and Kamien and Schwartz, 1982). Although that research does not directly address entry timing, it provides two useful insights. First, competitive pressure is likely to cause earlier product development (Kamien and Schwartz, 1982). Second, along with current rivals, potential competitors also influence actions (Bain, 1956; Phillips, 1966; Barzel, 1968). Together, these arguments imply that entry timing into new technical subfields will be influenced by the number of potential entrants.

Analysis of evolutionary paths of economic development has also disclosed incentives for a firm's entry timing to vary in different market structures. Nelson and Winter (1982: chap. 13) simulated development time-paths for several interactions of technical and competitive conditions. When product imitation was easy and there were many firms (16 competitors), an aggressive investment policy was likely to lead to increased concentration. Given the same imitability but few firms (4 rivals), however, investment aggression had little influence on concentration. Concentration may be a desirable outcome for the firms that survive the competitive process. If so, and if early entry is a form of aggressive investment, the simulation helps us understand the incentives underlying entry timing. Early entry will be appropriate when there are many competitors but will offer no advantage when there are few competing firms.

Strategic preemption researchers have directly considered the advantages of early entry. These include achieving technical leadership, capturing use of scarce resources, and creating buyer switching costs (Lieberman and Montgomery, 1988). The research has also identified early entry disadvantages, including appropriation of an early entrant's investment by rivals, technical uncertainty, and market uncertainty (Lieberman and Montgomery, 1988). The risk of being locked into an undesirable position may also be a disadvantage, but only because of uncertainty about which position will be appropriate. Often, the disadvantages will outweigh the potential benefit. MacMillan (1983) has argued that preemptive attempts are inherently risky.

For preemption to succeed, argued Lieberman (1986), several conditions must hold. Those conditions reduce to three: the early entrant must possess nonimitable specialized assets, it must be able to move before its rivals, and its rivals must not enter. The specialized assets necessary for successful preemption, therefore, are not sufficient. If rivals can move as quickly as a preemptor, the incentives for late entry are likely to override the preemption opportunity.

However, the preemption argument has a flip-side. A firm possessing specialized assets must sometimes enter early not to preempt but to avoid being preempted by rivals that also possess specialized assets. Wernerfelt and Karnani (1987) argued, for instance, that more competitors increase the incentives to act early, which extends Bowman's (1982) argument that firms in danger of failing are more likely to undertake risky ventures. Although risky, early entry to an emerging subfield is sometimes necessary if a firm wishes to continue to participate in the industry.

At the center of entry-timing issues, then, are questions about protecting the value of core products and securing the value of specialized supporting assets. If a firm enters early, will it be able to recover its entry investment before competitors imitate its products, perhaps improve them, and take advantage of lower development costs to drive down prices? Conversely, if a firm waits to enter, will it be able to imitate successful early entrants before they establish strong market positions?

Two factors are particularly important to an industry incumbent. If a new product succeeds, an incumbent will generally need to offer it in order to maintain sales and to grow. And, because of its incumbency, a member of the existing industry will often possess assets required for the successful development and marketing of the new good. If an incumbent can contract for others to use one of its specialized assets, it need not enter a new subfield at all but can reap the value of the asset by allowing other entrants to use it. Sometimes, though, the firm will lose the value of its asset by contracting for its use; in other cases, contracting is not possible because the core and supporting products must be integrated within one organization. Often, therefore, the holder of an asset will be forced to enter if it wishes to secure its value (Teece, 1981, 1986; von Hippel, 1982).

This study explores the questions of whether and when incumbents enter new technical subfields by examining entry into five new subfields of the medical diagnostic imaging industry. In order to understand what entry means in this context and what issues are involved, some background is necessary.

THE DIAGNOSTIC IMAGING INDUSTRY

Technical Subfields

The beginning of the twentieth century was marked by the development of important medical diagnostic tools. The first commercial x-ray equipment was available within a year of Roentgen's 1895 discovery that short electromagnetic waves would produce fluorescence in mineral salts. During the first two decades of the century, electrodiagnostic instruments such as electrocardiographs and encephalographs were also introduced to medical markets. X-ray and electrodiagnostic techniques improved during the next 60 years, as better tubes, full-wave rectification methods that reduced imaging times, equipment to focus radiation, better film, and cathode-ray tube monitors appeared (Hodges, 1945; Cromwell et al., 1976). Until the mid-1950s, however, doctors had few ways of seeing inside their patients. They could use x-ray equipment to produce dim images of bones and organs, electrodiagnostic instruments to depict physiological activity, or scalpels to cut open their subjects.[1]

Beginning in the late 1950s, several distinct new subfields of the imaging industry appeared, as shown in column 1 of Table 1. The first nuclear medical imaging instrument to receive clinical acceptance, a rectilinear scanner that produced

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Detailed descriptions of the diagnostic imaging industry, the data gathered to describe it and the sources from which the data were gathered are contained in Mitchell (1988). See also U.S. Congress, Office of Technology Assessment (1978, 1981), McKay (1983), Friar (1986), and Steinberg and Cohen (1984) for descriptions of some subfields.

Table 1

Descriptive Statistics on the American Diagnostic Imaging Industry

Imaging industry technical subfields	First year subfield products sold in U.S.	No. of incumbents during year before subfield emerged: All	No. of incumbents during year before subfield emerged: Multiple-subfield*	No. of entrants to subfield by end of 1988: All firms	No. of entrants to subfield by end of 1988: Incumbents	Average wait of incumbents that entered subfield (years)
Early subfields:						
X-ray	1896					
Electrodiagnostic	1911					
New subfields:						
Nuclear medical	1959	43	4	65	7	14
Ultrasound	1963	47	4	165	12	12
Computed tomography	1973	95	15	30	12	6
Magnetic resonance	1980	117	32	31	9	4
Digital radiography	1981	134	34	29	18	2
Total		436		320	58	

* Number of manufacturers that were participating in at least two imaging industry subfields the year before the new subfield emerged.

images of thyroid glands and brain tumors, was introduced in about 1959. An ultrasonic soft tissue imager for identifying cancer was marketed in 1963. The first American hospital to obtain a computed tomographic (CT) scanner did so in 1973. The first American nuclear magnetic resonance imaging (NMR or MRI) system was put into clinical practice in late 1980. Digital radiographic equipment was first shipped during 1981. Each type of instrument partially substituted for the others, at least when purchasers allocated a limited budget among second and third units (Emmitt, 1980; McKay, 1983).

The imaging instruments all draw from physical science and applied engineering but use several scientific and technical knowledge bases within those fields. Conventional x-ray instruments record the absorption of short waves of radiation after they have passed through the body. Electrodiagnostic devices interpret electrical signals. Nuclear medical imaging instruments measure the gamma ray emissions of radioactive materials that have been administered to a patient. Ultrasonic imaging instruments produce pictures by interpreting either sonic echoes from organs or frequency shifts induced by moving objects such as fetuses or blood. CT scanners record x-radiation and use computers to interpret the absorption patterns. Magnetic resonance imaging devices subject the body to a large magnetic field and then interpret changes in the resonance of atomic nuclei when a smaller radiofrequency electromagnetic force disturbs the original field. Digital radiographic instruments, like conventional x-ray and CT, detect x-radiation but store the absorption information digitally for adjustment and interpretation (Meschan and Ott, 1984). The instruments within each class, therefore, constitute technical subfields of the imaging industry.

In this study, the firms manufacturing x-ray and electrodiagnostic instruments before the emergence of the nuclear medical imaging subfield in 1959 provide an initial base from which to draw incumbents. As each new subfield emerged, its participants also became members of the diagnostic imaging industry and faced entry pressures when later subfields appeared.

Concepts and definitions. To conduct the study, it was necessary to define the product and geographic scope of the industry and choose analytic periods. The analysis omits component suppliers, examines the U.S. market, and uses years as the measure of duration. In addition, the study focuses on manufacturing entry and so ignores firms that only conducted R&D or distributed another company's product.

The analysis is conducted at the parent-corporation level rather than the organizational subunit level of analysis. At this level, entry and exit are recorded when one participant is acquired by another, even if the first operation continues. The parent-corporation level was chosen because even ongoing operations are likely to undergo major changes at the time of sale, and functions spanning subunits of a parent must change if one subunit is sold. Some of the strategies that affect the use of research and development laboratories, for instance, are established at corporate levels. Scott (1984) found that about half the variance of R&D to sales ratios in a sample of 473 companies could be explained by corporate and industry effects, rather than influences particular to a specific organizational subunit.

Key characteristics. Three key characteristics of the diagnostic imaging industry provide the context for this empirical study. First, technical and market uncertainties have been high in each emerging subfield (Hamilton, 1982). Moreover, to manufacture the new goods, even firms with strong imaging-industry bases have had to invest in idiosyncratic changes in their physical plant and knowledge (Hess, 1987). Second, product imitation in this industry has been possible. Although reproducing a competitor's imaging instrument cannot be compared to building a Heathkit electronic model, many firms possess the base of technical competence required to understand and incorporate imaging advances. Thus incumbents faced technical and market uncertainties before products were introduced, yet they possessed the ability to replicate successful products after introduction (McKay, 1983). Therefore, incentives to wait before entering have been strong.

The third industry characteristic is that entrants have needed to offer more than a good-quality core product to succeed in the imaging-equipment market. The prior reputations and specialized distribution and service networks of the manufacturers have been at least as important in convincing radiologists and hospital administrators to buy imaging equipment (Frost and Sullivan, 1974; Drew, 1987). Such reputation and systems have been impossible for industry newcomers to replicate quickly. Reputations, distribution systems, and service networks have been valuable imaging-industry specialized assets. Because firms possessing such assets before entering a new subfield have had competitive advantages over firms lacking them, no matter when they enter a new imaging subfield, industry incumbents typically survive longer than newcomers (Mitchell, 1988).

Yet early-entrant incumbents possessing specialized assets have had opportunities to impose buyer-switching costs on the industry incumbents that follow them, as Bond and Lean (1977) found in a study of the pharmaceutical drug market. The physicians using imaging instruments often are loath to switch from one company's products if the goods work well, the manufacturer has a reputation for keeping up with incremental advances, and the firm provides good after-sales services. For incumbents possessing complementary assets required for successful commercialization of imaging equipment, there have been advantages to entering early and risks to entering later than capable rivals.

Entry Dynamics of the Imaging Subfields

As shown in column 4 of Table 1, more than 300 entries into the five new imaging-industry subfields have been made (by about 240 firms, because some companies have entered many or all subfields). Entry frequency and timing have differed among subfields. Far more firms have manufactured nuclear medical imaging and ultrasound equipment than have entered the CT, magnetic resonance, or digital radiography subfields. The differences can be attributed to the ages of the subfields, the investment required to enter each, and segmentation in the imaging market. The oldest imaging subfields, ultrasound and nuclear medical, have had the most entrants. Until recently, manufacturing nuclear medical and ultrasound equipment also required relatively low capital investment. The ultrasound market, too, is divided into physicians' office and several hospital department segments, as well as the conventional radiology market segment. Many potential nuclear medical and ultrasound equipment manufacturers could afford to enter and found niches within which to fit.

There has been less variation in the number of incumbents to enter each new subfield (column 5 of Table 1). However, the average period that industry incumbents such as the General Electric Company, Philips NV, and Siemens AG waited before entering new subfields has varied widely (column 6 of Table 1). Although a few imaging-industry incumbents began to manufacture nuclear medical and ultrasound equipment soon after the subfields emerged, some waited more than 10 years to enter. In the CT subfield, incumbent entry occurred more quickly. And in the magnetic resonance and digital radiography subfields, many industry incumbents were among the earliest entrants.

Environments of the Imaging Firms

Two environmental characteristics have been critically important to imaging firms: the size of the market for imaging products and the number of firms serving the market. The American market for imaging equipment expanded steadily during the 1960s from a 1959 base of about $40 million ($130 million when adjusted by the 1982 Producer Price Index). Sales grew rapidly after the establishment of the Medicare and Medicaid programs in the late 1960s but fell during the late 1970s as many states initiated cost-containing measures (Joskow, 1981). The imaging market grew again during the early 1980s, only to fall slightly in 1984 after the inception of the federal Prospective Payment System for medical treatment covered by the Medicare program (U.S. Congress, Office of Technology Assessment, 1984; Hillman and Schwartz, 1986). Sales of imaging products quickly recovered, however, and reached about $2.7 billion in 1987 ($2.5 billion in 1982 dollars) (Brown, 1987).

Sales growth has differed among the subfields. Shipments of ultrasonic imaging instruments have steadily expanded. Other subfields, though, have been significantly affected by the emergence of new imaging products. Sales of electrodiagnostic instruments flattened as diagnostic ultrasound instruments diffused. X-ray equipment and nuclear medical imaging sales growth slowed following the introduction of commercial CT instruments during the mid-1970s. Conventional x-ray and CT instrument sales growth lessened following the introduction of magnetic resonance and digital radiographic sytems during the 1980s.

As the imaging market expanded, the number of imaging-equipment manufacturers grew from 43 in 1958 to 134 in 1980 (column 2 of Table 1). At the same time, the number of well-established manufacturers grew. One measure of broad-based participation, the number of firms participating in at least two subfields of the industry, rose from 4 to 34 (column 3 of Table 1). A noncompetitive radiology market (Peterson and MacPhee, 1973) had become a competitive diagnostic imaging market with some price rivalry and significant product and service competition (Frost and Sullivan, 1982). A firm's ability to proceed slowly into new technical subfields had been markedly reduced. If a company waited to see how products in a new subfield developed, it risked having aggressive competitors establish such strong positions that they would be impossible to dislodge. Incumbents entered emerging subfields much more quickly. Philips Medical Systems, for example, was a major competitor in many imaging subfields during the late 1970s. According to the director of the Philips nuclear magnetic resonance imaging unit, Philips entered the subfield to avoid being preempted: "Several companies were late to latch onto CT. Philips said, 'That's not going to happen to us again. NMR shows promise, so we better get on it early' " (William Joyce, quoted in Hess, 1987: 139).

Hypotheses

This paper argues that a firm possessing assets required to successfully develop and distribute a new good will face conflicting entry incentives. The risk of investing in necessary additional assets that may turn out to have no value creates an incentive either not to enter or to delay entry. The risk of losing the value of assets that the firm already possesses counteracts the incentive to wait. I predict that the extent of rivalry to realize the value of specialized assets will influence the probability and timing of entry by incumbents into emerging technical subfields of an industry. The prediction leads to two sets of testable hypotheses. The first set conerns whether a firm possessing specialized assets will enter, all other things being equal. The second predicts, ceteris paribus, when it will do so:

Hypothesis 1a: The more industry-specialized assets a firm possesses, the more likely it is to enter an emerging subfield.

Hypothesis 1b: The more firms possessing industry-specialized assets, the less likely an industry incumbent is to enter an emerging subfield.

Hypothesis 1c: An incumbent of a threatened subfield is more likely to enter the threatening subfield than is an incumbent of a subfield that is not threatened.

Hypothesis 2a: The more firms possessing industry-specialized assets, the earlier a firm possessing specialized assets will enter an emerging subfield.

Hypothesis 2b: The fewer industry-specialized assets a firm possesses, the less its entry waiting period will be affected by the number of firms possessing specialized assets.

Hypothesis 2c: An incumbent of a threatened subfield will enter the threatening subfield earlier than will an incumbent of a subfield that is not threatened.

METHOD

Dependent Variables

Entry probability. If a firm that manufactured imaging systems during the year before a new subfield emerged entered the new subfield at any subsequent time, an entry variable was coded as 1. Otherwise, the entry variable was coded as 0. Of 436 potential entrants, 58 had entered by the end of 1988 (columns 2 and 5 of Table 1). The entry variable also served as a right-censor dummy variable for the entry-timing analysis.

Right-censoring occurs when an entry into an emerging subfield is not observed during the period of the study. The accelerated event-time statistical models of entry timing used in this study incorporate the information that an observation is censored and weight the influence of the case accordingly. Unlike the accelerated event-time method, logistic regression analysis of entry probability does not control for right-censoring. That would be a problem in this study if incumbents that had not entered the emerging subfields by the end of 1988 were likely to do so later. But no presubfield imaging-industry incumbent that had not entered by December 1988 has done so since. Few will do so in the future because fewer than 25 percent of the nonentrants still participate in the diagnostic imaging industry. Thus, right-censoring is not a significant problem for the entry-probability tests.

Entry timing. A timing variable recorded the number of years an industry incumbent waited before entering an emerging subfield (with the count starting at 1 for a firm that entered during the first year). If a firm had not entered by the end of 1988 but continued to participate in the industry, the waiting period was set equal to 1989 minus the subfield introduction year. If a firm left the industry before entering a new subfield, its waiting period was calculated by subtracting the subfield introduction year from the year following the firm's exit.

Covariates for Predicted Influences

Specialized assets. To test hypothesis 1a regarding the probability of entry by firms possessing industry-specialized assets, three measures were defined: possession of a direct distribution system, industry experience, and industry market share. A direct distribution system is a specialized asset because it is both associated with long-term success and difficult to replicate quickly (Mitchell, 1988). Industry experience is a measure of a firm's specialized reputation with users. Industry market share is associated with possession of other specialized assets, such as research, development and manufacturing systems. Discussions of participants in the ultrasound (Friar, 1986), CT (U.S. Congress, Office of Technology Assessment, 1978; Abell, 1980), and magnetic resonance (Steinberg and Cohen, 1984; Hess, 1987) subfields are consistent with this contention.

The direct-distribution-system variable was coded as 1 if an incumbent used direct distribution before the emergence of a new subfield and 0 if it used independent sales representatives. If no information about sales type was available (about 20 percent of the cases), a firm was assumed to use sales representatives. To check for bias introduced by the assumption, an assumed-distribution-system dummy variable was set equal to 1 in such cases and 0 otherwise. To measure industry experience, the year that a firm began selling diagnostic imaging equipment anywhere in the world was subtracted from the year that products in a new subfield were first sold to U.S. buyers. An industry-market-share variable recorded the firm's share of sales across all subfields during the year before a new subfield emerged.

Potential rivals. Hypothesis 1b predicted reduced entry likelihood as the number of firms possessing industry-specialized assets rises. To test the prediction, the number of potential rivals was defined as the number of multiple-subfield incumbents during the year before a subfield emerged. Such firms were those participating in at least two subfields of the imaging industry. The rivalry measure was chosen because multiple-subfield status was positively correlated with possession of specialized assets. As reported in Table 2, industry sales leaders (3 percent or more of market share) and multiple-subfield followers (the classes are defined below) tended to possess direct distribution systems and industry experience. All 26 sales leaders and 54 of 66 multiple-subfield followers possessed direct sales systems. Single-subfield follower status is negatively correlated with each direct measure of specialized assets. Only 115 of 344 such firms possessed direct sales systems.

Table 2

Product-Moment Correlation between Specialized Assets and Incumbent Status the Year before a New Subfield Emerged

Incumbent status	No. of firms in class (N = 436)	Correlation between incumbent status and possession of specialized assets: Direct distribution system	Industry experience	Industry market share
Industry sales leader (3% or more market share)	26	.280	.374	.914
Multiple-subfield follower	66	.315	.133	−.125
Single-subfield follower	344	−.439	−.334	−.421

To test hypotheses 2a and 2b regarding entry-timing pressure, three rivalry variables were defined. Incumbents were first divided into the three classes referred to above. Industry sales leaders were defined as those holding at least 3 percent of the industry market share during the year before a new subfield emerged (all were multiple-subfield incumbents). Firms participating in at least two subfields but holding less than 3 percent of the industry market share were defined as multiple-subfield followers. Firms participating in only one subfield and holding less than 3 percent of industry sales were classed as single-subfield followers.

An effect-on-industry-sales-leaders variable was then set equal to the number of multiple-subfield participants if the potential entrant was an industry sales leader and 0 otherwise. Similar effect-on-multiple-subfield-followers and effect-on-single-subfield-followers variables were created. An increase in the number of potential rivals was expected to hasten the entry of industry incumbents (hypothesis 2a). The influence was predicted to be weaker on multiple-subfield followers than on industry sales leaders and weaker still on single-subfield followers (hypothesis 2b).[2]

Threat to core products. To test hypotheses 1c and 2c regarding entry incentives created by threats to an incumbent's core products, a member-of-threatened-subfield variable was created. The variable was coded as 1 if the potential entrant participated in a threatened subfield and 0 otherwise. Incumbents of the electrodiagnostic subfield were threatened by the emergence of ultrasound instruments. Nuclear medical imaging system producers were threatened by CT. X-ray equipment manufacturers were successively threatened by the introduction of CT, magnetic resonance, and digital radiographic instruments. CT, in turn, was threatened by magnetic resonance and digital radiography.

Covariates for Other Influences

Independent variables were also defined for other possible influences on entry probability and timing. To control for market-size incentives, aggregate sales in the first seven years of each subfield were recorded as a subfield-sales variable (deflated by the 1982 Producer Price Index). Subfield deflated seven-year aggregate sales ranged from $6 million (ultrasound) to $536 million (CT). The values were further divided by 10 in order to obtain coefficients with a tractable number of decimal places.

To control for entry actions induced by experience with similar products, a dummy variable was coded as 1 if a potential entrant had such experience and 0 otherwise. Table 3 reports the basis used to assign similar-product experience.

Larger firm size may reduce the risk of earlier entry by gaining diversification economies (Nelson, 1959) or allowing costs to be spread (Stoneman and Ireland, 1983). Conversely, a large firm may suffer bureaucratic inertia (Crozier, 1964) or use its size to come from behind (Wernerfelt and Karnani, 1987). A firm-size variable recorded the natural log of firm sales during the year before a subfield emerged (deflated by the Producer Price Index). Firm annual sales ranged from over $20 billion to almost 0. When sales information was missing (about 10 per-

2
Another means of estimating the rivalry effects would be to test the interaction of the rivalry measure with each direct measure of specialized assets. With two of the three measures of specialized assets, however, the interaction would be of two continuous variables (experience *rivals and market share*rivals). Because continuous interactions are difficult to interpret, I tested for the interaction of rivalry with the categorical incumbent-type variables.

Table 3

Classification for Experience-with-Similar-Products Variable

New subfield	Prior experience
Nuclear medical imaging	Radiopharmaceutical, non-imaging nuclear medical
Ultrasound	Industrial ultrasound
Computed tomography	Medical or industrial x-ray
Magnetic resonance	Industrial spectroscopy
Digital radiography	Medical or industrial x-ray, computed tomography

cent of the cases), the average sales value of $700 million was assigned. To check for bias introduced by this action, a dummy variable for assumed firm size was coded as 1 in such cases and 0 otherwise.

Foreign firms may follow different entry strategies than American-owned companies. Therefore an American-firm dummy variable was set equal to 1 for companies with majority American ownership and 0 otherwise. Of 436 potential entrants, 103 were foreign-based: 78 in Europe, 22 in Japan, and 3 elsewhere.

Because many of the firms in this study entered two or more subfields of the imaging industry, the observed entry timing might be explained by historical firm-specific behavior. Therefore, a past-entry-waits variable recorded the average number of years a firm had waited to enter earlier subfields. Firms that had not been industry incumbents when earlier subfields emerged were assigned the average waiting period value. To avoid bias introduced by the shorter observed age of later subfields, the waits were capped at eight years.

Statistical Methods

Two statistical methods, logistic regression and accelerated event-time analysis, were used to test the hypotheses. The logistic regression estimates were obtained with the logit procedure of LIMDEP (Greene, 1986). PROC LIFEREG of PC-SAS Version 6 (SAS Institute Inc., 1985) was used to obtain the accelerated event-time estimates. Because it is commonly used in the organizational literature, logistic regression is outlined only briefly here. The accelerated event-time method has received less use in organizational studies, although it is widely-used in biomedical analysis and, so, is described in more detail.

Logistic regression. Tests of the entry probability hypotheses were carried out by calculating a logistic regression equation with the following functional form:

$$\ln P_i/(1 - P_i) = a + BX_i \quad (1)$$

P_i is the probability that the ith unit will experience an event (in this study, the probability that an industry incumbent will enter a particular subfield). The log odds of the probability is held to be linearly affected by a vector of covariates X_i with coefficient vector B and intercept a. The effect of a one-unit change of the jth covariate $X_{i,j}$ on the probability of observation i entering a subfield is $B_jP_i(1 - P_i)$. Because the estimates were obtained with maximum likelihood methods, no grouping of the data was necessary (Hanushek and Jackson, 1977; Maddala, 1983).

Accelerated event-time models. Logistic regression is suited to testing predictions regarding entry probability. To investigate entry timing, however, one must examine the length of the wait as well as whether an entry occurred. The accelerated event-time method provides a means of estimating influences on the length of waiting periods.

The principal advantage of the accelerated event-time method over more conventional regression techniques is its use of right-censored cases. In this study, the ability to use such observations is crucial; over 85 percent of the incumbents had not entered the new subfields by the end of 1988. Moreover, with different observation periods for each of the five subfields (8 to 30 years) incumbents had longer to enter the older subfields. If the only firms included were those that entered, the larger populations of incumbents in the later subfields would produce downward-biased estimates of entry waiting periods. Event-time analysis controls for variation across subfields because it incorporates the information that some incumbents had not entered.[3]

The accelerated event-time method assumes that the event times (entry waiting periods, in this study) are distributed according to a parametric baseline distribution that would hold if all independent variables were zero (Kalbfleisch and Prentice, 1980; Cox and Oakes, 1984; Hannan, 1987; Mitchell, 1988). The effects of covariates are then estimated as exponentially multiplicative accelerations or decelerations of the baseline distribution. The additive logarithmic form of the model is expressed as

$$\ln T_i = a + BX_i + se_i \quad (2)$$

T_i is the observed event-time of the ith case; X_i is a vector of covariates associated with the ith case; a and B are an intercept and a vector of coefficients associated with the independent variables. A positive B accelerates the baseline distribution of event times and a negative coefficient decelerates the distribution. The error vector e is distributed according to the assumed parametric distribution and is scaled by a variance-related factor s. A shape parameter k is also associated with some distributions.

Accelerated event-time analysis requires that an underlying distribution be specified. Although many distributional assumptions are possible, the generalized gamma distribution is particularly flexible. The generalized gamma is a three-parameter distribution that estimates underlying entry rates and the influence of covariates that are not specified in the model (Kalbfleisch and Prentice, 1980; Tuma and Hannan, 1984). The generalized gamma also has the property of collapsing to the simpler two-parameter Weibull or lognormal distribution if unspecified covariates do not have significant influences. The lognormal distribution, which holds when the gamma shape parameter k equals 0, will model cases in which there is an underlying nonmonotonic entry rate (entry at first occurs slowly, then quickly, and then declines again). The Weibull, which holds when the gamma shape parameter equals 1, is appropriate for monotonically decreasing rates. The Weibull,

3

For the entry-timing tests, partial and maximum likelihood entry-rate methods such as those used and described by Tuma and Hannan (1984) and Hannan and Freeman (1989) could be used in place of the accelerated event-time models. The accelerated event-time and rate methods are related: the dependent variable of the accelerated event-time method is a duration, which is an inverse function of the entry rate. Partial likelihood, however, depends on the ordering of events; in this study there are many tied events and much of the power of the method would be lost. Maximum likelihood analysis of entry rates, such as that obtained with the statistical package RATE (Tuma, 1980), does not depend on event ordering and so could be used here. For analysis conducted at the level of the individual organization, however, individual waiting periods are intuitively appealing dependent variables. In addition, the method is available in the widely used mainframe and personal computer versions of the SAS statistical package (SAS Institute, 1985), as well as the PC-oriented LIMDEP package (Greene, 1988). The accelerated event-time method, therefore, is a useful complement to maximum likelihood rate analysis, particularly at the organizational level of analysis.

in turn, collapses to the exponential distribution if entry rates are constant (the Weibull scale parameter equals 1).

RESULTS

Both sets of hypotheses were supported. The first column of Table 4 reports the entry-probability tests. The second column of the table reports the tests of the entry-timing hypotheses.

Entry Probability

The entry-probability model as a whole is strongly significant, as shown by the loglikelihood chi-squared statistic. Adding the independent variables reduced by over 50 percent the

Table 4

Logistic and Accelerated Event-Time Estimates of Effects on Probability and Timing of Incumbents' Entry into New Imaging-Industry Subfields*

Variable	Probability	Timing
Specialized assets:		
Industry experience (years)	.007	.003
	(.014)	(.004)
Industry market share (%)	.287••	−.093
	(.148)	(.062)
Direct distribution system	2.952•••	−1.351••
	(1.121)	(.588)
Assumed distribution system	.356	−.521
	(1.317)	(.659)
Potential rivals: Number of multiple-subfield incumbents	−.048••	
	(.021)	
Effect on industry sales leaders		−.052•••
		(.011)
Effect on multiple-subfield followers		−.024•••
		(.009)
Effect on single-subfield followers		−.019•
		(.011)
Threat to core products: Member of threatened subfield	2.286•••	−.988•••
	(.489)	(.221)
Other influences:		
Subfield sales ($10 million)	−.042•••	.013••
	(.016)	(.006)
Experience with similar products	.026	−.010••
	(.018)	(.005)
Firm size (log $1 million)	−.164	.085•
	(.103)	(.044)
Assumed firm size	−2.050•••	.522•
	(.776)	(.308)
American firm	−.943••	.336••
	(.441)	(.172)
Past entry waits (years)		.061
		(.039)
Intercept	−1.404	4.105•••
	(1.330)	(.684)
Weibull scale parameter		.548
		(.061)
Potential (actual) entrants	436 (58)	436 (58)
Model loglikelihood	−84.6	−116.2
No-covariate loglikelihood	−171.0	−188.5
Loglikelihood chi-squared	172.7•••	144.6•••

• $p < .10$, •• $p < .05$, ••• $p < .10$ (two-tailed tests).

* Standard errors are in parentheses. Negative logistic regression coefficients in column 1 indicate lower entry probability. Negative accelerated event-time coefficients in column 2 indicate earlier entry.

unexplained variance of a model containing only an intercept. The individual hypotheses 1a, 1b, and 1c were also supported.

Each measure of specialized assets had the positive sign implied by hypothesis 1a, which predicted that the more industry-specialized assets a firm possesses, the more likely it is to enter an emerging subfield. Possessing a direct distribution system for diagnostic imaging equipment before a new subfield emerged was significantly associated with greater probability that a firm would enter. Similarly, the greater a firm's industry market share during the year before a new subfield emerged, the more likley it was to enter the new subfield. Greater industry experience was also associated with positive entry probability, but not at a statistically significant level.

As predicted by the operationalization of hypothesis 1b, entry probability fell as the number of multiple-subfield incumbents rose. Hypothesis 1c was also strongly supported. If a firm was a member of a threatened subfield, it was significantly more likely to enter the threatening subfield than was an industry incumbent that did not face such Schumpeterian competition.

Some entry-probability control variables also displayed significant influences. Increases in subfield sales were associated with lower entry probability, perhaps because of concurrent increases of potential rivals. Firms possessing prior experience with similar products were more likely to enter, although the coefficient was not statistically significant. The larger a firm, the less likely it was to enter a new subfield, again to an insignificant extent. The assumed-firm-size dummy variable, however, was both negative and significant. If the companies for which size information was missing were smaller than average, which is likely, any negative firm-size influence will be exaggerated. Hence, firm size had little association with entry probability. Finally, an American firm was less likely than its foreign competitors to expand into a new subfield.

Entry Timing

Based on graphical analysis of the residuals of models of accelerated event-time entry waiting periods, a Weibull distribution was chosen for the underlying parametric assumption.[4] Because the Weibull scale parameter differed from 1, as shown in column 2 of Table 4, reduction to the exponential distribution was not appropriate. The loglikelihood chi-squared statistic for the overall accelerated event-time model was strongly significant. The entry-timing predictions of hypotheses 2a, 2b, and 2c also were supported.

As implied by hypothesis 2a, industry incumbents entered significantly earlier as the number of multiple-subfield incumbents rose. The strength of the rivalry influence was weaker in the multiple-subfield case than in the sales-leader case, as implied by hypothesis 2b. The rivalry effect was slightly weaker still and less significant for single-subfield followers, again consistent with hypothesis 2b.

Hypothesis 2c predicted that an incumbent of a threatened subfield will enter the threatening subfield earlier than will a member of a subfield that is not threatened. The prediction was strongly supported. A threat to core products not only

4 Graphical checks (Kalbfleisch and Prentice, 1980) for model fit were carried out for study data, as was sensitivity analysis. The qualitative results did not change when the underlying entry pattern was fit to lognormal and loglogistic distributions. Examples of the fit and sensitivity analysis can be obtained from the author. Cox and Oakes (1984: 5.2) noted that the accelerated event-time method assumes the dependent variable to have constant variance at different levels of the covariates. Across the five subfields of this study, the assumption is violated. Across the later three subfields, however, it appears to be valid. Therefore, the estimated effects of the covariates were also obtained for a sample containing only the CT, magnetic resonance, and digital radiography entry waiting periods. The results were qualitatively similar to the five-subfield analysis, showing that the violation of the constant variance assumption for the entire sample is not critical.

drove members of threatened subfields to enter (column 1 of Table 4), it caused them to enter earlier (column 2).

The entry-timing control variables also provide useful insights. Possession of specialized assets, independent of the interaction with potential rivalry, was less likely to influence entry timing than it was to affect entry probability. Only the direct distribution system measure of specialized assets had a statistically significant association with entry timing; of the two nonsignificant coefficients, one was positive (industry experience) and the other negative (industry market share). The interaction between specialized assets and rivalry thus has the greatest influence on entry timing, not possession of specialized assets alone.

Increases in subfield sales were associated with later entry, just as they were with lower entry probability. Here, too, the explanation likely lies with the association with increased rivalry. Firms having experience with similar products tended to enter earlier, consistent with Brittain and Freeman's (1980) argument that prior possession of necessary core capabilities leads to early entry. Large firms tended to enter later, as shown by the firm size coefficient, but the coefficient of the assumed-firm-size variable was also positive and significant. If firms for which size data is not available are smaller than average, the firm-size coefficient will be upwardly biased. Thus there may be little or no relationship between firm size and entry timing. Long past-entry waits were associated with long current-entry waits, but not at a statistically significant level; rivalry appears to overwhelm historical tendencies. Finally, just as an American firm was less likely to enter a new subfield, it tended to enter later than its foreign competitors.

DISCUSSION AND CONCLUSIONS

This study adds to our understanding of the effects of technological discontinuities. Tushman and Anderson (1986) argued that whether technological change enhances or destroys a firm's capabilities will influence its entry timing. If competences will be destroyed, they argued, a firm will not be the first entrant. The threat-to-core-product measure in this paper advances that argument. This study shows that a distinction must be made between a core product and the supporting assets needed to commercialize it successfully. A firm will move quickly to defend a threatened core product, but if its core products are not threatened it will often wait to introduce technically discontinuous products.

Alternative Hypotheses

The estimates of the core product, specialized asset, and rivalry influences described in this paper are robust. Control variables for subfield sales, similar-product experience, firm size, nationality of ownership, and past-entry waits do not eliminate the effects. Several other factors might also be associated with the results, but their influences are not likely to confound the study.

The analysis does not control directly for differences in technical or market uncertainty across the subfields. The experience-with-similar-products variable, however, provides a partial measure of technical uncertainty. Moreover, technical and market uncertainty in the subfields that experienced rapid entry were at least as high as in those that did not. Although sales levels have increased (for which a control is included), both sales fluctuations and public healthcare policy variability were at least as high in the early 1980s as during the 1960s.

Sales effects might not be linear. There may be a hurdle at some level between lower ultrasound and nuclear medical sales and higher sales in the later subfields. Nonetheless, model specifications that included log and quadratic terms as sales influence controls did not eliminate the significant core product, specialized asset, and rivalry influences.

Potential rivalry was measured as the number of multiple-subfield incumbents. There may also be total density influences (Hannan and Freeman, 1989). In the diagnostic imaging industry, though, changes in total and multiple-subfield density are so strongly correlated that independent influences could not be disentangled.

Early-entry incentives such as leading technically, preempting use of scarce resources, and creating user-switching costs (Lieberman and Montgomery, 1988) may have applied more to some subfields than to others. In the diagnostic imaging industry, however, the first two incentives have not been important. Any preemption advantages created by technical leadership have been small: patents (Gilbert and Newberry, 1982) have not blocked entry, and proprietary learning curves (Abernathy and Wayne, 1974; Spence, 1981) have been shallow because of low cumulative unit production and significant product change. Similarly, physical and know-how resource inputs have been widely enough distributed that early entrants could not control access to them.

Buyer-switching costs, the third preemption incentive, do exist in diagnostic imaging equipment markets. Early entrants have certainly sought to take advantage of firm-specific learning that buyers undertake when they purchase imaging instruments. But the existence of such costs and the ability of some firms to create them are at the center of the rivalry argument. The costs existed in the early subfields as well as in the later ones. It is the number of firms that possessed specialized assets and so could create buyer switching costs, not simply that the costs could be created, that has influenced entry probability and timing.

Further Research

This paper has examined influences on entry by industry incumbents. An extension of the work is the examination of the effects of incumbents' entry. Such effects include at least three elements. First is the success of the industry incumbents themselves. The success of a firm possessing specialized assets is likely to be related to when it enters a new subfield, relative to the entry order of other such firms. Its success is less likely to be related to its entry order relative to firms that do not possess specialized assets. Not entering an emerging subfield is also likely to affect an incumbent's success. When technical and market spillovers occur across subfields, industry incumbents that do not expand are likely to experience competitive disadvantages in their base-product lines.

Second, the speed with which industry incumbents enter a new subfield is likely to influence the success of industry newcomers. When incumbents enter quickly, newcomers that attempt to compete with them are likely to fail quickly. Some newcomers, however, will seek to complement the incumbents' operations. Newcomers that enter complementary niches may actually find greater success when incumbents enter quickly than when most established firms wait to introduce the new set of products.

Third, the rate at which incumbents enter an emerging subfield is likely to affect the development trajectory taken by products within the subfield. The technological direction of a new set of products often is relatively undefined early in a development period. If firms possessing specialized assets wait to enter, the companies that do participate may develop a new set of specialized resources and product development may take unexpected directions. The sooner that traditional specialized assets are brought to bear, however, the sooner that the technological trajectory is likely to become fixed and the more likely it is to be fixed around the old specialized assets.

Industrial change takes place through processes that are both exogenous and endogenous to the incumbents of an industry. An incumbent must react to external forces, whether they comprise new materials or processes upstream, customer requirements downstream, or cross-stream turbulence caused by changes in social demands. It must determine whether its existing resources will be valuable in the changed industry, whether they must be complemented with new assets, or whether they must be abandoned. And the incumbent's managers must decide how and when to acquire the knowledge required for its reaction. But the form of the reaction—including its probability and timing—is also affected by internal characteristics of the industry. How many competitors a firm faces will affect its reaction, as will the national dispersion of the competitors if global strategic norms vary.

Each reaction, moreover, whether exogenously or endogenously induced, creates other internal forces. The trajectory that will be taken by the many-stage game of industrial change is not fixed by technological imperatives and will instead be strongly influenced by the strategic choices of industrial participants. Any observed pattern of industrial change is a complex web of action and reaction, cause and effect, opportunity and threat. Analysis of industrial change, therefore, requires audacity—the audacity to treat some factors as independent in what we recognize is really a nonlinear multi-equation system and probably a chaotic one at that. Nonetheless, the inferences that we draw from investigation of intertemporal strategic actions are important to our understanding of organizational and social forces. Much useful research remains to be done.

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