Technological Platforms and Diversification

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Abstract

As the invention of fundamental new sciences spawns subsequent research, discovery, and commercialization, core technologies branch into new applications and markets. Some of them evolve over time into many derived technologies, whereas others are essentially "dead ends." The pattern of evolution and branching is called a "technological trajectory." An intriguing question is whether some firms can ride the trajectory by developing proprietary experience in a "platform technology."Because the knowledge is proprietary, firms that originate in industrial fields based on a platform technology acquire the technological skills to diversify and to mimic the branching of the underlying technological trajectory.

The ability to compete in hypercompetitive markets depends on the acquisition of know-how that is applicable to a wide set of market opportunities. Such capabilities serve as platforms into quickly evolving markets. To respond rapidly to market changes, a firm must have already acquired fundamental competitive knowledge. In a high-technology industry, such knowledge invariably is derived from experience with the underlying science and related technological fields.

The authors examine capabilities as platforms by analyzing the temporal sequence of diversification as contingent on market opportunities and previous experience. The pattern of diversification of firms reflects the evolutionary branching of underlying technologies. In that sense, the aggregate decisions of firms are driven by the technological trajectories common across an industrial sector. Certain technologies have wider technological and market opportunities, and consequently experience in those technologies serves as a platform for expansion. The authors propose that a firm s experience in platform technologies increases the likelihood of diversification when environmental opportunities are favorable.

The proposition is tested with the sample of 176 semiconductor startup companies founded between 1977 and 1989. Evidence from multidimensional scaling of expert opinion and from an analysis of patent records was gathered to identity relatedness among subfields and the evolutionary direction of the technologies. A discrete hazard model is specified to estimate the effect of technological histories on subsequent diversification. The results confirm the relationship between relatedness and directionality of technologies and the industrial path of diversification. The finding that diversification depends on technological experience and market opportunity has important implications for firms' entry decisions. The authors discuss those implications by describing experience as generating options on future opportunities and distinguishing between the historical path by which the stock of knowledge is accumulated and the path by which new knowledge is generated and commercialized.

(*Platform Technology*; *Diversification*; *Technological Trajectory*; *Knowledge Accumulation*; *Option*)

Competing in rapidly evolving industries poses the complex problem of choosing what capabilities should be developed for highly uncertain and volatile markets. Freeman (1987) has observed that forecasting the class of future technologies has proven to be easier than identifying future markets and products. The implication of that seemingly innocuous observation is rather radical. Developing competence in new but broad-based technological skills is an investment in a platform to participate, by a process of expansion and diversification, in the evolution of future opportunities. In contrast, forecasting demand for specific products may lead to the development of capabilities poorly suited for the markets that eventually prove to be economically interesting.

Industries in which competitive advantages of innovations quickly erode are commonly called "Schumpeterian" or "hypercompetitive." In such an environment, the capability to upgrade products and diversify into related segments is often built on the accumulation of experiential know-how that allows for expansion during windows of opportunity.[1] In that sense, the initial

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experiences of firms provide platforms, or options for diversifying into new markets when the timing is right.

We explain the pattern of diversification of startup firms in rapidly growing industries as linked to the evolutionary branching of technologies and market opportunities. A central idea in research on the evolution of firm capabilities is that the local search process builds on previous knowledge that can be transferred to new fields. Our conceptual contribution is to link the path of a firm's diversification to the development of the underlying technological trajectory. The notion of a trajectory implies that technologies differ in their potential to generate new paths of development and to serve as platforms into new markets. Some technologies provide a starting point or platform for the exploration and development of new resources and have a high potential to spawn new markets. Other technologies are specific to certain applications and represent essentially dead ends for further major development.

We predict that firms with experience in platform technologies have a significantly greater opportunity and tendency to diversify into related subfields than firms with products narrowly dedicated to a market. Experience with a platform technology generates the organizational capability to compete in related fields, but it does not guarantee that a firm will, in fact, diversify or succeed. That process is not uniquely driven by technology, but by firms' efforts to grow in the presence of competition and the expansion of new market opportunities. In that sense, the accumulation of experience provides platforms to enter future but uncertain markets whereas the *timing of diversification* should depend on the growth of the related subfields.

We develop and test the proposition that the pattern of diversification reflects the branching of the underlying technologies contingent on market opportunity. An overview of the literature on technological evolution establishes two points: that a trajectory is the cumulative knowledge resulting from local search, and that the knowledge may be specific and proprietary to firms because of experimental learning or system effects. It is only when the knowledge from the search is proprietary and firm-specific that technological branching and diversification should be related. After a brief review of the history of technological branching in the semiconductor industry, we analyze the subfields to determine their "relatedness" and "directionality." An application of multidimensional scaling to questionnaire data shows that experts differentiate subfields of semiconductors into distinguishable clusters. We then analyze the subfield distribution of patent histories of 53 startup firms. The analysis shows clear directional differences in the frequency, speed, and subfield diversity of patent activity according to the technological origins of the startup firm.

Longitudinal regression tests were applied to a sample consisting of the diversification and survival histories of 176 startup semiconductor firms founded between 1977 and 1989. We find strong support for the idea that particular subfields, as suggested by the technical literature and by the MDS and patent results, serve as platforms into other markets. Our discussion broadens the investigation by considering whether firms make entry decisions myopically or with foresight.

Overview

The argument we present consists of three parts:[2]

1. Technologies follow an observable trajectory. Some technologies are more likely to serve as platforms into new markets than others. The trajectory and the platform can be identified empirically.
2. Organizations differ in their points of origin and in their accumulation of know-how with different technologies. Those that gain experience in platform technologies will be more likely to diversify into new markets than those with experience in nonplatform technologies.
3. Organizations tend to diversify into new markets when the markets are growing.

A common approach in studies of diversification is to relate a firm's portfolio of businesses to a measure of relatedness, or to relate a firm's diversification decision to such a measure. We have two wider objectives. The first is to explain dynamically the path of a firm's diversification history in terms of its acquisition of related knowledge in a particular industry or subfield. The second is to show that the pattern of diversification at the firm level corresponds to a broader technological trajectory in which particular technologies act as platforms into more specialized applications. A key element in that explanation is the relationship between firm-level diversification into distinct markets and macro technological trajectories. To make that connection, we develop three points: that trajectories are defined by both technological and market opportunities, that knowledge accumulates in response to a firm's experience in solving particular problems, and that a firm's diversification history is linked to the trajectory because knowledge is proprietary.

Technological Trajectories

Potential technological developments can be seen as a transition matrix in which current technologies evolve

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into new ones. The matrix can be considered the potential technological space. If there were no logic to technological development, the transition would be essentially random. The notion of a trajectory suggests the contrary: that technological evolution is influenced by the past. The term "technological opportunity" captures the idea that not all transitions are equally likely and that some are favored by the inherent richness, or evolvability, of a technology.

Nelson and Winter (1982: 255–6) make a similar observation:

> In many technological histories the new is not just better than the old; in some sense the new evolves out of the old. One explanation for this is that the output of today's searches is not merely a new technology, but also enhances knowledge and forms the basis of new building blocks to be used tomorrow.

The choice of a technology is determined not only by current capabilities and technological bottlenecks to be solved. Technologies must also be accepted for use. The selection process may be determined abstractly by a market, but market forces are outcomes of the institutional environment, including government policies (which were influential in the early history of semiconductors). The historical record supports the importance of the coincidental effects of current technical capabilities and socioeconomic conditions on opportunities for future expansion (Mowery and Rosenberg 1981, Bijker and Pinch 1987).

The union of organizational factors that create a "technological push" and environmental conditions that create a "market pull" underlies the notion of what Nelson and Winter (1977, 1982) and Dosi (1982) have called "technological trajectories." Such trajectories represent the expansion of a core set of solutions (e.g., mechanization of production) that are favored by the institutional forces that condition their selection and survival. The revealed trajectory is the conjunction of both technological and market factors, and is determined by neither individually.

A trajectory implies that early investments in a technology reap increasing returns. One expression of that dynamic is the tendency toward increasing specialization, or divergence. Occasionally, specialized technologies converge in new combinations, which then follow a pattern of specialization. The repeated application of a particular set of technologies or organizing principles eventually exhausts the set of potential combinations and market opportunities. Because opportunities are limited, the expansion of a trajectory is both constrained and finite.

Local Adaptation and Diversification

A trajectory is tied to the local search efforts of firms. There is an interesting analogy between the trajectory in technologies and the observed pattern in diversification. Diversification is the outcome of temporally ordered decisions to adapt or acquire knowledge for exploitation in new markets. The fact that diversification from a given industry is not randomly distributed over all other industries suggests that industry experience guides the evolution of technological and product market choices of individual firms (Teece et al. 1994).

The dependence of the capability to expand by diversification on the history of industry experience of firms supports a view of evolution by adaptive search. Firms are not strictly inert, but diversify and adapt by learning within the developmental constraints of their current capabilities. An organization is developmentally constrained in its acquisition of both new information and new ways of doing things. Consider, for example, the research on the acquisition of knowledge by technology transfer and innovation. A common observation in studies on technology transfer has been the importance of prior experience in determining the adopter's capabilities to absorb the technology (Teece 1976; Contractor 1981; Pavitt 1987). Similar conclusions have been reached about the process by which knowledge is accumulated and learned (Cohen and Levinthal 1990; Henderson and Clark 1990; Helfat, 1994).

History in a particular industry appears to govern the opportunities for diversification for individual firms. In industries where technological capability is an important determinant of competitive advantage and market success, the diversification pattern of a firm is coupled to its ability to tap into the technological trajectory of its industry. In that case, the analogy between diversification and technological evolution is not metaphorical, but reflects a link between the diversification path of the firm and a technology's trajectory.

Because search is local, it is not surprising that innovations are often recombinations of existing ideas and practices (Kogut and Zander 1992). Schumpeter (1968: 65–66) argued that, in general, innovations are new combinations of existing "materials and forces." Usher (1971: 50) called the process of invention a "cumulative synthesis of many items which were originally independent."[3] The explanation of why innovations tend to be recombinations lies partly in the domain of what individuals can know and partly in the fact that what organizations know and learn is delimited by their rigidity in changing their information and structuring of roles.

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Platform Technologies and Diversification

A trajectory suggests direction in technological development. It is a simple step to proceed from the notion of a trajectory branching into new applications and markets to an explanation for the diversification path of firms. However, one point in the logic must be clarified: Why and when should an individual firm replicate the branching of a trajectory through its own diversification pattern?

The notion of an adaptive search is part of the basis for understanding the bridge between trajectories and diversification paths of firms. In general, the diversification literature, following Penrose (1959), has stressed the importance of related diversification to performance. In the tradition of the seminal study by Rumelt (1974), that literature has focused primarily on the cross-sectional relationship between relatedness and performance. The evidence tends to show that firms enter industries related to their current lines of business (Montgomery and Hariharan 1991).

The findings on relatedness are consistent with a process by which a firm's diversification path is coupled to a technological trajectory.[4] However, there is a difference. A trajectory implies that diversification should follow a broad *direction*. Relatedness at a point of time is only a cross-section of the dynamic relatedness across time. The points of divergence and convergence in a trajectory represent opportunities for established firms to diversify into new subfields. The creation of those critical junctures often depends on the efforts of new firms, but the subsequent development of the resultant subfields tends to show a clear mixture of entry by both entrepreneurial and established firms (Tushman and Anderson 1986). Relatedness does not establish that a given firm needs to span different markets.

However, both relatedness and direction are necessary to isolate a trajectory. Any temporal series of changes in technology or diversification will suggest a path. For a sufficient number of observed changes, a conservative approach is to test whether the series follows a random path. Such tests often plagued by low power in a statistical sense. An alternative method is to identify relatedness of a technology at time 1 to that at time 2 by looking at measures of their relatedness. (That approach is equivalent to saying there is systematic serial correlation in diversification over time.) It is the combination of direction with a determination of relatedness that defines a trajectory empirically.

One way to think about those issues is to distinguish between technologies that are specialized to particular new markets and applications. A platform technology represents the development of a capability that maps onto a wide variety of market opportunities, a capability that is consequently characterized by a high degree of intertemporal relatedness to a wide expanse of new markets. We call such dynamic relatedness the "*directionality*" of a technology.

What makes a technology a platform is its formative influence on a newly evolving trajectory that is characterized by increasing returns to investment in further exploration. The increasing returns are achieved either through network externalities of components in a wider technological system (e.g., the rotary converter in electrical grids) or through the accumulation of learning by doing that is useful for the generation of new products. Those two dynamic factors of network evolution and learning, separately and jointly, lead to self-organizing and irreversible historical patterns (Arthur 1985, David 1975, Silverberg et al. 1988). When they are proprietary, they tie the expanding trajectory to the diversification paths of firms.

Proprietary learning in design and production is the basis for viewing some semiconductors as "technology drivers." As Howell and his coauthors (1988: p. 28) explain:[5]

> The significance of learning economies has imparted a tremendous strategic importance to certain types of semiconductors for which significant unit demand exists—and which can thus be produced in high volumes—but which are also highly complex. The mass production of such extremely complex devices generates "learning" about complex production processes which can be applied to a much wider range of other device types which are produced by a company in lower volume. Such high complexity, high volume "technology drivers" are widely viewed as a prerequisite to remaining competitive in semiconductors over the long run. Consequently, these product areas have been the principal areas of international competition in microelectronics since the early 1970s.

Udayagiri (1993) has shown that learning economies in one generation of semiconductors lowers the costs of subsequent generations. When those learning economies are also useful for application to other markets, we should expect the branching of a platform technology into new and related subfields.

System dependence and proprietary learning, independently or jointly, tie the opportunity of a firm to the overall success of its trajectory. Only if the platform is proprietary will technological relatedness be reflected

If the benefit of the externality or learning is entirely public, trajectories will still occur, but there would be no advantage for firms experienced in the technology to be the engine of growth through diversification. For that reason, proprietary learning in the absence of network externalities commonly serves as a platform

startup companies in the semiconductor industry to record their initial subfield entry and their subsequent timing of diversification. The event of diversification is the dependent variable to be related to a firm's technological experience.

Table 1 Technological Subfields—Primary Product Segments

Subfield	Product Segments
Analog	Operational amplifiers, comparators, data conversion products, interface products, voltage regulators, and sensors
ASICs	Gate arrays, cell libraries, and progammable logic devices (PLDs)
DSP	Single-chip DSP microprocessors, microprogrammable devices, special function circuits, and ASIC DSP products
Discrete	Diodes, transistors, power field-effect transistors (FETs), and thyristors
GaAs	Discretes (small-signal transistors and power FETs), optoelectronics (light-emitting devices, detectors, and integrated opto devices), and other applications (analog and digital)
Memory	Dynamic random access memory (DRAM), static random access memory (SRAM) read only memory (ROM), erasable programmable read only memory (EPROM), and ferro-electric memory
Micro	Microprocessors, mass storage, system support, and key / display chip sets
Opto	Light emitting devices (LEDs), light sensing devices, optocouplers, and photodiodes
Telecom	Dialers, modem, line interfaces codec / filter, and switch arrays

Source Dataquest (1988 1990)

Trajectories in Semiconductors

Before reporting the regressions, we describe the historical trajectory in semiconductors, and then determine the pattern of relatedness and evolutionary direction among the subfields. That is, even if currently there are two subfields, we need to provide evidence of an asymmetry: experience in one subfield serves as a platform for expansion into the other, but not vice versa. Simple relatedness is not sufficient for understanding the evolutionary pattern of diversification.

Descriptive Overview

The notion of a trajectory can be illustrated by analyzing the recent history of technological development in the semiconductor industry. The industry grew out of the laboratories of AT & T, but the early demand for the devices was driven by the growing appetite for military applications (Nelson 1962; Brittain and Freeman 1980). In the United States, the increasing importance of computers gradually shifted supply to the production of digital devices, especially memory; in Japan, the growth of consumer electronics pulled the local industry toward specialization in analog semiconductors (Malerba 1985). The reorientation of Japanese producers to digital production occurred only in the mid-1970s. That example of a successful transition in specialization from analog to digital devices also illustrates the importance of the selection environment. The MITI policy of favoring Japanese computer makers effectively pulled production toward the development of digital capabilities (Anchordoguy 1989). Another important difference was the role played by startup companies in the United States and by established firms in Japan.

The history of technological branching of the industry can be represented by a dendrogram, as shown in Figure 1. A dendrogram is a model (in contrast to a theory) that "is a more or less accurate representation of the path of evolution" (McKelvey 1982: 296).[6] Our classification traces the divergence of the basic technology by market segmentation, as opposed to being a strict classification by technical trait. It thus resembles Hannan and Freeman's (1987) pragmatic approach of identifying classes of organization by niches. (Subsequently, we validate the classification by statistical procedures.) There are obviously other ways to construct the tree, such as by the electrochemcial properties (e.g., MOS) or by manufacturing sophistication (as used by Schoonhoven et al. 1990).

The trunk of the tree is the basic discovery of the discrete transistor (and related discrete components) and integrated circuit. Integrated circuits developed

Table 2 Ratio of Initial and Subsequent Entry

	Analog	ASIC	DSP	Discr	GaAs	Memory	Micro	Opto	Tele
Initial entry	65	46	43	75	95	83	43	36	21
Subsequent entry	35	54	57	25	05	17	57	64	79

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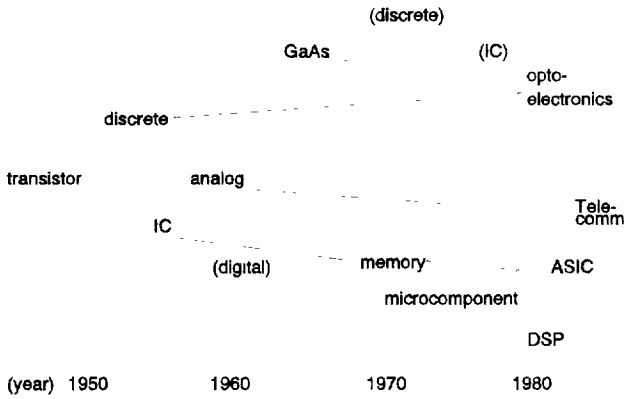
Figure 1 Evolution of Semiconductors



along two lines associated with analog and digital encoding. Another way to distinguish the evolutionary branching is by use of material or, more generally, by tracing the evolution of materials as "co-evolving" with the applications. Early use of germanium gradually was dropped in favor of silicon. An alternative material, gallium arsenide, was introduced with slow acceptance. By the early 1970s, the industry began to divide into new subfields, first memory and then microprocessors. The divergence of semiconductor technologies evolved into the newer subfields of digital signal processors (DSPs, used to replace some analog devices in consumer electronics) and ASICs (used for customized functions).

An especially interesting subfield is telecommunications, for which a semiconductor device is a hybrid of digital and analog technologies. Similarly, the properties of gallium arsenide have proven to be useful for optoelectronics. Those subfields are outcomes of "convergent" technologies.[7] In evolutionary biology, a dendrogram (or "cladist" taxonomy) is a strictly hierarchical tree whose branches always diverge and never converge again (Dawkins 1986, p. 258–259). Innovation, in contrast, as the outcome of recombining elements, produces both divergent and convergent technological trajectories.

Technological Relatedness and Directionality

Before testing the propositions, we validated the relationships posited in Figure 1. History provides a kind of demonstration proof by showing that a particular evolution is feasible. We are interested in a stronger statement, namely, that the historical patterns represent a tendency toward increasing specialization stemming from technologies that embody the greatest opportunities. Some technologies have proven to be less fecund; others have failed entirely. In essence, we want to show that the historical evolution represents a *directional tendency* that should be mapped onto the diversification paths of firms.

We first drew on our interviews and technical literature to assemble a set of priors on the relatedness among the subfields and branches, and then turned to more formal methods to validate those impressions. To establish a stronger claim to directionality, we also reviewed the patent histories of startup firms that reported patents to analyze the evolutionary pattern of technological diversification in the patent record. The details of that analysis are given in Appendix 1.

Summary of Findings on Relatedness and Directionality

Our analysis of the technical literature, expert opinions, and patent histories serves as a method of triangulation to establish patterns of relatedness at a point of time and directionality over time. Table 3 summarizes the overall results. As noted in the discussion of the sample, we are analyzing the effects of previous technological experience on subsequent entries. Our hypotheses are applied to entry into ASICs, microcomponents, optoelectronics, and telecom ICs, where subsequent entries occurred in significant numbers. The principal finding is that memory is related to several other subfields, both cross-sectionally and dynamically. Analog experience is expected to be significant in entering telecom ICs. Following the strong suggestion of the technical literature and expert opinions, we hypothesize that experience in discrete and GaAs devices should help firms enter optoelectronics. Patent analysis does not clearly capture those relationships, however. All three analyses suggest strong relatedness between DSP and microcomponents, but the issue is directionality. Patent analysis reveals strong direction-

Table 3 Matrix of Entry Sequence (Predicted)

From \ To	ASICs	Micro	Opto	Telecom
Analog				(+)
ASICs				
DSP		(+)		
Discrete			(+)	
GaAs			(+)	
Memory	(+)	(−)		(+)
Micro				
Opto				
Telecom				

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ality from DSP to microcomponents but not vice versa; hence we hypothesize that relationship.

The method of triangulation is important because each technique analyzes different data, yet reveals similar patterns. The technical literature provides a straightforward look at the technological evolution of semiconductors. The multidimensional scaling relies on the opinions of experts about both technological and market relatedness. (See Appendix 2 for questionnaire.) Finally, the analysis of patents provides insight into directionality, as well as technological opportunity. Table 3 is a distillation of the findings of the three approaches.

We next test whether the pattern of technological relatedness and directionality is replicated in the diversification histories of individual firms. Even though the innovation of memory semiconductors preceded ASICs chronologically, the analysis looks at firms that have entered at a time when those subfields were conterminous. It is not surprising that subsequent fields should be shown to be related to historically precedent industries, but the historical ordering is hardly accidental. There is no historical necessity for startup firms in our sample to replicate history, other than the fact that there is an experiential relationship between the capabilities gained in the platform technologies and the other subfields. Nevertheless, as reported subsequently, advancing the historical clock (that is, beginning the observations at a later date so that all subfields begin in the same calendar year) does not influence the results.

Regression Analysis

The regression analysis of the link between the diversification path and the direction of the underlying trajectory is longitudinal and at the firm level, with all variables time-varying. The dependent variable is entry into a subfield at a given time and is set to one if the firm entered and zero otherwise. The experiential acquisition of the firm's technological capability is captured by dummy variables for each subfield, equal to one if the firm was currently active in the area. In addition, as larger firms might have greater resources than smaller ones, we collected data on the size of the startup firms, linearly interpolating the estimates for years for which we lacked data. **SIZE** is measured by the number of employees.

The munificence of the selection environment is indexed by two variables, density and growth of shipments. The variable growth of a subfield (**SHIPMENT GROWTH**) is measured by the yearly rate of changes in shipment volumes. **DENSITY**, as a measure of competitive effects, is a count of the number of all firms listed as making sales in a subfield. As many studies have found that entry and density have a quadratic relationship, we also included the square of density.[8]

Method of Analysis

One of our central claims is that a firm accumulates experience by operating in one subfield that may serve as a platform in other subfields. Because we do not have direct observations on the stock of experience, we use a method that proxies it in two ways. First, we record by a dummy variable whether a firm is active in a particular subfield. Second, we analyze the conditional waiting time, or hazard, from the time a firm is first recorded as existing to the time of its entry into another field. We expect firms that are active in an industry based on a platform technology to diversify more rapidly into related fields. Accordingly, we specify the regression as estimating the hazard, or conditional waiting time, to diversification.

A discrete time hazard model was used to calculate the hazard rate of diversifying among the startup firms (Allison 1984). That method defines the set of startup firms at risk for each annual cross-section or time spell, that is, those firms that had not previously entered a subfield. Because the period of observation lasted from 1977 through 1989 and we treated each year as a spell, there were 13 discrete time spells. The 13 cross-sections were then stacked. That discrete method is similar to continuous-time estimation by partial likelihood, though the two models do not exactly converge to the same specification (Cox and Oakes 1984, Allison 1984).

To test the effects of explanatory variables on the hazard rate, we used a logit specification. For each subfield, a binomial model was used to estimate the effects of the covariates.[9] If T is an integer-valued random variable showing the waiting time from the inception of a startup firm to the diversification event, the hazard rate is defined as the probability of an event at time t given no previous diversification in the subfield:

$$P_t = Pr(T = t | T \geq t).$$

The logit model for estimating the effects of the covariations on the discrete hazard is specified by:

$$\log\left[\frac{P_{it}}{1 - P_{it}}\right] = \alpha + \beta X_{it}$$

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where P_t is the probability of the firm diversifying into subfield i at time t, α is a constant, β is a vector of coefficients, and X is a vector of time-varying covariates. The changes in the hazard rate are restricted in this model to arise from changes in the time-varying covariates; the intercept α is assumed fixed. That restriction can be relaxed, but the inclusion of year dummies shows that the results are not very sensitive to such a specification.

The appeal of a hazard specification is that it captures the effects of both the technological push and the environmental pull. Experience in certain subfields can be expected to accumulate faster and to be more closely related than that in other areas, and hence should lead to a more rapid rate of diversification. Further, we would expect the timing of diversification to depend on the favorability of market conditions. We capture both effects by use of a hazard model with time-varying covariates that pick up the differences in experience accumulation and market opportunities across subfields.

Table 4 Discrete Time Logit Regression Estimates[a]

	ASIC	Micro	Opto	Telecom
Constant	−5 20	−9 90	75 8	−93 13**
	(−65)	(−57)	(61)	(−2 32)
Analog	190	1 36	−15 3	2 77***
	(26)	(1 47)	(−009)	(3 82)
ASIC		801	−476	735
		(1 16)	(−40)	(1 13)
DSP	−16 9	−[illegible] 71	−14 7	1 01
	(−005)	(−28)	(−006)	(96)
Discrete	−16 6	095	1 05	396
	(−005)	(06)	(76)	(39)
GaAs	094	301	2 38**	−14 8
	(10)	(26)	(2 44)	(−007)
Memory	1 43***	3 73***	−107	1 29*
	(2 18)	(4 56)	(−09)	(1 77)
Micro	−997		652	2 40***
	(−1 17)		(51)	(3 26)
Opto	−16 4	−13 2		−15 0
	(−005)	(−006)		(−005)
Telecom	−15 8	−12 4	−14 3	
	(−003)	(−003)	(−004)	
Shipment growth	026**	033**	−065	102**
	(2 05)	(2 45)	(−1 25)	(2 41)
Density	137	323	−5 34	4 92**
	(48)	(38)	(−57)	(2 12)
Density	−001	−006	089	−070**
	(−77)	(−62)	(51)	(−2 06)
Firm size	0007	003***	−008	−006
	(52)	(3 70)	(−1 02)	(−58)
Log-likelihood	−67 547	−58 395	−35 062	−46 254

[a] t-statistics in parentheses, two-tailed test
*prob < 10, **prob < 05, ***prob < 01

Regression Results

Table 4 reports the discrete time logit regression estimates. Shipment growth significantly increases the likelihood of entry into ASICs, microcomponents, and telecommunication ICs, but is not significant in optoelectronics. Density measures are significant only in the telecommunication subfield. Firm size is significant only in microcomponents. The primary factor explaining the *timing of diversification* is the growth of the market.

Table 5 is a more concise summary of the effects of competing in one subfield on subsequently diversification. Memory emerges clearly as a technological platform. The effect of experience in memory subfields is shown to be significant and positive in increasing the hazard of entry into the ASICs, microcomponents, and telecommunication IC subfields. Experience with discrete semiconductors, however, does not seem to be a significant factor in explaining entry into optoelectronics, whereas gallium arsenide experience proves to be significant in entry into that subfield. DSP experience is not significant in entry into microcomponents. Analog experience is a significant platform for entering the telecommunication IC market.

The relationships between the prior and subsequent entry are consistent with the broad distinction between analog and digital technologies. There are no crossovers in those two clusters of technologies. It is especially interesting that entries in the subfield of telecommunication devices—which embody both digital and analog technologies—are significantly related to prior entry in microcomponents and memory (i.e., digital technologies) as well as in analog circuits. As expected, the superior optical property of gallium arsenide in comparison with silicon serves as a platform into the optoelectronics subfield.

Although all of the subfields existed at the beginning of our period of observation, certain products, especially memory devices, originated much earlier. Some industries only had new firm entries until a few years after the beginning our analysis period. To validate the results, we ran the regressions starting at a later date, 1983. The results summarized in Table 4 were replicated.[10]

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Table 5 Matrix of Entry Sequence (Actual)[a]

From \ To	ASICs	Micro	Opto	Telecom
Analog				(+)***
ASICs				
DSP		(+)		
Discrete			(+)	
GaAs			(+)**	
Memory	(+)**	(+)***		(+)*
Micro				[+]***
Opto				
Telecom				

[a]( ) hypothesized, [ ]: not hypothesized
*prob < 10, **prob < 05, ***prob < 01

Discussion

Specific Observations

Initial entry into the memory subfield serves as a particularly broad platform by which to enter other subfields. Yet, no subfield serves as a significant entry point into memory. In contrast, experience in ASIC production appears to be a sink, with no indication that it can be used as a way to gain entry into other subfields. Industry growth has a significant effect on attracting entry of startup companies that began in other markets. Thus, although the costs of entry into ASICs appear low, the competitive pressures on startups are substantial.

That inference is supported in Table 6, where the exit ratio for the total entrants (i.e., 180 startups) into each subfield is calculated. ASIC firms have two times the exit rate of firms making gallium arsenide devices, which have the next highest rate. ASIC startups face a difficult task of developing competitive capabilities in their own markets against the head start of entering companies from other subfields.

To test the significance of that claim, we ran a partial likelihood analysis on the exit (hazard) rates of startup firms that began in the four subfields of memory, microcomponents, telecommunications, and ASICs; the covariates were the same as before, but market growth represented the growth of the initial subfield. (The results are available on request.) Given the low number of exits, the results are poor. However, the result of interest is that the effect of being begun in the ASIC industry significantly raises the hazard of exiting; beginning in the other subfields has no significant effects.

Successful ASIC firms are in a quandary. Their success in their initial market cannot be applied easily for entry into other subfields, and yet entry into their market is easy for other firms. They illustrate the classic dilemma of a competency trap. Not surprisingly, as indicated in Table 6, acquisition rates of ASIC startup firms are considerable. Such firms have nowhere to go, and the acquisition of their subfield experience is valuable for firms diversifying into the industry.

General Observations: Myopia versus Foresight

The results support the explanation of firm diversification as the evolution of a stock of experiential knowledge that provides a platform by which to enter related fields. The relatedness among technologies and markets appears to map onto the path of diversification of firms. That path is not entirely foreseeable, for it depends on both the uncertain attractiveness of future markets and the success of the firm in its current activities.

The concept of technological platforms has significant consequences for understanding that what a firm does lays the foundation for what it can be. In his analysis of the historical development of nineteenth century American industries, David (1975, p. 4) simi-

Table 6 Exit Ratio by Subfield[a]

	Analog	ASIC	DSP	Discr	GaAs	Memory	Micro	Opto	Tele
Dissolution	031	200	000	143	182	050	000	111	000
Merger and acquisition	063	133	063	000	000	100	091	000	000
Total	094	333	063	143	182	150	091	111	000

[a]Total number of exit / total number of entry (for 180 startup firms founded between 1977 and 1989)

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larly proposes that "choices of technique become the link through which prevailing economic conditions may influence the future dimensions of technological knowledge."

The "link" raises two fundamental issues about the nature of uncertainty and foresight of organizations. Rumelt (1984) notes that even in a stringent model whereby success is determined initially by some random draw, startup firms over time differentiate themselves. He writes (p. 565):

> Which activities should the entrepreneur combine? The general answer is, *those that will exhibit strongly dependent postentry efficiencies.*

Dependent post-entry efficiency, which is synonymous with path dependence, is the cornerstone of the concept of a trajectory and has a subtle implication. Given that the investment and entry an organization makes today form its subsequent capabilities, current decisions have what can be called an "option" quality. Entering the memory market provides a wider set of options to enter other subfields than entry into ASICs. (See Appendix 3.)

The option consideration runs counter to the mainstream treatment of risk explored in the tradition of Cyert and March (1963), in which organizations are described as creating buffers against uncertainty. It is consistent with the distinction between exploitation and exploration made by March (1991) and Hedlund and Rolander (1990). An established firm has the choice to exploit its resources in its current activities or to explore new markets. Because of heterogeneity in their accumulated experiences or in slack resources, firms may differ in the extent to which they divert resources from current activities to the accumulation and recombination of experience.

An important issue raised by the argument and results of our study, therefore, is whether organizations follow myopic and forward-looking policies, both in the initial choice of entry and in the subsequent path of development. The large number of entrants into the ASIC market suggests that impediments to entry are low, but the high rate of exit and low rate of diversification suggest that such easy entry is coupled with high risk to survival. Profitability may be higher in that industry than in others, but survival rates are less favorable.

High entry and exit rates conform with a Lippman and Rumelt (1982) model in which post-entry dependence—that is, the option value for subsequent diversification—is low. In that model, a firm pays an entry fee to see whether it is (randomly) assigned a profitable technology. Because ASIC production can be contracted out so that the capital investment is only in design, entry and exit costs are not high. If diversification options generated from the initial technology are low, a high exit rate should be expected. (See Klepper and Graddy (1990) for a formal treatment.)

The relationship between current profitability and diversification options corresponds closely to D'Aveni's (1994) notion of a hypercompetitive environment in which know-how and timing are important. In such an environment, the profitability of a given product quickly evaporates, forcing competitors to be constantly developing and exercising options for product improvements or diversification into fields related to the current experiential stock or know-how. In the absence of options, hypercompetition results in high exit rates, as in the ASIC subfield.

An option approach is a handy way to analyze the case of hypercompetition when timing and know-how advantages matter. D'Aveni (1994: 22) notes that "one way to escape [the] cycle of competition on price and quality is to enter a new market or launch a new product. Timing of market entry and the know-how that allows entry form the second arena for competitive interaction."

In our study, the know-how is the learning by doing that is accumulated in the source industry. We can think of the value of remaining in that industry as $V(s)$, where s is the cash flows from current and future production. The value of cash flows from diversifying into a new target industry, or introducing new product or service changes, is $V(d)$. Normally, we treat value of the firm as $V = V(s) + V(d)$. However, because experience in producing S is useful for producing the target industry product, additivity is no longer obeyed; there are interactions among the projects, such that $V = V(s) + V(d|s)$. The second term captures what Myers (1977) called a "growth option." To incorporate the timing dimension, we would need to add time subscripts.[11]

Several subtle issues must be refined, especially in relation to the selection environment and experimentation. For example, a forward-looking strategy would suggest that by diverting resources to experimentation, an organization gains incremental experience that provides a platform to launch into new industries. However, although such expansion may enhance a firm's long-range opportunities, it also diverts resources and thus may increase the hazard of failure in the short-run.

A critical contextual variable, then, is the stringency of competition, which may limit a firm's ability to divert resources to the accumulation of new learning. To the

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extent that risk-taking and exploratory search require slack resources, organizations that have entered competitive environments are handicapped in their abilities to develop the requisite flexibility and diversity of resources.[12] The findings of Carroll and Hannan (1989) on the negative effects of competitive environments on survival during a firm's early years are consistent with that view. It is not surprising that incumbent semiconductor firms have won share in ASICs. Regressions not reported here show no effect of the number of competitors or industry growth on exit rates of startup firms. That finding is not surprising, for the ASIC subfield, in which so many exits have occurred, is still growing rapidly. Given the rather high exit rates, the findings suggest that unobserved organizational capabilities play an important role in the evolution of new subfields.

The radicalness of a technology is specific to firms' organizational capabilities to explore new fields given

The finding that experience in memory production has been historically useful for diversification is no guarantee that it will be in the future. The volume of microprocessor production has greatly increased over the past decade. The relatedness among new flows of technological progress is no longer the same as the relatedness that drove the accumulation of the stock of technological knowledge. In principle, a firm can repeat the exact historical path of technological learning by focusing on memory production and then branching into other (but no longer new) markets. Whether future market opportunities and the current set of evolving technologies would be suited to the replication of historical lessons is unlikely. The observation is an old one: one can enter the river once, but never the same river twice.

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Within the category of integrated circuits, analog and digital signaling are the two primary branches of the technology. Digital technology can be further divided into memory, microcomponent, and application-specific integrated circuits (ASICs). The three subfields share a common characteristic in terms of their principal end market, computers.

There is fairly wide consensus that memory has acted as a platform. The preceding quotation on technology drivers ends with the conclusion that "at present, the most common 'technology drivers' are advanced computer memory devices for which high volume demand exists—dynamic and static random access memories (DRAMs and SRAMs) and erasable programmable read only memories (EPROMs)" (Howell et al. 1988, p. 28). Similarly, Borrus et al. (1983, p. 214) write that "... MOS (metal oxide silicon) memory ICs are complex circuits that require technically sophisticated design and production capabilities. Technical sophistication here is transferable to the design and production of other complex products. . ."

Memory, like all of our subfield classifications, is an aggregation of many products. Particular products may be more important drivers than others. Moreover, the function may change over time. In his study on Intel, Burgelman (1993) noted that Intel dropped DRAM production when SRAM was discovered to serve as a substitute for driving the learning in design and testing for both memory and microprocessor devices. The switch from DRAM to SRAM does not change our memory category as a critical platform for gaining experience relevant to other subfields.

The importance of memory devices to the microcomponents subfield, especially microprocessors, is evident in its origins. (Other areas of microcomponents such as mass storage and graphic chip set are basically extensions of memory technologies.) The microprocessor was created when a Japanese company wanted to develop a semiconductor to provide certain logical functions to support a new range of calculators. It turned to a newly founded company, Intel, that had "expertise in the design and manufacture of memory chips. . . ." (Braun and MacDonald 1982, p. 108). Since then, the current investment required to produce DRAM has moved beyond the resources of new firms, but SRAM have grown in importance and have become a high volume product serving as a driver for many firms (Wolf 1986, p. 619).

A similar relationship is evident between memory and ASICs subfields. For example, standard cells, often called "cell libraries," the most recent product segment of ASICs, are customer-specified combinations of a number of functional cells, from logic gates to memories and even complete processing units. Memories are almost always included as part of the device.

Digital signal processing (DSP) is another subfield in which digital technologies are applied. The fundamental technological problem of the DSP subfield has been real-time implementation of digital technologies in miniature (Mitra and Mondal 1987). Technological advances in integrated circuits around memory and microprocessors have been a major driver of that new application area (Oppenheim 1975).

Finally, telecommunication integrated circuits were originally a segment of analog integrated circuits, as the data to be processed in telecommunications have been mostly analog (i.e., continuous signal). Recent applications of telecommunication ICs to office automation through networking personal computers, however, seem to be pushing the technological boundary of the subfield toward digital areas.

MULTIDIMENSIONAL SCALING OF EXPERT OPINIONS: RELATEDNESS. There is danger of being too glib about the messy issue of the subfield classification that we adopted from industry convention. Because the claim of shared learning implies a potential symmetry among subfields, it suggests the possibility that a platform switch such as that from DRAM to SRAM within memory could occur across subfields. Recall that the revealed technological branching represents the conjunction of technological accumulation and market opportunity. It is not surprising, therefore, that once technological learning has accumulated, changes in market opportunity (e.g., a large demand for microprocessors that generates sufficient experience effects independent of memories) can shift the revealed relatedness in diversification.

Such potential switching among subfields implies that the classifications should be built up from a multidimensional scaling of product characteristics. We take a middle ground by maintaining the historical classifications, but validating a structure of relatedness among them by a statistical analysis of a distance metric across several dimensions. The distances were derived by sampling expert opinions. A questionnaire was sent to a small number of selected industry experts. Six institutions were chosen on the basis of their reputation and ease of access: two marketing research firms (Dataquest and Integrated Circuits Engineering), two industry associations (Electronics Industry Association and Semiconductor Industry Association), a manufacturing company (AT & T) and an academic institution (School of Engineering at the University of Pennsylvania). The questionnaire was sent to a person identified through personal telephone calls. Of the six, five responded (the expert from the Semiconductor Industry Association did not respond).

We asked the experts to rate technological relatedness between subfields on a scale of 1 (not related) to 5 (highly related). A total of 36 combinations of pairs (i.e., ${}_9C_2 = 36$) were used to estimate technological "distance" between any two subfields. The data were then analyzed by multidimensional scaling techniques (MDS), a method commonly used to map perceptual (or psychological) distance among a number of objects (Green and Tull 1978; chapter 14, Kruskal and Wish 1978; Davies and Coxon 1983).

We ran the MRSCAL (metric scaling) program of the MDS(X) package with the data on technological relatedness. MRSCAL is a metric distance scaling program that positions a set of stimulus objects as points in a spatial map. The input data for MRSCAL are the lower triangle, without diagonal, of a square symmetric data matrix—average (dis)similarity scores of the respondents.

The results of the scaling can be represented spatially to show the hidden structure. The spatial representation consists of a geometric configuration of points, which correspond to the objects analyzed. The larger the dissimilarity between two objects, the farther apart they are in a spatial map.

Figure 2 is the spatial representation of the nine semiconductor subfields—the two-dimensional map of technological relatedness. (See Kim (1992) for an analysis of the dimensionality and stress and a Shephard diagram of fit.) The inference from the literature is clearly confirmed in the scaling derived from the expert opinions.

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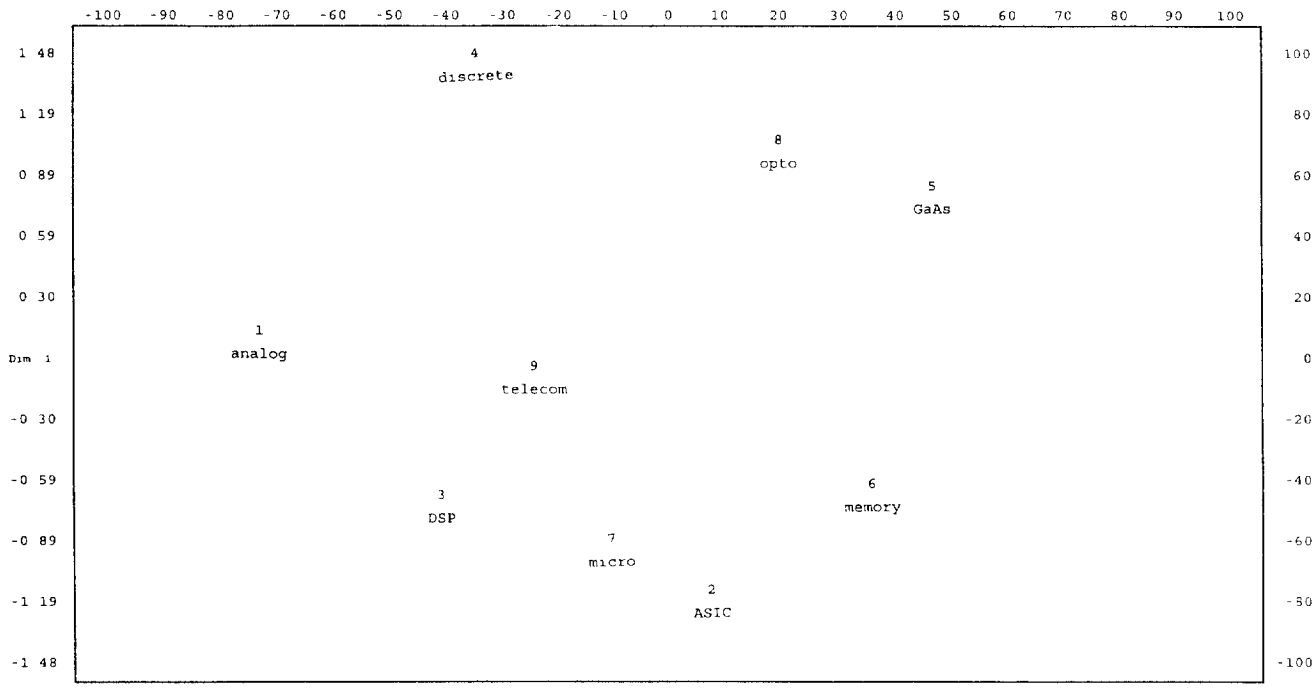
Figure 2 Multidimensional Scaling Analysis: Metric Scaling



There is a distinct but overlapping division between the digital and analog clusters. Memory, ASICs, microcomponents, and DSP form a cluster of digital technologies. Telecommunication integrated circuits are between the digital and analog clusters. Discrete semiconductors are separated from integrated circuits (digital and analog) clusters. Optoelectronics and gallium arsenide, as expected, form another cluster.

PATENT EVIDENCE: DIRECTIONALITY[14] The preceding section examines the relatedness between technological subfields based on the history of subfield evolution. Through the use of patent data, we can analyze not only the relatedness but also the "directionality" of subfields. That analysis provides further support for our propositions: (1) subfields in the semiconductor industry differ in the extent to which they facilitate technological diversification and (2) some subfields (namely, memory devices) serve as technological platforms for entry into other subfields whereas others (such as ASICs) are less likely to facilitate diversification.

The population considered was the 180 startup firms in the semiconductor industry established between 1977 and 1989. We examined the patenting histories of those by using the computerized patent database available of LEXUS, which contains complete details (other than technical drawings) of all U.S. patents granted from 1974 to date. For the purpose of the analysis, only firms that had been granted three or more patents by May 1993 were selected. A total of 53 firms fit into that category.

For each of the 53 firms, we developed a patent profile showing the distribution of the patents across time and across technologies (the nine technological subfields in the semiconductor industry). The year of patent application (commonly accepted as the year of innovation in patent analysis) was available directly from the front page of the patent, but classification along technological subfields was challenging. The patent classification system is based on technology and contains about 400 primary classes and up to a 100,000 subclasses. Such classification of the patents did not facilitate categorization along the technological subfields we were considering.

For the purpose of the study, therefore, we examined individually more than 750 patents belonging to the 53 firms. Two electrical engineers read the detailed patent documents and, according to their primary field of application, classified each patent along one of the nine semiconductor subfields. The more general patents and ones that did not fit neatly into any of the subfields were placed in a special category, "other." Thus, we obtained the complete patent history of the 53 firms across time and across technology.

The 53 firms were assigned to their subfield of initial market entry. For each category the percentage of total patents in each subfield and the percentage of firms patenting in each subfield were calculated.

Table 7 is a comparison of patenting activities of firms with initial experience in different technologies. The firms belonged primarily to the memory, ASICs, analog, and GaAs subfields. Discrete, telecom ICs, DSP, and microcomponents were represented by only a few firms (four or fewer) and no firm in the sample initially belonged to optoelectronics.

The pattern of patenting activities shows that memory devices best fit the description of a platform technology. The patents of

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Table 7 Platform Technologies—Evidence from Patents

		Subfield of Initial Entry							
		Memory (15 firms)	ASICs (9 firms)	Analog (11 firms)	GaAs (9 firms)	DSP (4 firms)	Telecom (2 firms)	Discrete (2 firms)	Micro (1 firm)
Subfield of Granted Patent[a]		%	%	%	%	%	%	%	%
Memory	- A	**24**	**5**		**2**	**11**			
	- B	73	22		11	25			
ASICs	- A	**18**	**63**	**1**	**4**	**6**			
	- B	40	78	9	11	25			
Analog	- A	**17**	**1**	**49**	**24**				
	- B	27	11	82	44				
GaAs	- A				**36**				
	- B				67				
DSP	-A	**7**	**12**	**18**	**10**	**37**			
	- B	27	56	36	22	75			
Telecom	- A	**5**	**5**	**15**	**3**		**100**		
	- B	27	22	27	33		00		
Discrete	- A			**1**				**67**	
	- B			18				100	
Micro	-A	**3**	**1**			**26**			**100**
	-B	13	11			50			100
Other	- A	**26**	**12**	**16**	**22**	**20**		**33**	
	-B	73	56	64	78	50		100	
Patents per firm		16 7	16 1	16 8	12 2	8 8	13	9	3
Technological diversification*		2 1	1 8	1 5	2	1 8	0	1	0
Time to diversification**		2 3	3 7	4 9	2 6	4 3		4	

[a]A and B indicate percentages along columns, that is, along subfields of initial entry A = % of patents granted belonging to a particular technological subfield (columns should sum to 100) B % of firms with patents granted within a particular subfield

*Mean number of subfields in which patents were granted for a typical firm (excluding own subfield)

**Mean number of years before first successful patent application in a new subfield

memory firms on average are diversified across the highest number of fields (as indicated by technological diversification) and those firms are also the fastest to patent in a field outside their own subfield. The time to diversification is 2.3 years for memory, the least among all subfields The patenting activity also suggests memory firms are likely to diversify into ASICs and to a lesser extent into analog, DSP, and telecommunications.

ASIC firms have less diversified patenting records than memory firms and are slower to patent outside their own field. The only likely field of diversification (for ASIC firms) as indicated from patent data is DSP. GaAs experience can aid entry into analog and DSP is related to microcomponents (primarily microprocessors). Patent diversification of firms with original experience in the discrete and microcomponent subfields is narrow.

Similar to memory firms, analog companies have a diverse patent history, with patent activity especially high in telecommunications and DSP fields However, the patent diversification is less notable than that for memory firms

We checked also whether patents preceded or followed market diversification. In 35 cases, startup firms filed patents in areas other than the original subfield in which they were founded. In 29 of the 35 cases, patents were granted prior to entry into that market (i e , technology came first) In only three cases was the patent obtained after market entry (i e . market came first) and the remaining three patents were granted in the same year as market entry Those trends indicate that technological knowledge is acquired prior to market diversification.

Overall, the findings support the expectation that experience in memory increases opportunities for technological diversification over a wide range of fields Experience in other fields, such as ASICs, did not lead to a broad or rapid pattern of patenting Whereas memory firms may easily gain technological expertise in ASICs, the converse is not true Such asymmetry supports the claim of directionality in the development of a trajectory

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Appendix 2: Expert Opinion Questionnaire

According to the Dataquest, there are nine product subfields in the semiconductor industry. (Please see Table 1 for the list of product segments.)

How much are the following subfields technologically related to each other?

	Not related				Strongly related
1. analog - ASIC	1	2	3	4	5
2. analog - DSP	1	2	3	4	5
3. analog - discrete	1	2	3	4	5
4. analog - GaAs	1	2	3	4	5
5. analog - memory	1	2	3	4	5
6. analog - micro	1	2	3	4	5
7. analog - opto	1	2	3	4	5
8. analog - telecom	1	2	3	4	5
9. ASIC - DSP	1	2	3	4	5
10. ASIC - discrete	1	2	3	4	5
11. ASIC - GaAs	1	2	3	4	5
12. ASIC - memory	1	2	3	4	5
13. ASIC - micro	1	2	3	4	5
14. ASIC - opto	1	2	3	4	5
15. ASIC - telecom	1	2	3	4	5
16. DSP - discrete	1	2	3	4	5
17 DSP - GaAs	1	2	3	4	5
18. DSP - memory	1	2	3	4	5
19. DSP - micro	1	2	3	4	5
20. DSP - opto	1	2	3	4	5
21. DSP - telecom	1	2	3	4	5
22. discrete - GaAs	1	2	3	4	5
23. discrete - memory	1	2	3	4	5
24. discrete - micro	1	2	3	4	5
25. discrete - opto	1	2	3	4	5
26. discrete - telecom	1	2	3	4	5
27. GaAs - memory	1	2	3	4	5
28. GaAs - micro	1	2	3	4	5
29. GaAs - opto	1	2	3	4	5
30. GaAs - telecom	1	2	3	4	5
31. memory - micro	1	2	3	4	5
32. memory - opto	1	2	3	4	5
33. memory - telecom	1	2	3	4	5
34. micro - opto	1	2	3	4	5
35. micro - telecom	1	2	3	4	5
36. opto - telecom	1	2	3	4	5

Appendix 3: Hypercompetition and Growth Options

As noted in the text, the attribution of technological accumulation implies that a firm acquires an option to diversify into related fields. That option has two features. One is a modified experience effect, whereby the accumulated experience in one field (i) such as memory lowers the production costs of another field (j), say ASICs. More formally, we can write

$$C(Q_{j,t}) = ce^{-\delta \Sigma_0^t Q_{i,t}}.$$

The second feature is the growth of the target industry (e.g., ASICs). We can think of growth as proxying a stochastic process that governs the price of ASICs. One representation is simply geometric Brownian motion, whereby

$$\frac{dP}{p} = \rho\, dt + \sigma\, dz.$$

If the price of ASICs crosses a particular threshold (P^*), entry is worthwhile.

The problem is similar to the analysis of learning curves by Majd and Pindyck (1989). To fit the model, production of memory devices must depend on a known and certain price. Experience effects would then be deterministic. Analytical solutions are possible for that case.

A more complicated characterization is to let the price of the currently produced product (memories) and that of the target industry (ASICs) be governed by two distinct stochastic processes. (In reality, they would probably share a common disturbance term.) Solving for two stochastic processes is numerically tractable, but more complicated than solving for the single process of Majd and Pindyck. A simplifying solution is to view the firm as resource constrained and consequently faced with the choice between producing in the source industry or diversifying. In that case, using a single process to describe the ratio of the prices of the two industries can suffice.

In our empirical study, we do not analyze the value of the option but rather the hitting time distribution, or hazard rate. Leaving aside industry and other effects, the hazard model corresponding to a Wiener process is the inverse Gaussian. To include time-varying covariate effects, we would set either the mean or variance or both to be a function of the covariates. We avoid the difficult specification issues associated with that parametric approach by working with the semiparametric discrete hazard model. Thus, the underlying option model is not transparent, because we work with the hitting time distribution and we do not specify that distribution parametrically.

To return to the Majd and Pindyck model, we implicitly follow the case of a single stochastic process for the price of the target industry, which we proxied by shipment growth. We assumed that experience accumulates in some way from the time of entry in the source industry. The experience effect is captured by time-varying dummy variables that serve as the state variables. The other principal state variable is price. When price, proxied by the growth rate (with other covariates held constant), crosses some threshold, the firm enters the target industry. The other covariate effects (i.e., density) are added to the reduced-form equation, but are derived (*ad hoc*) from a structural model in which price is partly endogenous to market structure.

An important issue, given that characterization, is when the firm should diversify. That question is the same as asking whether the hitting time is when the option is exercised. A formal way to understand hypercompetition in terms of timing and know-how is in a dynamic context where difficult-to-imitate assets are accumulated by experience, and entry is the hitting time when market growth, or price, hits a critical threshold.

To add more strategic content to the formulation, we could consider competitive interactions, as highlighted by D'Aveni, and the

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choice to allocate resources to learning. Competitive interactions in an option context are especially complex, because price becomes endogenous. Kulatilaka and Perotti (1994) provide an analysis of the related question of whether to maintain the wait option or early exercise of entry. Learning is analyzed in Kogut and Kulatilaka (1994). (Paper available from the authors upon request.)

Endnotes

[1]See D'Aveni (1994) on hypercompetition and chapters 2 and 4 for a discussion of the conversion of know-how to stronghold advantages. See also Eisenhart (1990) on high velocity environments.

[2]We thank an anonymous reviewer for consolidating this argument.

[3]See the operationalization of new knowledge in Schoonhoven et al. (1990).

[4]Not only technology, but also the applicability of other capabilities such as marketing and distribution, may drive diversification to the new industry.

[5]We thank Naren Udayagiri for bringing this quote to our attention.

[6]See Dawkins (1986: 258ff.) for a discussion and Barley (1990) for another use of a dendrogram.

[7]David and Bunn (1990) call the innovations that bridge technological branches "gateway technologies". Sahal (1981) has called such convergence "creative symbiosis."

[8]See, for example, Hannan and Freeman (1987) and Carroll and Hannan (1989). Theoretical issues are associated with the use of the density squared measure (Klepper and Graddy 1990), primarily concerning misspecification due to omission of demand effects. We include demand effects in our model. Also, density squared is highly

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